DOES THE MESH SIZE OF THE PLANKTON NET AFFECT THE RESULT OF STATISTICAL ANALYSES OF THE RELATIONSHIP BETWEEN THE COPEPOD COMMUNITY AND WATER MASSES?

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ABSTRACT

We examined if the results of statistical analyses of the relationship between copepod communities and water masses would be affected by the mesh size of the plankton net, by comparing abundance and species composition of copepods in plankton samples collected by plankton nets of different mesh sizes. Our samples were collected during the summer of 2006 in the East China Sea (ECS) by plankton nets with mesh sizes of 100 and 330 μm. The abundance of copepods collected by the 100 μm-mesh plankton net was about two orders of magnitude higher than that collected by the 330 μm-mesh plankton net. The difference in abundance was mainly due to the loss of small-sized copepods in the samples collected by the plankton net with the larger mesh. Species richness was higher in samples collected by the 100 μm-mesh net and Piélo’s evenness was generally higher in samples collected by the 330 μm-mesh net. Although species composition of copepods varied in samples collected by plankton nets with different mesh sizes, the statistical analysis of the relationship between the copepod community and the water masses in these samples appeared not to be affected.

RÉSUMÉ

Nous avons examiné si les résultats des analyses statistiques sur les relations entre les communautés de copépodes et les masses d’eau étaient affectés par la taille de la maille des filets à plancton, en comparant l’abondance et la composition en espèces de copépodes dans les échantillons de plancton collectés à l’aide de filets de différentes tailles de maille. Nos échantillons ont été prélévés au cours de l’été 2006 dans la mer de Chine orientale (ECS) à l’aide de filets à plancton de 100 et 330 μm de taille de maille. L’abondance des copépodes récoltés avec le filet de 100 μm de taille de maille était environ de deux ordres de magnitude plus élevée que celle obtenue avec le filet à plancton de 330 μm de vide de maille. La différence d’abondance était principalement due à la perte des

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copépodes de petite taille dans les échantillons collectés avec le filet ayant la plus grande taille de maille. La richesse spécifique était plus élevée dans les échantillons collectés avec le filet de 100 μm de taille de maille et la régularité de Piérou était généralement plus élevée dans les échantillons collectés par le filet de 330 μm. Bien que la composition en espèces des copépodes variait dans les échantillons collectés avec des filets de différentes tailles de maille, l’analyse statistique de la relation entre la communauté de copépodes et les masses d’eau dans ces échantillons est apparue comme n’étant pas affectée.

INTRODUCTION

In general, copepods are the main component of oceanic mesozooplankton, usually contributing about 55-95% to the total zooplankton community (Longhurst, 1985). Small-sized copepods, such as adults and copepodites of the genera *Paracalanus*, *Pseudocalanus*, *Acartia*, *Clausocalanus*, *Oithona*, *Oncaea*, *Corycaeus*, and *Microsetella* and nauplii of almost all copepod species are always underestimated (Hopcroft et al., 2001; Turner, 2004).

There are several sampling methods for quantifying zooplankton density, the most common one being by plankton net (Sameoto et al., 2000). The factors that influence success or sampling efficiency of a plankton net include extrusion of zooplankton through the net mesh and clogging of the net mesh (Sameoto et al., 2000). Many previous studies have indicated that finer plankton nets (53-160 μm) catch zooplankton better than coarser plankton nets (200-600 μm), the finer nets collecting an 8-fold to 2 orders of magnitude as much as the coarser (Evans & Sell, 1985; Calbet et al., 2001; Hopcroft et al., 2001; Wang & Wang, 2003; Hwang et al., 2007; Di Mauro et al., 2009). Hopcroft et al. (2001) found that copepods with prosome lengths less than 450 μm were collected efficiently by plankton nets with mesh sizes of 64 μm, those with 450-1400 μm prosome lengths with mesh sizes of 200 μm, and those with 1400 μm prosome length with mesh sizes of 600 μm. Although copepods of different sizes are efficiently collected by plankton nets of different mesh sizes (Nicols & Thompson, 1991; Hopcroft et al., 2001; Wang & Wang, 2003; Di Mauro et al., 2009), coarse plankton nets (>200 μm) have generally been used to collect zooplankton in most marine field surveys (e.g., Zuo et al., 2006; Dur et al., 2007; Lan et al., 2008).

Because of their weak swimming ability (Hannan, 1984) and physiological adaption to a specific marine environment (Mauchline, 1998), the distribution of copepod communities or the occurrence of a specific species could be a biological indicator for water masses (e.g., Noda et al., 1998; Zuo et al., 2006; Lan et al., 2008). Past studies about copepods in the East China Sea (ECS) have focused on the relationship between water mass and species composition of the copepod community (Shih & Chiu, 1998; Liao et al., 2006; Zuo et al., 2006, 2007; Lan et
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al., 2008). Many have shown a close relationship between copepod communities and the hydrological characters of water masses (Shih & Chiu, 1998; Hsieh et al., 2004, 2005; Zuo et al., 2006; Lan et al., 2007, 2008; Tseng et al., 2008). The efficiency of plankton collecting is significantly different between plankton nets of different mesh sizes, especially for small-sized copepods. Overall, the small-sized copepods compose about 30% of the total collection by 500 μm-mesh plankton nets (Shih & Chiu, 1998), 55% by 330 μm (Lan et al., 2008), >66% by 150 μm (Hsieh et al., 2005), and 83% by 100 μm (Tseng et al., 2008) in the ECS. These examples are a good indication that the small-sized copepods will be missed in plankton samples collected by plankton nets with larger mesh sizes. A bias of collection clearly exists, and therefore affects an analysis of the relationships between copepod communities and water masses.

The ECS is a western marginal sea of the northern Pacific Ocean and is comprised of two water masses in summer, the Changjiang Diluted Water within the Changjiang Plume (<31 psu) and the northward flowing Taiwan Current Warm Water (Beardsley et al., 1985; Gong et al., 1996, 2003). The changing hydrological environments have resulted in a diverse species composition of copepods (Shih & Chiu, 1998; Hsieh et al., 2005; Liao et al., 2006; Zuo et al., 2006; Lan et al., 2007, 2008; Tseng et al., 2008). However, no studies have compared the results of sampling between plankton nets with different mesh sizes in the same water mass. This study investigated whether results of statistical analysis of the relationship between the copepod community and water masses would be changed due to the mesh size of the plankton net.

MATERIAL AND METHODS

Between 23 June and 1 July 2006, during Cruise 1360 of the “Ocean Research II”, surface zooplankton samples were collected. In total, samples were collected at 21 out of 33 stations in the ECS. Temperature and salinity were recorded by CTD at the surface for all 33 stations along 7 cross-shelf transects, covering the entire continental shelf of the ECS (fig. 1).

Zooplankton samples were collected with plankton nets (45 cm opening, 2.25 m in length) in two mesh sizes, 100 μm and 330 μm. A flow meter was mounted at the centre of the net mouth, and the net was towed horizontally at the surface for 10 minutes at 0.5 m per second. After collecting, samples were washed into a 500 ml plastic bottle and preserved in neutralized formalin (10% final concentration).

In the laboratory, the samples were repeatedly split with a Folsom Plankton Splitter to obtain a final subsample of approximately 500 individuals for identification and enumeration. Copepods were identified to species or generic level and the
measurements of total length for each species were based on 20 individuals picked randomly. General references for identification were Chen & Zhang (1965), Chen et al. (1974), and Chihara & Murano (1997). The biomass of the copepods was calculated following White & Roman (1992), determining the empirical relationship between weight and length. Species diversity of the copepods was calculated by Shannon’s Diversity Index, and the relative abundance of species by Pielou’s Evenness Index. The relationship between copepod species composition and water mass was illustrated by multidimensional scaling (MDS) based on Bray-Curtis similarity.

RESULTS

Hydrographic condition

The surface temperature and salinity were 23-29°C and 25-34 psu, respectively, in the ECS during summer (fig. 2A, B). Salinity had a radial distribution pattern and gradually increased from the Changjiang River estuary to the outer shelf. The Changjiang River Plume was defined as starting from the radial center and extending to an area of salinity of less than 31 psu (Gong et al., 1996) (fig. 2B). Water with high temperatures and salinity (>28°C, >33 psu) intruded into the southern ECS from the Taiwan Strait (fig. 2A, B). Based on the T-S diagram
(Gong et al., 1996) (fig. 3A), the ECS is composed of two water masses, namely a low salinity Changjiang Diluted Water (CDW) and a high salinity Taiwan Current Warm Water (TCWW). With one exception, the Changjiang River Plume was entirely occupied by the CDW (fig. 3B). At St. 4, located in front of the mouth of the Minjiang River, the low salinity water resulted from the outflow of the Minjiang River. The rest of the continental shelf was occupied by high salinity TCWW water...
intruding from the Taiwan Strait (fig. 3B). A lower temperature region (<25°C) was observed at the outer shelf stations along the northern transect (fig. 2A). This area was affected by the Yellow Sea Water.

Copepod communities

The abundance of copepods ranged from 0.5 to 4000 ind. m⁻³ (average 389 ± 864 ind. m⁻³) in our samples taken with the 330 μm-mesh net, and from 50 to 75,000 ind. m⁻³ (average 12,490 ± 20,802 ind. m⁻³) in samples taken with the 100 μm-mesh net (fig. 4A, B). There was a higher copepod abundance collected with the 330 μm-mesh net in the southern ECS than in the
northern ECS (fig. 4A), while there was higher copepod abundance collected with 100 μm in the coastal area (fig. 4B). In addition, we found a positive exponential correlation of copepod abundance between mesh sizes, with the 100 μm mesh size collecting an abundance two orders of magnitude higher than the 330 μm mesh size (fig. 5A). If the analysis was based on copepod biomass, then the total biomass
Fig. 5. The relationship of: A, copepod abundance; and, B, biomass between the 330 μm-mesh and the 100 μm-mesh plankton net. The abundance (ind m$^{-3}$) and biomass (μg m$^{-3}$) were log-transferred before plotting. The solid line is the fitted linear curve of all data points; the dotted line is the slope 1:1.

of copepods at each station showed the same correlation as abundance (fig. 5B). The species most significantly affected by the mesh size (paired t-test, $p < 0.05$) were Canthocalanus pauper (Giesbrecht, 1888), Farranula concinna (Dana, 1847), Oncaea spp., Microsetella norvegica (Boeck, 1864), Macrosetella gracilis (Dana, 1847), and copepodids.

We recorded 50 copepod species belonging to 34 genera and 20 families in the samples taken with the 330 μm-mesh plankton net, and 70 copepod species belonging to 30 genera and 18 families in the 100 μm-mesh plankton net. With a
few exceptions, the relationship of species diversity between the samples collected by plankton nets of the two different sizes was distributed along the 1:1 line at most stations (fig. 6A). On the other hand, species richness was higher in samples collected by the plankton net with 100 μm mesh than with the 330 μm mesh (fig. 6B) and the evenness of species was higher in samples taken with the plankton net with 330 μm mesh than with the 100 μm mesh at most stations (fig. 6C). The species composition of copepods was significantly affected by water mass. The copepod community could, therefore, be divided into a CDW assemblage and a TCWW assemblage in the samples taken by the plankton nets of both 330 μm and 100 μm mesh (fig. 7). The area of CDW and TCWW assemblages collected with the two net sizes were not significantly different, except at stations with low temperatures resulting from the influx of Yellow Sea Water (fig. 7C).

**DISCUSSION**

Several reports have demonstrated an underestimation of copepod abundance based on samples collected with coarse plankton nets in many regions (Kršinić & Lučić, 1994; Calbet et al., 2001; Hopcroft et al., 2001; Di Mauro et al., 2009; Riccardi, 2010). Our work was the first similar study carried out in the ECS. We therefore compared copepod abundance and plankton net mesh size in a number of studies based on samples taken in the ECS. The results gave 61-348 ind. m$^{-3}$ by plankton net with 330 μm mesh in Liao et al. (2006), 63-242 ind. m$^{-3}$ by 330 μm mesh in Lan et al. (2008), and 18-264 ind. m$^{-3}$ by 500 μm mesh in Shih & Chiu (1998), as compare to 138 ind. m$^{-3}$ by 330 μm mesh and 8673 ind. m$^{-3}$ by 100 μm mesh in the present study. It is thus clear, that copepod abundance in the ESC has been greatly underestimated in previous reports. Previous studies also indicated that the underestimation of copepod abundance by the coarse plankton net was mainly due to the extrusion of small copepods through the mesh (e.g., Hopcroft et al., 2001; Wang & Wang, 2003; Di Mauro et al., 2009). In the present study, the abundance of copepods less than 1.6 mm body length in the samples collected by the plankton net with 100 μm-mesh was 1-4 orders of magnitude higher than that collected with 300 μm-mesh, though no significant difference between the sampled copepods larger than 1.6 mm body length taken by these two mesh sizes was found (fig. 8).

In the oceans, small copepods outweigh larger copepods both in abundance and number of species (Mauchline, 1998; Turner, 2004). In the past, attention was mainly focused on the difference of abundance between coarse and fine nets (Evans & Sell, 1985; Hopcroft et al., 2001; Wang & Wang, 2003; Hwang et al., 2007; Di Mauro et al., 2009), but rarely was it focused on the change in
Fig. 6. The relationship of: A, Shannon Diversity; B, species richness; and, C, Pielou’s Evenness of the copepod community, between samples taken by the 330 μm-mesh and the 100 μm-mesh plankton net from the same station. The dotted line is the slope 1 : 1.
Fig. 7. MDS ordination of sampling stations based on the Bray-Curtis similarity matrix. A, 330 μm-mesh plankton net; B, 100 μm-mesh plankton net; C, location of MDS ordination group. Symbols: triangle, Taiwan Current Warm Water; circle, Changjiang Diluted Water.
species diversity and richness (Riccardi, 2010) or species composition. Riccardi (2010), conducting a one-year zooplankton survey in a Mediterranean lagoon, found that the number of taxa in the samples taken by a plankton net with 200 μm mesh was distinctly less than that taken with an 80 μm mesh, although no clear differences were found in species diversity and evenness. In our study, the result of species richness was also consistent with the above-mentioned study (fig. 6B), but species evenness was generally higher in samples with 330 μm mesh than with 100 μm mesh (fig. 6C). There was a smaller number of genera and families caught in the 100 μm mesh than in the 330 μm mesh, resulting from rare species of large-sized copepods (e.g., Aetideopsis, Gaetanus, Eucalanus, Pleuromamma) that were only caught by the 330 μm mesh. The missing of a number of small-sized copepods in the samples taken by the plankton net with 330 μm mesh resulted in a lower species richness and a higher evenness. However, the relationship between copepod community and water mass remained unchanged in samples taken by plankton nets of both types (fig. 7). Although there were differences in abundance, species richness, and evenness between the samples taken by both mesh sizes, the two matrices of the corresponding values respectively, for these samples of different mesh sizes in Bray-Curtis similarity were well related (R = 0.45) (fig. 9). Our result of statistical analysis indicated no significant change in spatial distribution pattern of the copepod community (CDW Community and TCWW
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Fig. 9. The relationship of the Bray-Curtis similarity matrix of homologous values between samples taken with the 330 $\mu$m-mesh net and the 100 $\mu$m-mesh net ($R = 0.45$).

Community) in samples taken by plankton nets with two different mesh sizes. Hence, there was a significant difference in species composition and abundance of copepods in each community. Though we have found a significant difference between different mesh size nets, the characters of species composition in both communities were still retained. Therefore, there was an insignificant change in the relationship between the copepod community and water mass when the statistical analysis was based on samples taken by plankton nets with two different mesh sizes, e.g., 330 $\mu$m and 100 $\mu$m.

Our study confirmed that the underestimation of copepod abundance collected by a coarse plankton net was due to the loss of small-sized copepods, and consequently caused the differences in species richness and evenness between the 330 $\mu$m-mesh and the 100 $\mu$m-mesh. We also proved by MDS analysis that there were no significant differences found in spatial distribution pattern, exhibited by samples taken with two different mesh sizes.

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