

Rank-Abundance Allocations as a Tool to Analyze Planktonic Copepod Assemblages off the Danshuei River Estuary (Northern Taiwan)

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(Accepted May 23, 2008)

Jiang-Shiou Hwang, Sami Souissi, Hans-Uwe Dahms, Li-Chun Tseng, Francois G. Schmitt, and Qing-Chao Chen (2008) Rank-abundance allocations as a tool to analyze planktonic copepod assemblages off the Danshuei River estuary (northern Taiwan). *Zoological Studies*. 48(1): 49-62. The planktonic copepod assemblages off the Danshuei River estuary, at the boundary of the East China Sea and the northeastern tip of the Taiwan Strait, were studied as a function of conductivity-temperature-depth (CTD) data obtained from the area from Oct. 1998 to July 2004. From seasonal copepod samples, 120 copepod species were identified off the Danshuei estuary during a 6-yr study period. In a methodical comparison, the rank-abundance (RA) was compared to quantitative estimates and diversity indices of copepods (i.e., the occurrence rate, mean abundance, Shannon-Wiener diversity index, and evenness and species richness index). The present study shows for the first time long-term patterns of planktonic copepod communities, thus demonstrating the usefulness of the RA tool in characterizing plankton bioindicator species to monitor environmental changes. A general model of species successions with season is exemplified by 1 coastal species that dominated the copepod communities during warm-water situations: *Temora turbinata*. *Calanus sinicus* was an indicator species belonging to relatively cold-water species transported from the Yellow Sea and East China Sea during the northeastern monsoon in winter. <http://zoolstud.sinica.edu.tw/Journals/48.1/49.pdf>

Key words: Rank abundance analysis, Monitoring, Bioindicator species, Taiwan Strait, Copepod succession.

One of the hallmarks of modern ecology, particularly in marine plankton research, is the increasing size of datasets. This trend has been favored by programs such as GLOBEC, with several large, local datasets (i.e., Continuous Plankton Recorder (CPR), California Current System (CCS)). As electronics have become cheaper and personal computers more powerful, scientists have increasing access to instruments that produce large datasets. Additionally, the World Wide Web has enhanced and allowed researchers easy access to huge data archives. The number of data points referred to in the term “large datasets” is ever increasing. There is thus a growing need

for data analytical techniques that can efficiently, powerfully, and routinely be used. Many existing statistical approaches implicitly require the assumption of a Gaussian distribution, which is rarely tested. Herein, we applied a rank analysis approach to analyze species abundance data, using a Zipf-plot representation which basically assumes non-Gaussian distributions.

Indices that are representative of biotic diversity are widely used to describe the state of natural communities. Species diversity indices are measures that take into account the richness and abundance patterns of species. However, the concept of a diversity index can be applied

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not only to species but to any other character with randomly distributed values. This is the case for rank-abundance (RA) relationships. Analysis of rank distributions is 1 approach to substantiating the selection of specific numerical indices of diversity (Frontier 1985). There are a number of studies on species diversity and RA relationships that characterize the numerical structure of communities (Warwick 1986, Warwick et al. 1987, Aoki 1995, Levich et al. 2004, Mitchell 2004). Rank distributions provide a transformed set of quantities: the most abundant group is assigned the 1st rank, the next-abundant group is assigned the 2nd rank and so forth to the least-abundant group of rank, which equals the number of groups in a community. Instead of rank distribution of species, rank distributions, for example, of size or age groups, or groups of physiologically and biologically similar organisms (e.g., those using the same resources) can be considered. Parameters of rank distributions are taken as numerical expressions of the presence or absence of environmental changes in the communities studied.

The hydrodynamic regime of the northern Taiwanese coast shows seasonal changes, although the predominant wind systems (northeasterly (NE) monsoon from Nov. to Mar. and the southwesterly (SW) monsoon from May to Sept.) slightly vary from year to year. Here, the NE monsoon is the primary driving force for the intrusion of marine species from the Bohai Sea, Yellow Sea, and East China Sea along the Chinese coastline to the Taiwan Strait (Hwang and Wong 2005, Hwang et al. 2006, Dur et al. 2007). The water circulation off the Danshuei River estuary is highly influenced by the Chinese Coastal Current (CCC) along the Chinese coastline from the Yellow Sea to the East China Sea then to the Taiwan Strait by the northeastern monsoon during winter (Tseng and Shen 2003, Hwang and Wong 2005, Hwang et al. 2006, Dur et al. 2007, Tseng et al. 2008b).

In order to understand long-term copepod population and community changes, we conducted a 6-yr study using seasonal and inter-annual samplings in this region. The species composition, dominant species, Shannon diversity, community structure, and RA analysis of copepod assemblages were studied. Since community structures are mainly driven by water masses and can be quite variable, we focused on the stability structure and diversity of each assemblage during each sampling. We used an RA analysis to

analyze common structures and compare fitted parameters using simple log-log linear regressions to the common measures of diversity indices and also to the main hydrological parameters of temperature and salinity.

The objective of this study was to evaluate the long-term impacts of local hydrodynamics and/or estuarine discharges on copepod species composition and diversity, using RA analyses as a monitoring tool to characterize indicator species. Concepts of diversity and RA relations were evaluated as potentially useful tools for analyzing biodiversity and as indicators of environmental change from a new methodological viewpoint.

MATERIALS AND METHODS

Sampling area

Zooplankton was collected from horizontal surface net tows at 19 stations off the Danshuei River estuary in northwestern Taiwan, in the western North Pacific Ocean (Fig. 1). The *Ocean Research Vessel II* of National Taiwan Ocean University, (National Science Council), Taiwan was used to conduct all samplings and collect conductivity temperature depth (CTD)

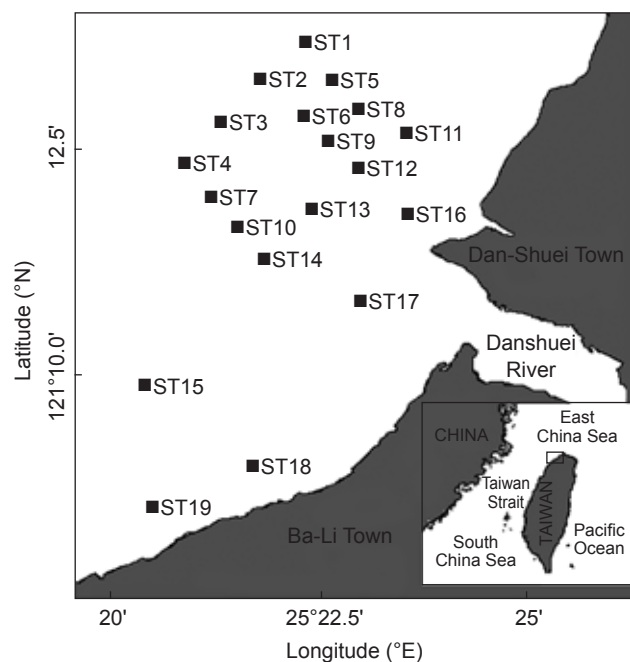


Fig. 1. Map of the Taiwan Strait and East China Sea, showing the location of sampling stations off the Danshuei River estuary, in northern Taiwan (western North Pacific).

measurements from Oct. 1998 to July 2004 seasonally throughout a period of 6 yrs. In total, 25 cruises were conducted to sample zooplankton. A Norpac zooplankton net (180 cm long, 45 cm mouth diameter, 333 μm mesh size) was used for all zooplankton samplings. Zooplankton samples were immediately fixed in 5% seawater-buffered formalin solution on board. The procedures for species identification and counting are the same as those described in Hwang et al. (2003 2004b 2006).

Analysis of community structure

Both species richness indices (as the total number of species at all stations) and Shannon-Wiener diversity indices were calculated. In order to study the community structures, the species were ranked in decreasing order of their relative abundances. Rank 1 was assigned to species having the largest relative abundance, and rank 2 was assigned to the species having the next largest relative abundance and so forth. Each species was marked along 1 axis (from the most abundant species to least abundant) while the proportional abundance (on a log scale) of each species was set on the 2nd axis. An RA diagram was constructed by plotting the relative abundances of species against their rank in the samples. Analyses of the outlines of these diagrams characterize the structures of the studied communities. An RA diagram presented in a log-log plot is called a Zipf plot (Frontier 1985, Mitchell 2004). Using this representation, we compared the extremes of a community dominated by a single species with a concave diagram to a community equally dominated by several species with a convex diagram (Frontier 1985). A previous study showed that the temporal heterogeneity of copepod community distributions was much higher than the spatial heterogeneity (Hwang et al. 2006). Consequently, we used only the average rank-abundances obtained from sampling data in the present study.

Most RA curves can be fitted by a simple linear regression in the log-log plane, corresponding to a power-law Zipf plot. Consequently, we used a Curve fitting toolbox of Matlab Software (Dur et al. 2007) to estimate the intercept and slope of each RA curve in a log-log plot. Then, temporal variations of these parameters were plotted and correlated with the Shannon-Wiener diversity index as well as with temperature and salinity. We used the

Spearman correlation coefficient and considered 3 significance levels of $p < 0.05$, < 0.01 , and < 0.005 .

RESULTS

Temperature and salinity variations

Figure 2 shows the patterns of the average water temperature recorded at all sampling stations during the study period, with the highest temperature values recorded during summer and the lowest temperatures recorded during late winter. During the study period the lowest temperature observed in Mar. 2000 was around 14°C, whereas the highest temperature of

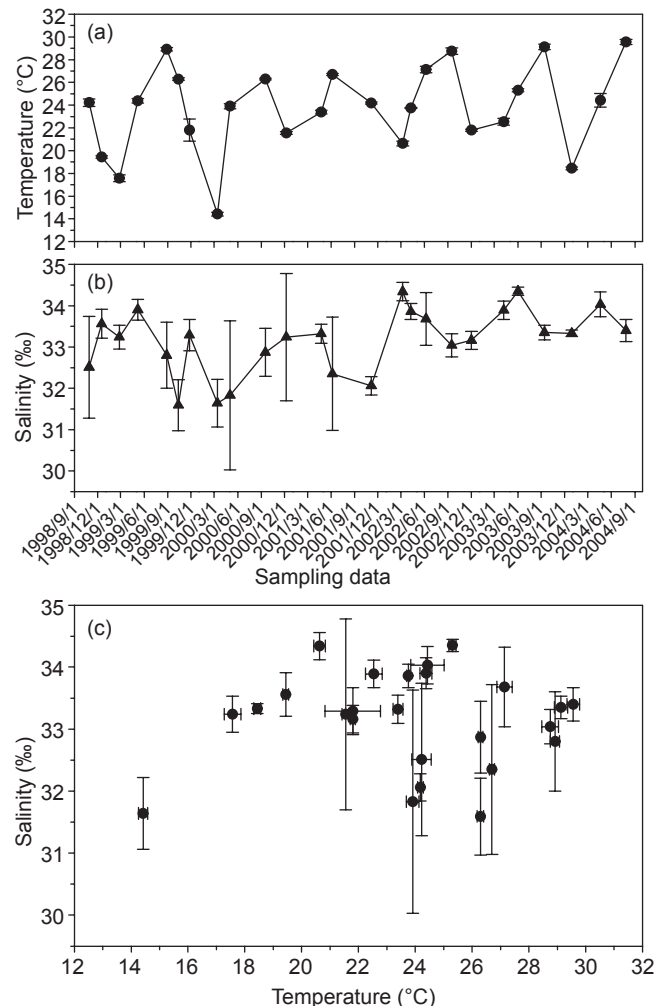


Fig. 2. Average water temperature (a), salinity (b), and temperature versus salinity diagram (c) of surface waters in the study area from Oct. 1998 to July 2004. Vertical bars indicate standard deviations.

> 29°C was recorded in Sept. 2004 (Fig. 2a). The variability of temperature between sampling stations was low during a given sampling cruise. However, salinity showed a much higher variability (Fig. 2b). Seasonal patterns of salinity during the study periods were less clear than those shown by temperature. The intrusion of estuarine waters with low salinity at some stations explains the high variability observed in May 2000, Dec. 2000, and June 2001 (Fig. 2c).

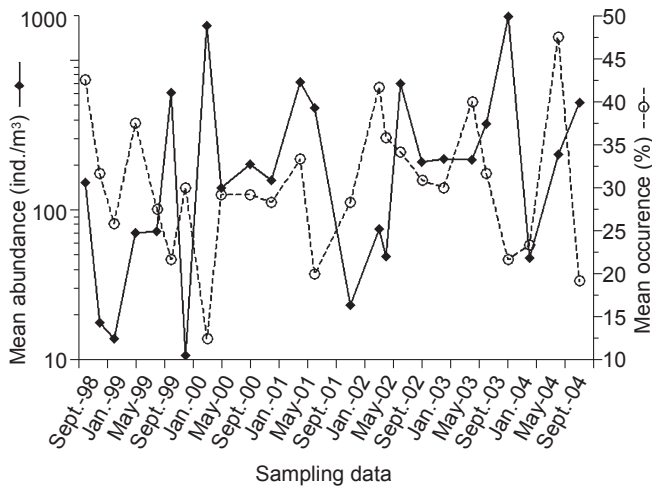


Fig. 3. Mean abundance and mean occurrence of planktonic copepod species sampled between Oct. 1998 and July 2004 in northwestern Taiwan.

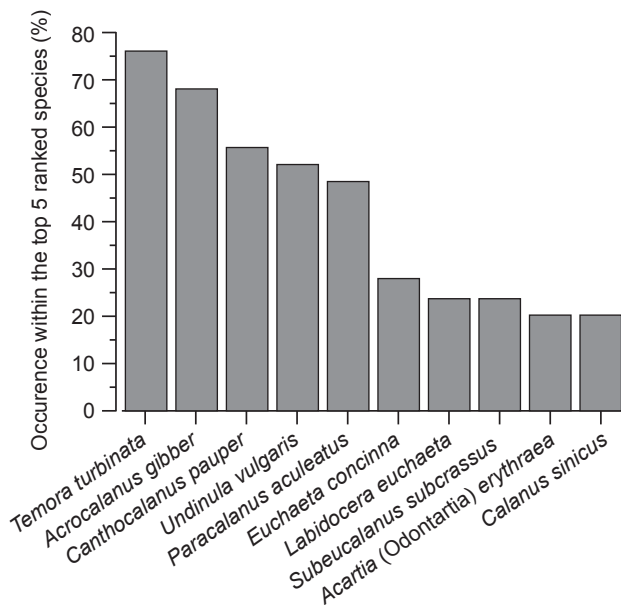


Fig. 4. Percentages of occurrence of 10 dominant copepod species providing > 20% of occurrence among the 5 top-ranked species of all 25 sampling cruises.

Temporal variations in copepod abundances and occurrences

Mean abundances and mean occurrences remarkably fluctuated during the 6-yr study (Fig. 3). Figure 4 shows the top 10 most abundant species and their occurrence rates within the top 5 ranks of each sampling cruise throughout the 6-yr sampling period. The Y-axis represents the percentage of occurrence of each species in the top 5 ranked species in our RA analysis over 25 sampling dates. The highest occurrence rate among the 120 species identified (see Hwang et al. 2006 for the species list of 110, with an additional 10 species identified since then) listed in the top 5 ranks for all sampling cruises was the calanoid copepod, *Temora turbinata*, with a > 75% occurrence rate in the top 5, followed by *Acrocalanus gibber*, *Canthocalanus pauper*, *Undinula vulgaris*, and *Paracalanus aculeatus*.

Temporal variations in species dominance and community structures

During summer, the community was dominated by a single species, *T. turbinata* (Fig. 5). We observed some inter-annual variability, but the pattern of community structure remained similar between years, and a strong transition was observed to occur from spring to summer and from summer to autumn. It is thus possible to test for any differences among log-log curves obtained for the seasons of different years.

A number of ecological models have been elaborated to explain the RA relations of several species (e.g., Bastow 1991). In this study, a general model of species successions with season was exemplified by 1 coastal species that dominated the copepod communities during relatively warm-water situations: *T. turbinata*. Other species belonging to the group of relatively warm-water species accompanied *T. turbinata* (Fig. 5).

Species of *Calanus sinicus* usually appeared in very high densities during the NE monsoon season when the CCC intrudes into this region (Fig. 5).

Temporal variation of species richness and diversity

Patterns of the RA curves were relatively similar, with some inter-annual variability (Fig. 6, Table 1). They were fitted to a power law

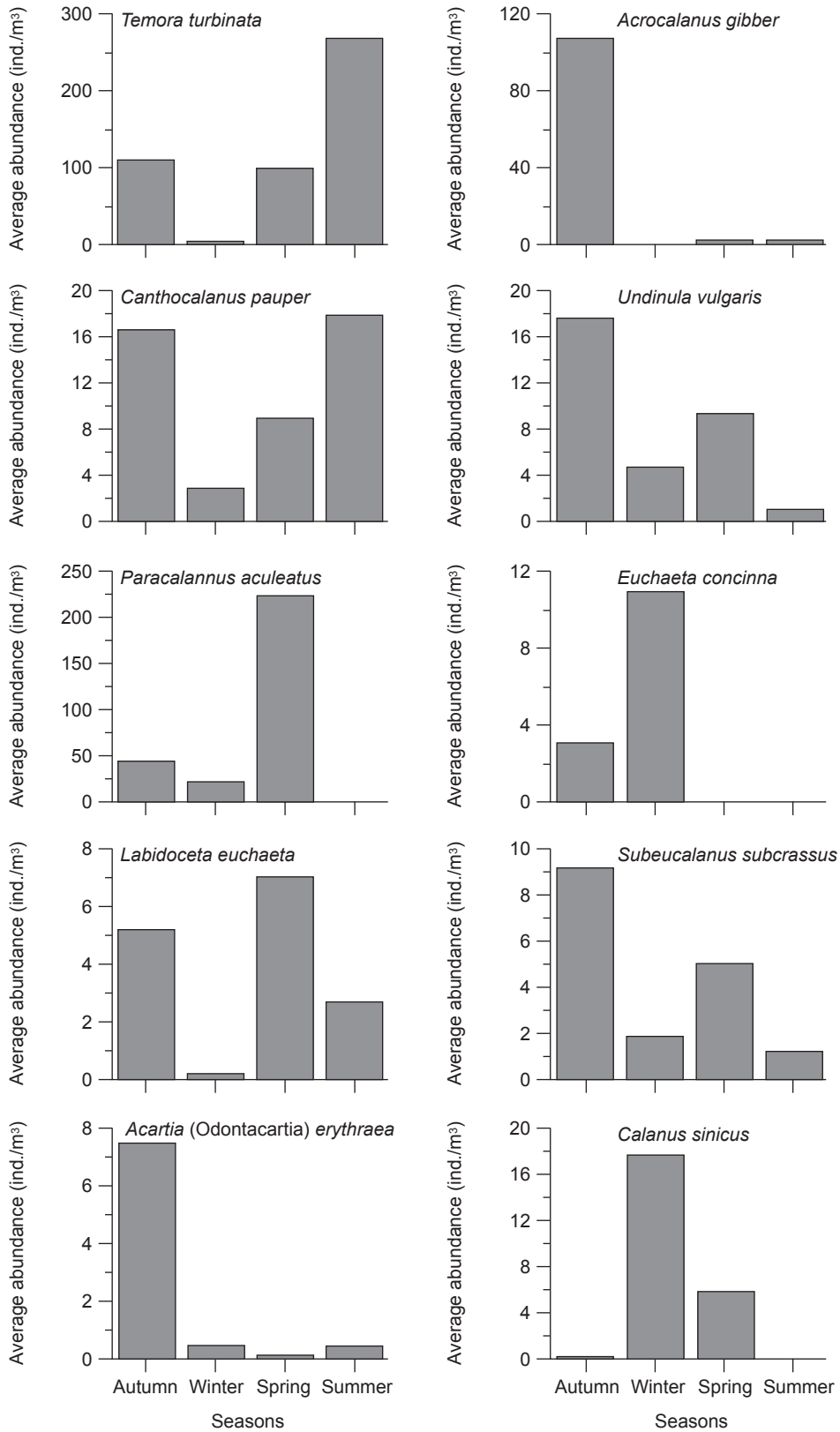


Fig. 5. Average abundance (individuals (ind.)/m³) of the 10 most dominant copepod species providing > 20% of occurrence over all samplings split into 4 seasons

($y = ax^{-b}$). We show the temporal variations with season of these parameters in figures 6, on a log-log scale, which provides a linear presentation of these power functions (Fig. 7). This gives a good summary of the dynamics of the copepod

community structures in the area. A high diversity was observed during autumn with RA distributions tailing off, which was caused by rare species (Fig. 7). This structure became more regular and nearly linear (in the log-log projection) in winter

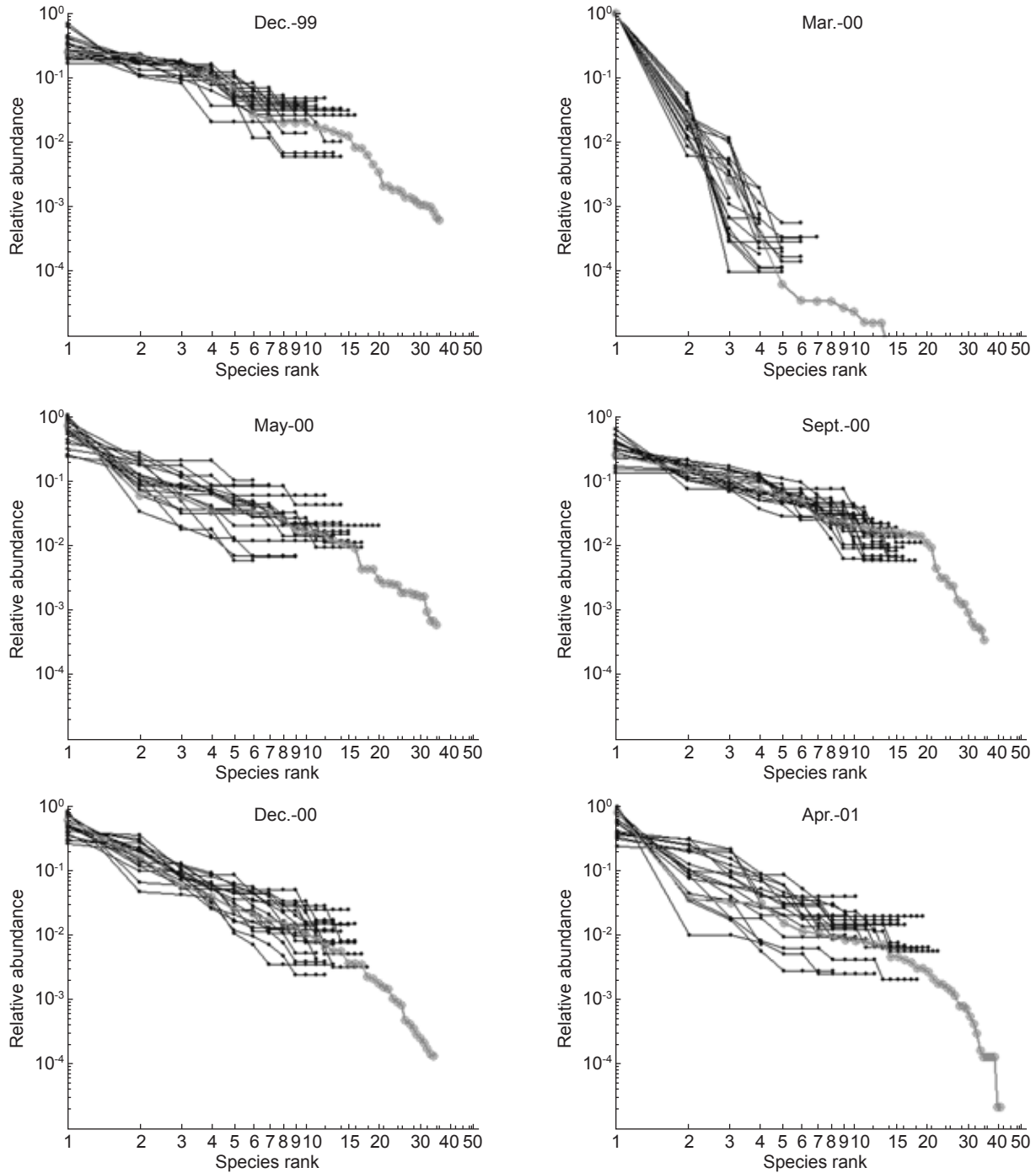


Fig. 6. Rank abundance diagrams concerning planktonic copepod species sampled between Dec. 1999 and Apr. 2001 off northwestern Taiwan (see Fig. 1). The green curve corresponds to the average abundances of species over all sampling stations. Both axes are log₁₀ scales.

and spring (except in Mar. 2000 when an intrusion of relatively cold water took place from the north) (Fig. 7).

An increase in the intercept regularly occurs in the area (Fig. 8). An increase in the intercept implies that only 1 or a few species dominate the sample. This indicates low diversity and a strong disturbance of the community (Fig. 8).

Classical diversity estimates based on species richness and the Shannon-Wiener diversity index, compared to RA analyses, demonstrated similar fluctuations. However, transitions between seasons were less evident (Fig. 9). The lowest diversity of copepods was observed in May 2000 with only 15 species recorded and a very low Shannon-Wiener diversity index ($H' = 0.20$). This low diversity coincided with the lowest temperature recorded during the study period (Fig. 2). The Shannon-Wiener diversity index was also low (≤ 1) in June of the following years of 2001 to 2004 and exceeded 3 in Dec. 1999, Sept. 2000, Nov. 2001, Apr. 2003, and Apr. 2004 (Fig. 9).

Classical diversity analyses based on species richness and the Shannon-Wiener diversity index have an inverse pattern with the RA fitted parameters. A high diversity is characterized by low values of RA parameters (Fig. 10). Evenness as measured by Shannon equitability was highly correlated with the RA parameters (Fig. 10). The Shannon-Wiener diversity index was not correlated with salinity ($p = 0.149$) but was negatively correlated with temperature if the Mar. 2000 data point was removed from the calculations ($p = -0.455^*$) (Fig. 11). In Mar. 2000, an intrusion of relatively cold water came from the north (Hwang et al. 2006).

DISCUSSION

The island of Taiwan is surrounded by several water masses (Chen et al. 1995, Shih and Chiu 1998, Hwang et al. 2000, Liang et al. 2003, Hwang et al. 2004a, Lin et al. 2005, Hwang et al. 2006, Hwang et al. 2007). To the east of Taiwan, the year-round northwardly flowing Kuroshio Current generates continuous inputs to the marine biodiversity of the region (Shih and Chiu 1998, Wong et al. 1998, Hwang et al. 2000, Tang et al. 2000, Hwang et al. 2004a b, Hwang et al. 2006). To the north of Taiwan, the northeasterly monsoon is the primary driving force for possible intrusions of marine species from the Bohai Sea, Yellow Sea, and East China Sea along the Chinese coastline to the Taiwan Strait (Hwang et al. 1998, 2006, Hwang and Wong 2005, Dur et al. 2007) during winter (Tang et al. 2000, Jan et al. 2002, Liang et al. 2003, Hwang and Wong 2005, Hwang et al. 2006, Dur et al. 2007). To the south of Taiwan, the southwesterly monsoon prevails and may provide a different pathway for intrusions of marine species either from the South China Sea or from the Luzon Strait (Hwang et al. 2000, 2006, 2007, Tang et al. 2000, Liang et al. 2003, Lo et al. 2004b, Dur et al. 2007). The water circulation off the Danshuei River estuary is highly influenced by the CCC along the Chinese coastline from the Yellow Sea to the East China Sea then to the Taiwan Strait by the NE monsoon during winter (Tseng and Shen 2003, Hwang and Wong 2005, Hwang et al. 2006). The hydrodynamic regime of the northern Taiwanese coast shows seasonal changes following the predominant wind systems (NE monsoon from Nov. to Mar. and SW monsoon from May to Sept.). Tseng and Shen (2003) used satellite-tracked surface drifters in their study of

Table 1. Statistics of rank abundance calculations

Sampling date	Intercept	Slope	R^2	RMSE
29 Oct. 1998	0.3779	1.2290	0.9535	0.0132
17 Dec. 1998	0.3510	1.1470	0.9519	0.0145
24 Feb. 1999	0.3401	1.1030	0.9269	0.0194
7 May 1999	0.3662	1.1680	0.9098	0.0196
28 Aug. 1999	0.8525	4.2160	0.9983	0.0063
13 Oct. 1999	0.4420	1.2980	0.9311	0.0258
25 Nov. 1999	0.2854	0.9998	0.8944	0.0019
13 Mar. 2000	0.9714	5.2620	1.0000	0.0023
2 May 2000	0.6237	2.9430	0.9854	0.0128
17 Sept. 2000	0.2683	1.0060	0.9676	0.0094
8 Dec. 2000	0.5914	1.9400	0.9991	0.0031
23 Apr. 2001	0.7787	4.0040	0.9962	0.0077
6 June 2001	0.9389	5.4810	0.9999	0.0022
5 Nov. 2001	0.2633	0.9207	0.8097	0.0261
8 Mar. 2002	0.5182	1.7430	0.9989	0.0025
9 Apr. 2002	0.6926	2.7460	0.9921	0.0096
7 June 2002	0.9573	5.8790	0.9999	0.0017
16 Sept. 2002	0.6218	2.5990	0.9853	0.0126
2 Dec. 2002	0.5032	1.5810	0.9933	0.0073
7 Apr. 2003	0.2862	1.0320	0.8777	0.0181
2 June 2003	0.8703	4.1720	0.9995	0.0031
13 Sept. 2003	0.3283	1.0190	0.8026	0.0367
29 Dec. 2003	0.4270	1.2470	0.9021	0.0295
19 Apr. 2004	0.2204	0.8836	0.8276	0.0167
28 July 2004	0.9086	5.3650	0.9995	0.0045

R^2 , determination coefficient; RMSE, root mean square error.

surface current patterns in the vicinity of Taiwan. They showed that the water circulation along the northwestern Taiwanese coast can be complicated due to strong effects of the semidiurnal tidal regime and its interaction with the Kuroshio Branch Current. Moreover, the same authors showed that a strong winter monsoon may eventually reverse the direction of circulation in northeastern Taiwan. An opposite current pattern may greatly affect the seasonal and inter-annual variability of copepod populations off the Danshuei River estuary (Fig. 9).

Most recent published papers on copepod biology and ecology from Taiwan focused mainly on short-term studies of their distributions and abundances (Hwang et al. 2004a, Lo et al. 2004a b), feeding ecology (Wu et al. 2004, Tseng et al.

2008a), taxonomy of new species (Chen and Hwang 1999, Chen et al. 2004, Hsiao et al. 2004), vertical migration in upwelling waters (Lo et al. 2004c), lagoon ecology (Lo et al. 2004a), and harbor ecology (Chang and Fang 2004, Tseng et al. 2008c). Relatively few studies of copepod assemblages in Taiwanese waters have been conducted in a long-term fashion except for Hwang et al. (2004b 2006). Very little is known about the succession patterns of RA allocations of copepod assemblages in Taiwanese waters. However, the present study provides information on RA allocations and copepod distribution patterns covering a reasonably long period of 6 yr.

The complexity of marine habitats surrounding Taiwan, from southern tropical waters to northern

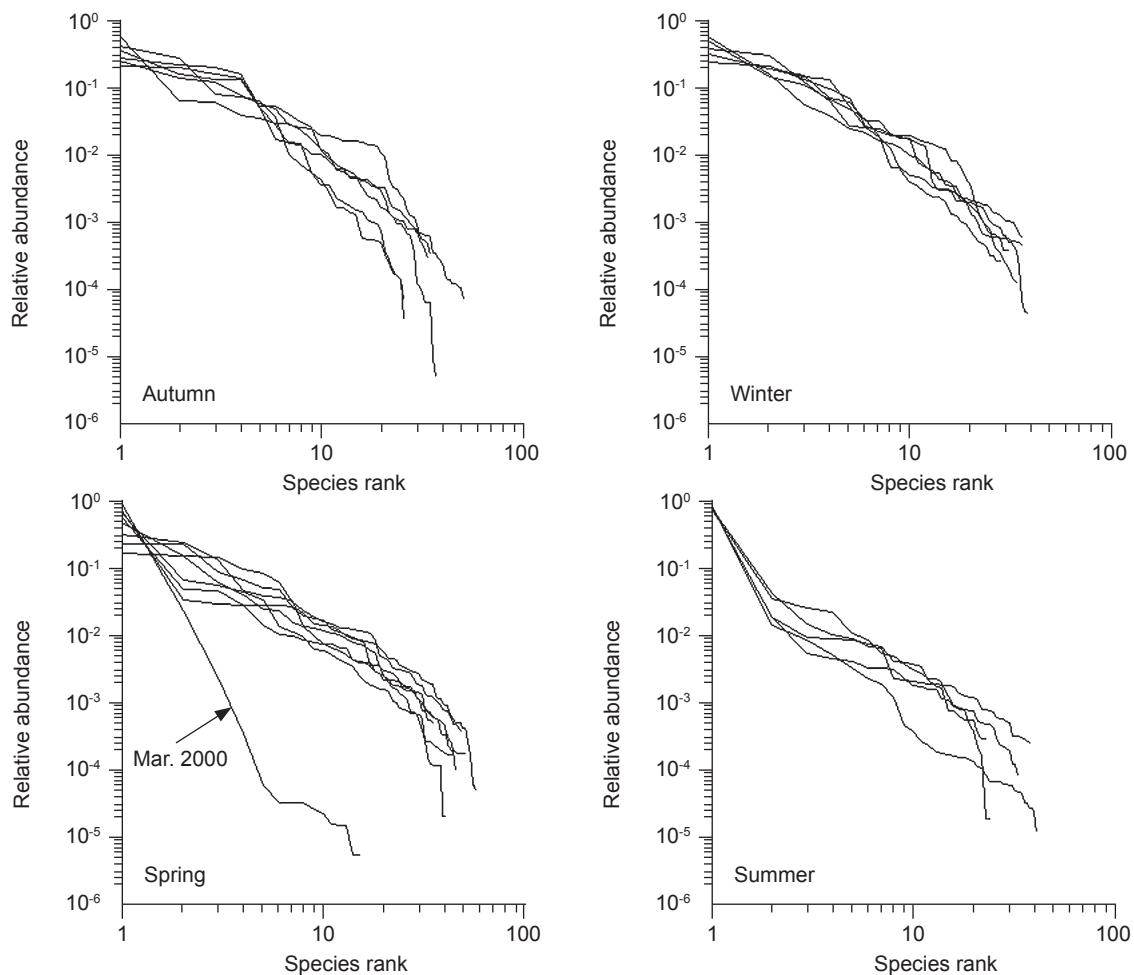


Fig. 7. Rank abundance diagrams of planktonic copepod species sampled between Oct. 1998 and July 2004 in northwestern Taiwan (see Fig. 1). Twenty-five sampling dates were allocated to the 4 seasons: Autumn (Sept.-Nov.); Winter (Dec.-Feb.); Spring (Mar.-May), and Summer (June-Aug.). Only curves corresponding to the average abundances of species over all sampling stations were considered here. Both axes are given in log 10 scales.

subtropical waters, supports its enriched marine fauna. Systematists have proposed that the waters of Taiwan comprise 10% of the global marine fauna at the species level (Shao 1998, Hwang et al. 2000). Shih and Young (1995) in a review of published records of copepod species, found 431 species occurring in the marginal seas of China, including the waters surrounding Taiwan. Shih and Young (1995) reviewed 325 copepod species occurring in the East China Sea. Lo et al. (2004c) reported 178 copepod species in an upwelling region of northern Taiwan. These values indicate relatively high species numbers and diversity of planktonic copepods around Taiwan. Apparently, most copepod species that occur in the East China Sea probably belong to rare species. This was also evidenced by our RA estimates, where 10 species accounted for over 20% of the copepod occurrence (Fig. 5). Several copepod species may originate from deep waters here, such as from upwelling systems (Lo et al. 2004c).

We used a particular sampling area, the Danshuei River estuary in northern Taiwan, at the boundary of the southern East China Sea and the northern Taiwan Strait as a study area for the evaluation of RA estimations. The hydrographic regimes are very complex in this area (a summary of the characteristics of this circulation is provided by Hwang et al. 2006), and the low diversity (slope in figure 8) indicates a strong disturbance of the community. This disturbance can be explained

by the very different water masses and sewage discharges from Taipei City since the sampling area is located in Taipei County downstream of Taipei and opens to the Taiwan Strait which is exposed to different physical driving forces. Such patterns match the sea surface temperatures (Fig. 2). Overall, copepod communities off the Danshuei River estuary on the northern coast of Taiwan are highly variable because of the complexity of the water circulation in this area.

The sampling sites in the present study were off the Danshuei River estuary and near the discharge site of a sewage treatment plant in Bali, Taipei County (Fig. 1); the average Shannon-Wiener diversity index of the surface copepod composition was relatively low (< 4) and the species richness was highly variable (< 60) (Fig. 9); however, 120 copepod species were identified. Copepod communities in the present study were dominated by the following 5 copepod species: *T. turbinata*, *Acrocalanus gibber*, *Canthocalanus pauper*, *Undinula vulgaris*, and *Paracalanus aculeatus* (Fig. 4). These 5 dominant species comprised 80% of the total copepod abundances during a period of 6 yr. According to an ecological classification of copepods proposed by Hirakawa et al. (1990) and Takahashi and Hirakawa (2001), almost all dominant copepod species found during the present study (Fig. 5) belong to relatively warmer-water species, except *Calanus sinicus*. Samples from most cruises were dominated by a

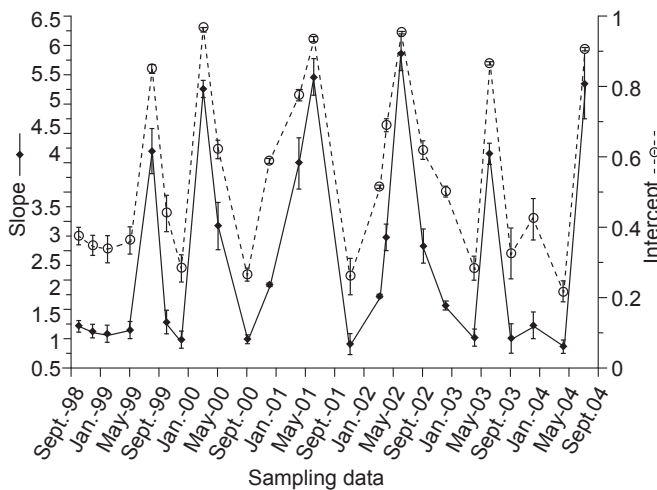


Fig. 8. Slope and intercept of rank abundance data of planktonic copepod species sampled between Oct. 1998 to July 2004 in northern Taiwan (see Figs. 1, 7).

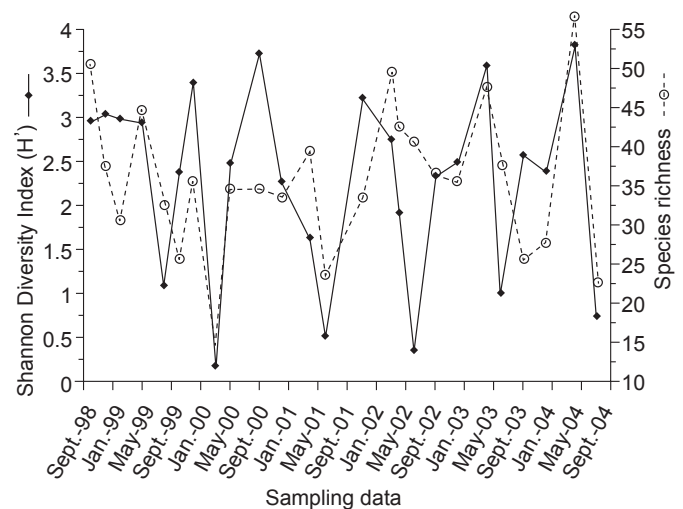


Fig. 9. Shannon-Wiener diversity index (H') and species richness of planktonic copepods changes within a 6-yr period. Diversity analyses of copepod species sampled between Oct. 1998 and July 2004 in northwestern Taiwan are based on the species richness and Shannon-Wiener diversity index.

few species, with a large number of other species, showing very low densities, which is comparable to the results of Lo et al. (2004c) and Hwang et al. (2004b). Lo et al. (2004c) pointed out that copepod species numbers are generally lower in surface waters than in deeper waters of upwelling systems. The distributive patterns of the Shannon-Wiener diversity index (Fig. 9) were mainly correlated to sea surface temperatures during the sampling cruises (Fig. 2).

Dominant copepod species play major roles in terms of feeding ecology and carbon transfer at the boundary of the East China Sea and Taiwan Strait. The present study also provides useful information for research within the GLOBEC and JGOF framework, by modeling physical and biological coupling processes and carbon fluxes in

their respective systems.

Functional interpretation of RA parameters

A simple parameterization may be found between RA parameters and H' . On the other hand, even if temperature seems to be a good explicative variable of the RA parameters (if we exclude Mar. 2000), the data are very highly dispersed. This means that the link between temperature and diversity is more complex and cannot be parameterized by a simple linear relationship. Nevertheless, the temperature of surface waters is a good tracer of the origin of the water observed in the study area, and consequently of the origin of the copepod community (Hwang et al. 2006). On the contrary,

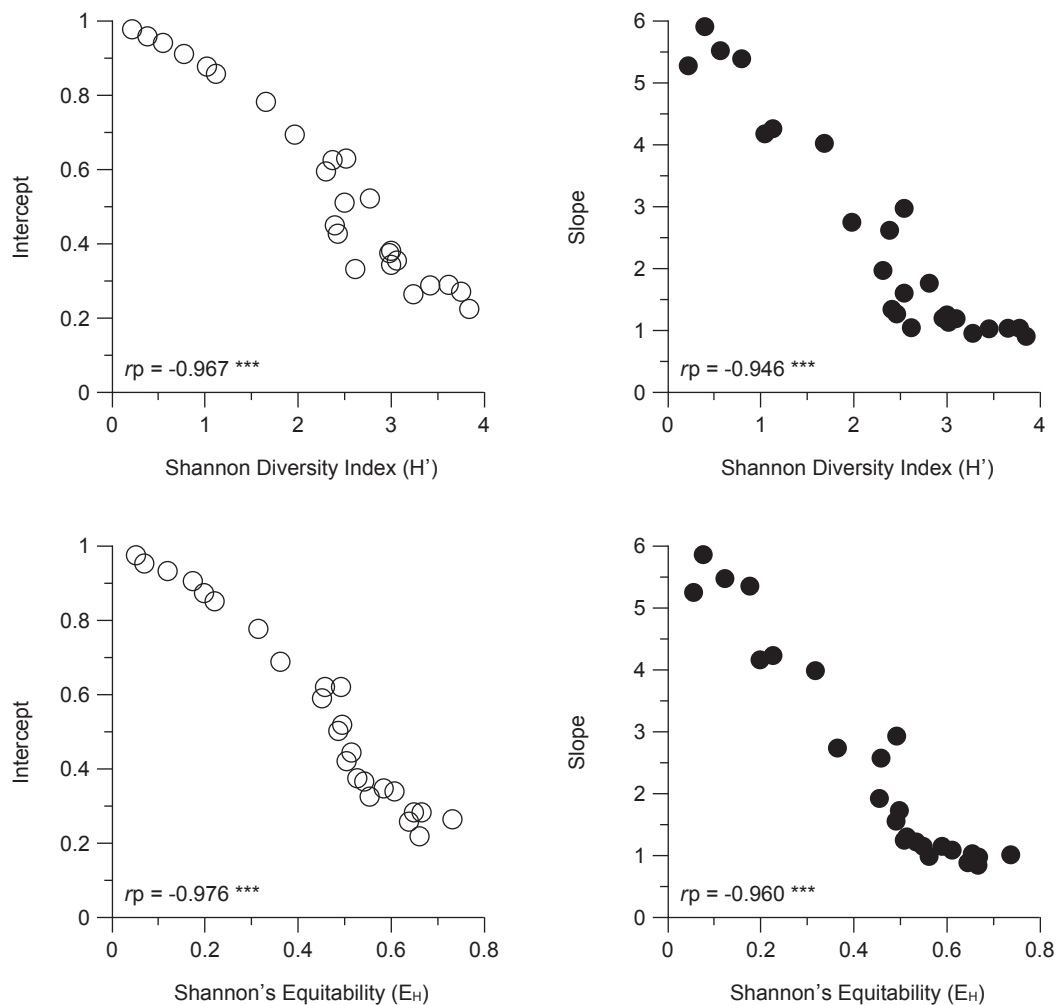


Fig. 10. Intercept and slope of the Shannon diversity (H') and Shannon's equitability (E_H) of planktonic copepod changes within a 6-yr period. Diversity analyses of copepod species sampled between Oct. 1998 and July 2004 in northwestern Taiwan are shown.

no significant correlation was observed between salinity and RA parameters (Fig. 11).

Except for 1 station in Feb. 1999 with low diversity and a concave shape, the different

stations showed the same general pattern of RA diagrams during a given sampling date. Hwang et al. (2006) showed that a colder-water species community dominated by *Calanus sinicus* and

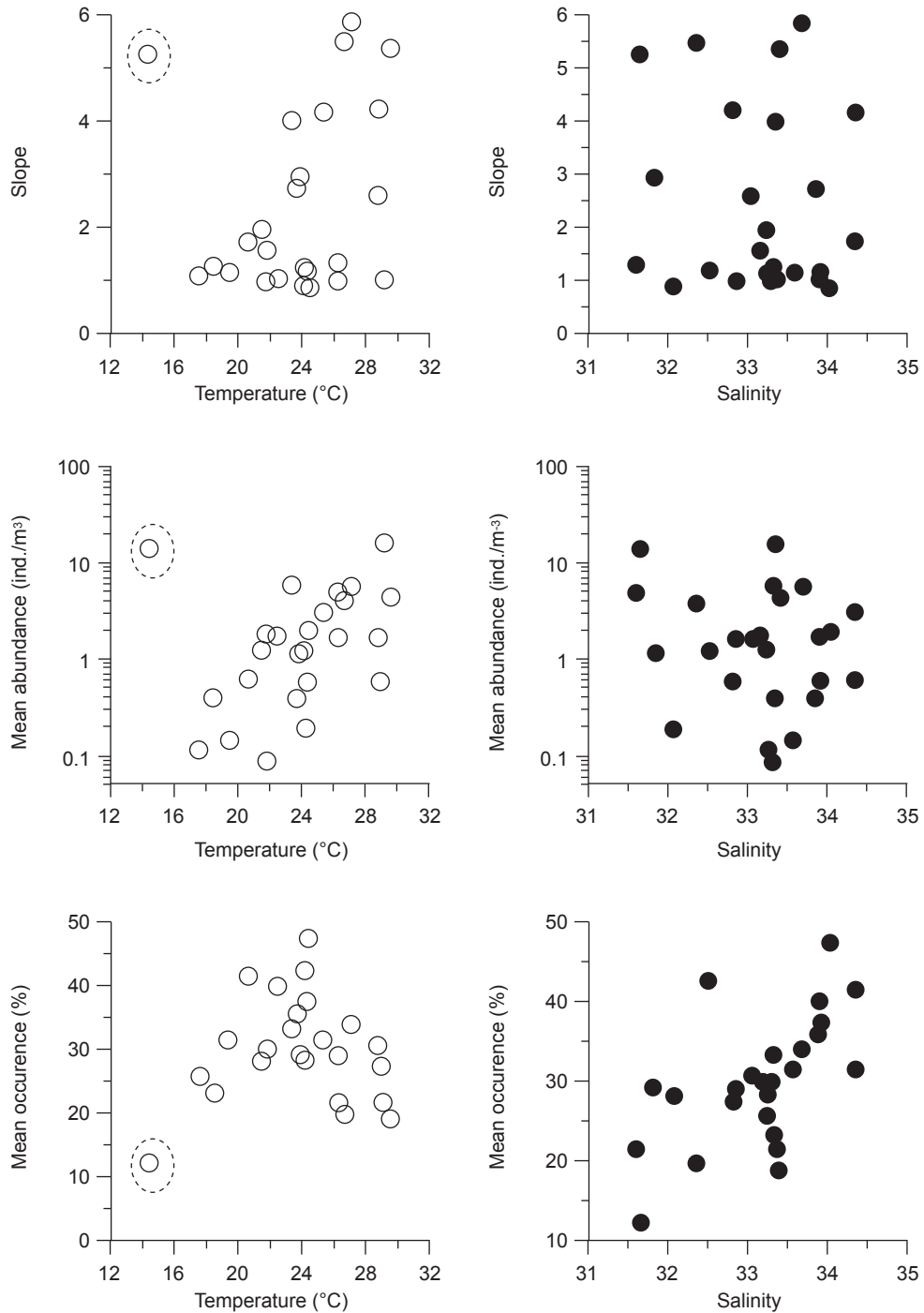


Fig. 11. Slope of the rank-abundance (RA) as diversity measurements in relation to average monthly sea-surface temperatures (SSTs) and salinities of surface waters in the studied area from Oct. 1998 to July 2004, and the mean abundance and mean occurrence related to temperature and salinity. The encircled station shows an exceptional situation in Mar. 2000.

Euchaeta concinna occurred in Dec. 1998 and Feb. 1999, when temperatures were below 20°C (Fig. 2A). *Calanus sinicus* is transported from the Yellow Sea and East China Sea by the NE monsoon during winter (Hwang and Wong 2005). When the temperature was around 24°C in Oct. 1998 and May 1999, 2 common species, *Undinula vulgaris* and *Acrocalanus gibber*, were in the top 5 dominant species in the community (Figs. 4, 5). During the Aug. 1999 sampling, the temperature was very high (28.9°C, Fig. 2a), and diversity significantly decreased. The copepod community during this period was dominated by a single species, *T. turbinata*, which comprised > 85% of the copepod community abundance (Fig. 5). The shape of the RA diagram shows this typical situation (see summer in Fig. 7). *Temora turbinata* was followed by *Canthocalanus pauper*, *Acrocalanus gibber*, and *Acrocalanus gracilis* which represented < 9% of the relative abundance, whereas the same 3 species represented 64% of the relative abundance of the copepod community in May 1999. In Oct. and Dec. 1999, the temperature decreased but stayed above 20°C (Fig. 2A); consequently, more-common relatively warm-water species including *T. turbinata* dominated the copepod communities (Fig. 5). *Temora turbinata* usually occurred in high abundances in summer when water temperatures are relatively high in northern Taiwan (Hwang et al. 2004b 2006).

The succession in dominance of the copepod community between the relatively cold-water species *Paracalanus aculeatus* and *Calanus sinicus*, to the relatively warmer water species of *Temora turbinata* are clear between Dec. 2002 and June 2003. The highest temperature was recorded in Sept. 2003 (29.13°C; Fig. 2a). Here, *Parvocalanus crassirostris*, *Oithona rigida*, and *Euterpina acutifrons* appeared for the 1st time among the top 5 dominant species. The occurrences of these latter species during the study period were very low.

CONCLUSIONS

The purpose of the present paper was to correlate the concepts of diversity and rank-abundance relationships with biotic compartments and to show the significance of the results which can be derived from such concepts. We determined the applicability of the available data to reveal the dependence of parameter values on the

area and time of sample collection. The application of rank sizing to plankton has the advantage of utilizing large datasets at high resolution, looking at scales and relevant mechanisms without the need of regular sampling intervals (Mitchell 2004).

Little is known about the temporal development of planktonic copepod assemblages in the study area. One of the reasons for this lack of knowledge is the high diversity of copepods in northern Taiwan that require a great effort in analyzing regular samplings. It should be emphasized that the relationship between the rank distribution parameters and considered habitat properties or time of sample collection (which can depend on changes of environmental quality indices) was not pronounced. Among other factors, this may have been due to parameter variability resulting from zooplankton sample processing in addition to impacts of environmental factors. It can be seen in figure 2c that this occurs regularly because water masses greatly differ and the sampling area is open to the Taiwan Strait and is under the influence of many physical driving forces.

The application of rank sizing to the study of plankton ecology basically has 3 advantages. First, it can handle large datasets of high resolution. It particularly points to a path of looking at scales and mechanisms that are relevant to demonstrate shifts in plankton communities. The 2nd aspect is the analytical advantage of the rank-size method which does not need regular sampling intervals. In addition, the RA approach is another way to consider the distribution of a dataset in order to emphasize rare events. This is a direct way of characterizing the distribution of rare species. Overall, there is an intuitive character to the method which is also associated with the information content. For zooplankton ecology, rank-size analysis provides a 3rd advantage: a method to rapidly analyze large datasets, which is necessary for characterizing microscale distributions. Commonly, researchers pursue the largest possible abundance gradients. But only a few marine zooplankton species constitute steep gradients, and are usually transient. Average zooplankton more often experience or cross small gradients or make up weak patches. The significance of the smallest, but most frequent gradients has been overlooked. As such, the key to improving understanding of plankton distributions and dynamics is likely to be the most common place rather than the most important gradients and interactions. Rank sizing is a

1st step in detecting structure that leads to an examination of higher resolutions of more-common zooplankton assemblages. The data provide a good summary of the dynamics of the copepod communities in an area.

RA analyses may also contribute to new understandings in ecological modeling. Most models were hitherto concerned with a single species, and it is not certain whether conclusions derived in that way can be applied to biotic compartments consisting of a number of species. Models of biotic compartments are more complicated than those of single species. One possibility could be that in rank-abundance patterns, a biotic compartment (an aggregate of species) behaves as an entity, as if it were a single species.

Acknowledgments: We are grateful to bilateral collaboration between the National Science Council of Taiwan (grants NSC94-2621-B-019-001, 95-2621-B-019-002, and 96-2621-B-019-002) and the National Centre for Scientific Research of France (CNRS grant 17473) for financial support of this project. We appreciate financial support from the Center for Marine Biotechnology, National Taiwan Ocean Univ. to J.S. Hwang. The authors acknowledge long-term assistance from the captain and crew of *Ocean Research Vessel II*, Taiwan and all samplings from the laboratory members of J.S. Hwang's technicians and graduate students.

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