Zoological Studies **50**(2): 155-163 (2011)

Zoological Studies

Mesozooplankton Distribution and Composition on the Northeastern Coast of Taiwan during Autumn: Effects of the Kuroshio Current and Hydrothermal Vents

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(Accepted November 9, 2010)

Samba Kâ and Jiang-Shiou Hwang (2011) Mesozooplankton distribution and composition on the northeastern coast of Taiwan during autumn: effects of the Kuroshio Current and hydrothermal vents. *Zoological Studies* **50**(2): 155-163. Many studies of mesozooplankton communities have been performed around Taiwan, except in northeastern waters where studies are still few. The mesozooplankton distribution and abundance were studied in coastal waters of northeastern Taiwan, including around Kueishan I., in autumn 2009. Samples were collected with a 333-μm-mesh net towed horizontally at 2 m of depth at 7 stations along the coast. Mesozooplankton abundance and diversity were high. *Noctiluca* sp. and copepods were the most important components of the zooplankton community. The Kuroshio Current showed a significant impact on the zooplankton composition since the most frequently found and dominant species (*Canthocalanus pauper*, *Clausocalanus arcuicornis*, *Cla. furcatus*, *Paracalanus aculeatus*, *P. nanus*, *Temora turbinata*, *Oncaea conifera*, and *Onc. venusta*) were common in Kuroshio waters. However, zooplankton associations distinguished three groups of stations, mainly due to the impact of hydrothermal vents. This study showed that the distribution and composition of mesozooplankton in coastal waters of northeastern Taiwan are highly influenced by the Kuroshio Current and by the presence of hydrothermal vents around Kueishan I. http://zoolstud.sinica.edu.tw/Journals/50.2/155.pdf

Key words: Zooplankton, Kuroshio, Kueishan Island, Venting.

The zooplankton constitutes the most abundant component of marine fauna and plays important role in food webs (Poulet and Williams 1991, Kiorboe 1997). Zooplankton organisms are sensitive to water mass properties, which are known to be important factors influencing their spatial distribution and abundance (Hwang and Wong 2005, Hwang et al. 2006, Alcaraz et al. 2007). This means that certain zooplankton species can be considered indicators of various water masses (Hwang et al. 2006 2007).

In recent years, many studies were conducted on zooplankton, especially on copepods around Taiwan. However, those studies mainly focused on northwestern waters (of the East China Sea and Taiwan Strait: Shih and Chiu 1998, Hsieh et al. 2004a b, Hwang et al. 2004 2006, Lo et al. 2004b, Hwang and Wong 2005, Dur et al. 2007, Tseng et al. 2008a b, Lan et al. 2009) and southwestern waters (of the South China Sea: Lo et al. 2001 2004a, Lan et al. 2008, Hwang et al. 2007 2010) of Taiwan. In contrast, very few studies were performed on zooplankton communities on the eastern side of Taiwan. More recently, limited studies were carried out on copepods on the northeastern coast of Taiwan (Hsiao et al. 2004, Lee et al. 2006 2009). However, this area may be important for zooplankton studies when taking into consideration the presence of Kueishan (Turtle Mt.) I. In particular, the presence of shallow (< 30 m deep) hydrothermal vents in this area of Taiwan, within 1 km east of Kueishan I., near the southern

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end of the Okinawa I. (Chen et al. 2005) may affect biological communities. It was reported that the magma under Kueishan I. is still active and is still degassing sulfur along with other gases such as CO_2 from the mantle (Chen et al. 2005). Chen et al. (2005) also reported temperatures to be as high as 116°C and pH values (at 25°C) to be as low as 1.52, with the presence of trace elements (such as SiO_2, Fe, Mn, CH_4, S_2, Cu, Cd, Pb, Ni, Al, and Zn) in the vents. The influence of volcanic activity on the marine biota is rarely mentioned (Prol-Ledesma et al. 2005). However, shallow vent sites are in some instances hotspots of biodiversity for eukaryotes (Morri et al. 1999, see review by Tarasov 2006). Venting areas can have significant effects on phytoplankton and zooplankton composition and quantitative parameters (Tarasov et al. 1999 2005, Skebo et al. 2006).

In Taiwan, the hydrothermal vents of Kueishan I. are reported to be a primary nursery habitat for early stages of the benthic crab *Xenograpsus testudinatus* (Hwang et al. 2008). There are few other studies of the zooplankton in this area. Comprehensive studies are necessary not only to understand the zooplankton community structure but also to provide insights into the biodiversity of the entire animal community around these vents.

The objectives of this study were to determine the mesozooplankton composition and abundance in waters of northeastern Taiwan, including Kueishan I., and to try to determine the effects of the presence of the hydrothermal vents on the community.

MATERIALS AND METHODS

Samples were collected during a cruise in Sept. 2009 from a series of seven stations extending in waters along the northeastern Taiwanese coast (Fig. 1) aboard the *R/V Ocean Research-II*. Four of these stations were located around Kueishan I. including a site with hydrothermal vents (St. 7).

Environmental data

Temperature and salinity were simultaneously recorded on board with a SeaBird CTD instrument every meter from the surface to the bottom, at each station.

Zooplankton sampling

Zooplankton samples were collected using a conical plankton net with a 45-cm mouth diameter and 333-μm mesh size. A flow meter (Hydro-Bios) was mounted at the center of the mouth opening. The net was towed at 2 m below the water surface. The sampling time was approximately 5 min at a vessel cruise speed of 2 knots. The zooplankton samples were immediately preserved in 5%-10% buffered formalin-seawater. Copepods were identified in the laboratory according to the methods of Chen and Zhang (1965), Chen et al. (1974), and Huys and Boxshall (1991). The abundance and species of copepods in each sample were recorded.

Data analyses

Shannon diversity index (Shannon and Weaver 1949) was used to calculate the species diversity at each station. A cluster analysis with normalized Euclidean distances was used to measure levels of similarity of species composition

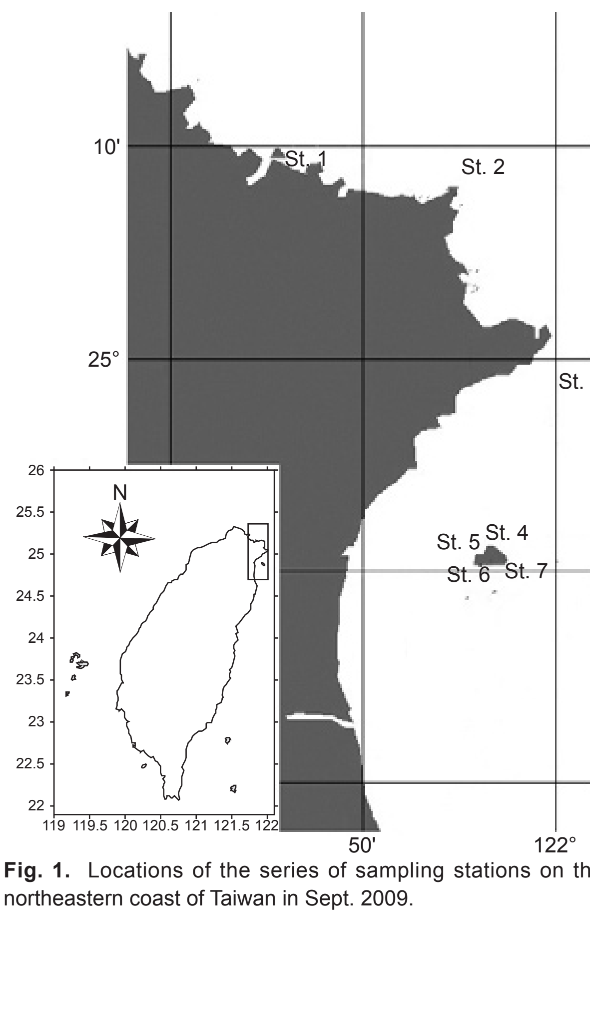


Fig. 1. Locations of the series of sampling stations on the northeastern coast of Taiwan in Sept. 2009.

among the sampling stations, and Ward's method (Ward 1963) was used to illustrate those relations as a dendrogram. Data used in the cluster analysis were transformed (log(x + 1)) abundances of zooplankters collected at each station.

RESULTS

Hydrography

Temperature-salinity curves of the stations are shown in figure 2. Water temperatures varied 15.9-26.6°C, and salinities varied 32.7-34.5 psu. The temperature-salinity curves showed that the lowest temperature (~22.8°C) and the highest salinity (~34.1) values were recorded from St. 1 to St. 5. A reverse trend was observed at St. 6 and St. 7, with the highest temperature (~23.9°C) and the lowest salinity (~33.9).

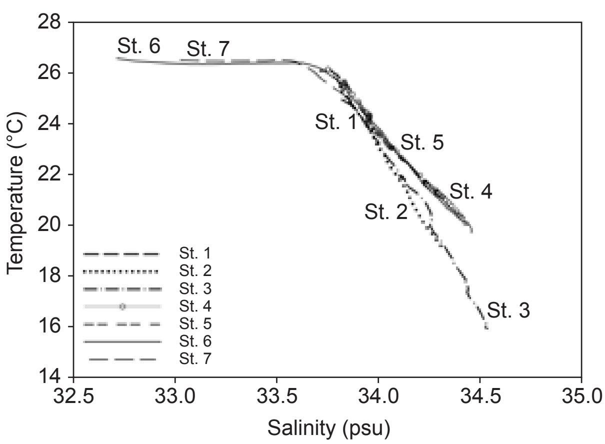


Fig. 2. Temperature-salinity diagrams at the different sampled stations in coastal waters of northeastern Taiwan in Sept. 2009.

Zooplankton

Variations in the abundances of different mesozooplankton groups are presented in figure 3. Mesozooplankton abundances were high, ranging 380-1954 individuals (ind.)/m^3. Copepods and *Noctiluca* sp. were the most abundant groups along the coast, respectively averaging 49% and 33% of the total abundance of the mesozooplankton (Table 1). However, the abundance of *Noctiluca* sp. decreased drastically in St. 6, at < 1% of the total abundance. Chaetognaths were the 3rd most abundant group, representing an average of 9% of the total abundance of the mesozooplankton (Table 1). *Flaccisagitta enflata* appeared at all stations and was the most abundant chaetognath species (Table 2). Appendicularians constituted an average of 6% of the total abundance of the mesozooplankton along the coast (Table 1). *Oikopleura rufescens* (at 100% occurrence) and *Oik. dioica* (at 86% occurrence) were the most abundant species, reaching maximum density of 231 ind./m^3 at St. 7 (Table 2). The other mesozooplankton groups were less abundant (Table 1).

Copepods

The diversity of copepods was very high (Fig. 4). The highest diversity index was observed

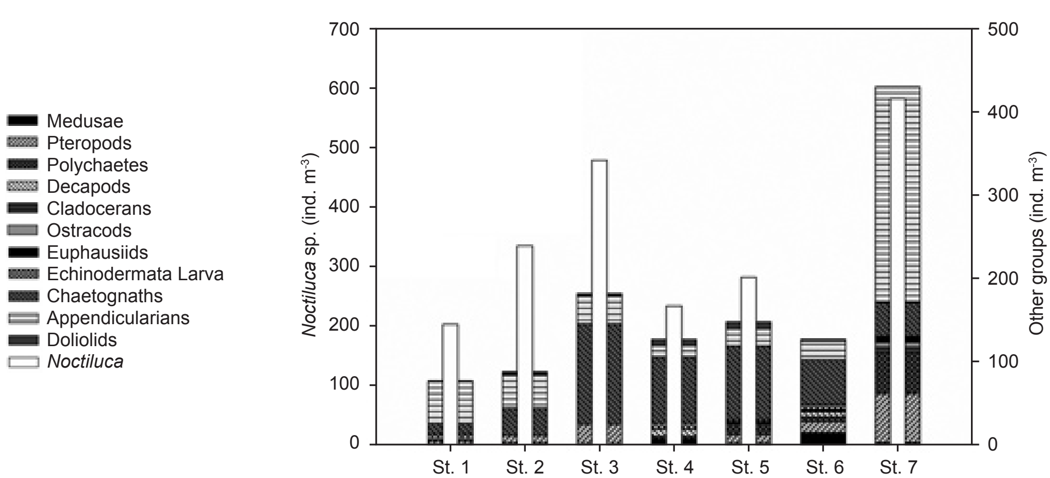


Fig. 3. Variations in the abundances of mesozooplankton groups (except copepods) at different stations in coastal waters of northeastern Taiwan in Sept. 2009.

Table 1. Mean relative abundances of mesozooplankton groups in coastal waters of northeastern Taiwan in Sept. 2009

Parameters	Units	Mean	SD	Min.	Max.
Total abundance	ind./m^3	939	543	380	1954
Noctiluca sp.	%	33.2	16.6	0.3	53.6
Foraminifers	%	0.1	0.1	0.0	0.3
Medusae	%	0.7	0.8	0.2	2.5
Ctenophores	%	< 0.1	0.1	0.0	0.2
Pteropods	%	1.5	0.9	0.0	3.0
Polychaetes	%	0.8	1.0	0.0	2.5
Decapods	%	0.3	0.5	0.0	1.2
Cladocerans	%	0.0	0.1	0.0	0.3
Ostracods	%	0.0	0.1	0.0	0.3
Copepods	%	48.4	15.5	25.6	77.9
Euphausids	%	0.1	0.2	0.0	0.5
Echinodermata larvae	%	0.6	0.8	0.0	2.0
Chaetognaths	%	7.1	3.7	2.1	11.2
Appendicularians	%	6.1	5.0	1.9	13.2
Doliolids	%	0.5	0.4	0.0	1.1
Fish eggs	%	< 0.1	0.1	0.0	0.2
Fish larvae	%	0.1	0.1	0.0	0.2
Others (larvae)	%	0.2	0.3	0.0	0.9

Table 2. List of the mesozooplankton taxa (except copepods), occurrence (Occ. in %), and the most abundant taxa (in bold) in coastal waters of northeastern Taiwan in Sept. 2009

Taxa	Occ.	Taxa	Occ.
***Noctiluca* sp.**	100	Decapods	43
Foraminifers	29	*Lucifer intermedius*	43
Medusae	100	*L. typus*	29
Algaura hemistoma	43	Echinodermata larva	57
Abylopsis tetragona	14	**Chaetognaths**	100
Diphyes chamissonis	14	*Aidanosagitta delicata*	71
Eutima neucaledonia	29	*A. regularis*	29
Lensia subtiloides	14	*Ferosagitta ferox*	57
Nanomia bijuga	29	*F. robusta*	43
Sulculeolaria chuni	14	***Flaccisagitta enflata***	100
Ctenophores	14	*Mesosagitta decipiens*	14
Pteropods	86	*M. minima*	57
Creseis acicula	43	*Pterosagitta draco*	14
Cr. clava	86	*Serratosagitta pacifica*	43
Cr. virgula	14	*Zonosagitta sinica*	14
Desmopterus papilio	43	**Appendicularians**	100
Polychaetes	71	***Oikopleura dioica***	86
Cladocerans	14	*Oik. longicauda*	29
Pseudevadne tergestina	14	***Oik. rufescens***	100
Ostracods	14	Doliolids	86
Euconchoecia aculeatus	14	*Doliolum denticulata*	86
Euphausiids	43	Fish eggs	29
Pseudeuphausia latifrons	14	Fish larvae	43
Stylocheiron carinatum	29	Others (larvae)	43

at the northernmost stations, Sts. 1 and 2, at 4.046 and 3.916, respectively. Stations 6 and 7, located in the vicinity of Kueishan I., also showed high diversity values (at 3.501 and 3.793, respectively), compared to the other stations (Sts. 3 and 4). Altogether, 62 different copepod species were identified, belonging to 31 genera: 42 calanoids, 3 cyclopoids, 3 harpacticoids, and 14 poecilostomatoids (Table 3). The number of species varied between a minimum of 22 at St. 5 and a maximum of 34 at St. 7 (Fig. 4).

Copepod abundances represented 26% (97 ind./m^3) to 79% (935 ind./m^3) of the total abundance of the mesozooplankton (Fig. 4). Both in terms of species richness and abundance, calanoids (42 species) dominated copepod populations. Calanoids represented an average of 81% of the copepod abundance along the coast, followed by poecilostomatoid copepods which represented an average of 17%. Minimum and maximum densities of these 2 groups were found at Sts. 1 and 7, respectively. Cyclopoids and harpacticoids were less abundant, representing in average of 1% each of the copepod abundance along the coast.

Several copepod species (*Acartia negligens*, *Canthocalanus pauper*, *Clausocalanus arcuicornis*, *Cla. furcatus*, *Paracalanus aculeatus*, *P. nanus*, *Temora turbinata*, *Oncaea conifera*, *Onc. minuta*, and *Onc. venusta*) were present at all stations (Table 3). Basically, these species were also the most abundant species numerically along the northeastern coast. Copepod abundances fluctuated spatially. *Clausocalanus arcuicornis* and *Cla. furcatus* reached their highest densities at St. 3, with 210 and 205 ind./m^3, respectively. Twenty-six copepod species reached their highest abundances at St. 7 (the side of Kueishan I. with vents). The most abundant species of these copepods were *P. gracilis* (191 ind./m^3) and *Onc. venusta* (130 ind./m^3). Six of these 26 species (*Acartia danae*, *Euchaeta indica*, *Pleuromamma robusta*, *Acrocalanus monachus*, *Scolecitricella bradyi*, and *Coryceaus lautus*) were exclusively observed at St. 7. *Pareucalanus attenuatus*, *Subeucalanus crassus*, and *S. subtenuis* were exclusively observed at St. 6 where *T. discaudata* reached its maximum abundance of 15 ind./m^3.

Zooplankton associations

According to the dendrogram results from the cluster analysis, the species composition of zooplankton for the seven stations was divided into

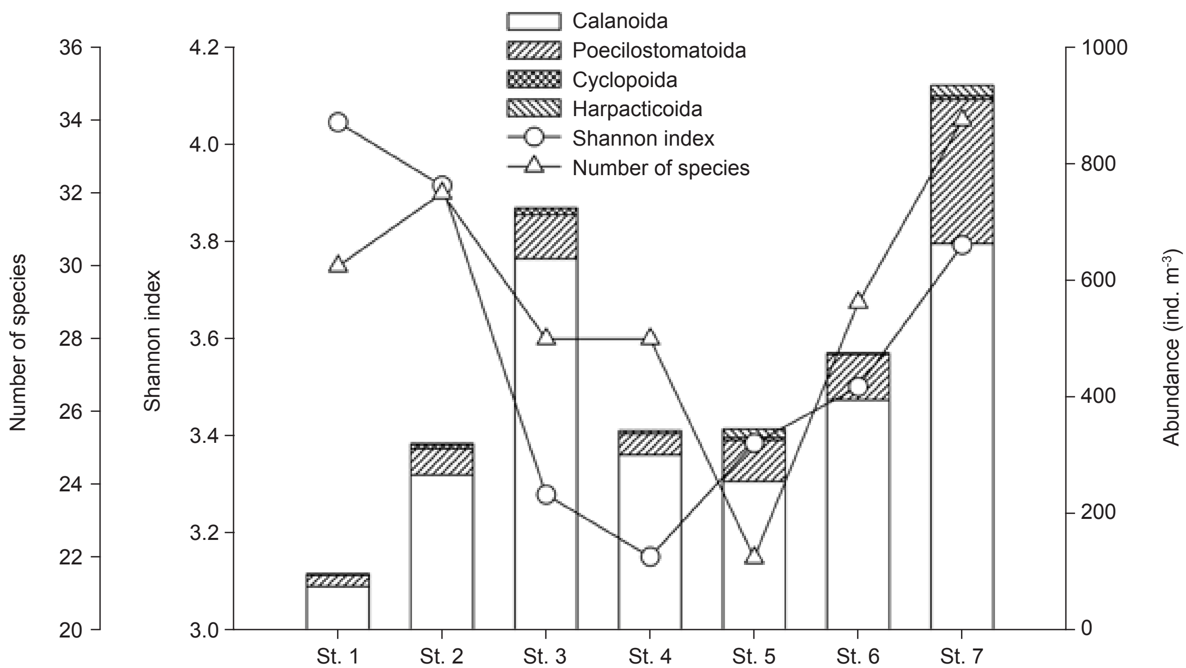
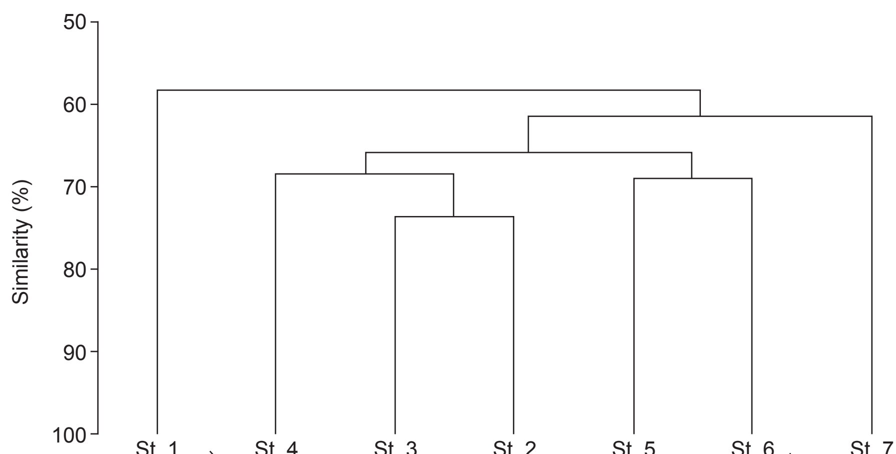


Fig. 4. Variations in the abundances of copepod groups at different stations in coastal waters of northeastern Taiwan in Sept. 2009.



Group I

Taxa	ind. m^{-3}	%
Noctiluca sp.	203	53.6
Oik. rufescens	42	11.0
P. nanus	16	4.1
Clau. arcuicomis	12	2.8
Canthocalanus pauper	11	3.1
Acrocalanus gracilis	11	2.8

Group II

Taxa	ind. m^{-3}	%
Noctiluca sp.	266	31.4
Flaccisagitta enflata	60	7.0
Oik. rufescens	21	3.0
T. turbinata	99	11.7
Clau. arcuicomis	78	9.2
Clau. furcatus	63	7.5
On. venusta	23	2.7

Group III

Taxa	ind. m^{-3}	%
Noctiluca sp.	583	29.8
Cr. clava	10	2.5
Polychaeta	6	2.5
Oik. dioica	231	11.8
P. gracilis	191	9.8
Clau. furcatus	154	7.9
On. venusta	129	6.6
Clau. arcuicornis	89	4.6

Fig. 5. Dendrogram resulting from a cluster analysis based on zooplankton communities at 7 stations in coastal waters of northeastern Taiwan in Sept. 2009.

three groups, with ~75% similarity (Fig. 5). These were group I (St. 1), group II (Sts. 2-5, and 6), and group III (St. 7). *Noctiluca* sp., *Oik. rufescens*, *P. nanus*, *Cla. arcuicornis*, *Canthocalanus pauper*, and *Acr. gracilis* were the dominant species in group I. *Noctiluca* sp., *Flaccisagitta enflata*, *Oik. rufescens*, *Cla. arcuicornis*, *Cla. furcatus*, and *T. turbinata* dominated group II. *Noctiluca* sp., *Creseis clava*, polychaetes, *Oik. dioica*, *P. gracilis*, *Cla. furcatus*, *Cla. arcuicornis*, and *Onc. venusta* dominated group III.

Table 3. List of the copepod taxa, occurrence (Occ. in %), and the most abundant taxa (in bold) in coastal waters of northeastern Taiwan in Sept. 2009

Taxa	Occ%	Taxa	Occ%
Calanoida		Pontellidae	
Acartiidae		*Labidocera acuta*	57
Acartia danae	14	*L. kroyeri*	14
A. negligens	100	*Pontellopsis tenuicauda*	14
Calanidae		*Pontellina plumata*	29
Calanus sinicus	43	Temoridae	
Cal. pavo	29	*Temora discaudata*	57
Cal. pavoninus	71	***T. turbinata***	100
Cal. plumulosus	29	Scolecithricidae	
Canthocalanus pauper	100	*Scolecitricella bradyi*	14
Cosmocalanus darwini	71	*Scolecitricella* sp.	43
Nannocalanus minor	14	*Scolecitrix danae*	43
Undinula vulgaris	71	Cyclopoida	71
Candaciidae		Oithonidae	
Candacia bradyi	71	*Oithona attenuatus*	29
Can. catula	29	*Oit. setigera*	57
Can. pachydactyla	14	*Oit. tenuis*	29
Centropagidae			
Centropages furcatus	43	Haroacicoida	86
Cen. orsini	43	Clytemnestridae	
Clausocalanidae		*Clytemnestra scutellata*	29
Clausocalanus arcuicornis	100	Euterpinidae	
Clau. furcatus	100	*Euterpina acutifrons*	14
Eucalanidae		Miraciidae	
Pareucalanus attenuatus	14	*Macrosetella gracilis*	86
Rhincalanus rostrifrons	29	Poecilostomatoida	
Subeucalanus crassus	14	Corycaeidae	
S. subcrassus	71	*Corycaeus affine*	71
S. subtenuis	14	*Cor. agilis*	57
Euchaetidae		*Cor. andrewsi*	14
Euchaeta indica	14	*Cor. catus*	57
E. rimana	71	*Cor. concinnuns*	71
Metridinidae		*Cor. dahli*	29
Pleuromamma robusta	14	*Cor. erythraea*	57
Paracalinidae		*Cor. gibbulus*	57
Acrocalanus gracilis	71	*Cor. lautus*	14
Acr. monachus	14	*Cor. speciosus*	29
Paracalanus aculeatus	100	Oncaeidae	
P. gracilis	71	***Oncaea conifera***	100
P. nanus	100	*Onc. mediterranea*	29
Parvocalanus crassirostris	14	*Onc. minuta*	100
Pontellidae		***Onc. venusta***	100
Calanopia elliptica	71		
C. minor	14		

DISCUSSION

Effect of Kuroshio water

A very high diversity of mesozooplankton, particularly copepods, was observed in our study. Very few variations were observed in copepods among the different stations, according to the Shannon index value. However, the highest values were recorded at the northernmost stations (Sts. 1 and 2) and on the side of Kueishan I. with vents (St. 7). Most of the copepods species observed in this study were previously recorded by earlier studies in these northeastern waters and originate from surface waters of southeastern Taiwan (Lee et al. 2009). In particular, the northern waters of the South China Sea are known to have very high copepod densities and species numbers (Hwang et al. 2006). These species are continually being carried to northeastern Taiwan waters by the Kuroshio Current which flows year-round northward offshore of eastern Taiwan (Hwang et al. 2006). Our study confirms that the copepods *Onc. venusta* and *P. aculeatus* are widely distributed in this region, as reported by previous studies (Lee et al. 2009). These 2 species, together with *Cla. furcatus* and *T. turbinata* among others, are reported to be associated with the Kuroshio Branch Current in the Taiwan Strait (Hsieh et al. 2004b, Lan et al. 2004, Hwang et al. 2006), and are commonly found in southwestern coastal waters of Taiwan (Lo et al. 2001, Tseng et al. 2008b). In particular, the tropical copepod *T. turbinata* is considered a warm-water indicator species (Hwang et al. 2006, Dur et al. 2007), and together with *P. aculeatus*, one of the most abundant species in waters surrounding nuclear power plants in northern Taiwan (Hwang et al. 2004). *Acrocalanus gracilis*, which was one of the dominant species at St. 1 in this study, is known to be abundant in the southeastern Taiwan Strait (Lo et al. 2004a).

In coastal waters of Hong Kong, Tse et al. (2007) suggested that chaetognaths were brought by currents from the South China Sea. The same hypothesis is suggested to explain the abundance of chaetognaths (especially *Flaccisagitta enflata*) on the northeastern coast of Taiwan in our study, which may be due to waters brought from southern Taiwan by the Kuroshio Current. The abundance of appendicularians, including three *Oikopleura* spp. observed in this study, is also linked to the Kuroshio Current in southern Honshu, Japan (Hidaka 2008). Hidaka (2008) showed close relationships between sea surface temperatures and the appendicularian community.

Probable effects of hydrothermal vents

Several studies reported a beneficial effect of islands on the abundance of zooplankton (Doty and Oguri 1956, Le Borgne et al. 1985, Hernández-León 1991). However, this hypothesis does not carry as much weight in this study because the highest zooplankton abundances were only observed at St. 7, compared to Sts. 4, 5, and 6, which are located around Kueishan I.

Stations 4, 5, and 6, located around Kueishan I. (on the side opposite St. 7), were closer to Sts. 2 and 3, according to the zooplankton associations revealed by the cluster analysis. In contrast, the mesozooplankton diversity and abundance were higher (3-fold for abundance) at St. 7, located on the side of the Kueishan I. with vents. Indeed, most of the zooplankton taxa, such as *Noctiluca* sp., pteropods, appendicularians, and copepods among others, were found to reach their maximum abundances at this station. The highest number of copepod species was also recorded at St. 7 (34 species). This resulted in the uniqueness of this station as revealed by the cluster analysis. Venting is reported to have a very strong effect on the zooplankton composition and quantitative parameters, especially at shallow depths (Tarasov et al. 2005). As in this study, it was reported that higher biomass was observed in waters in the vicinity of vents compared to surrounding waters (Tarasov et al. 1999, Skebo et al. 2006). At Kueishan I.'s vents (St. 7), the highest species richness and abundance of poecilostomatoid copepods (26% of total copepods for both parameters) were observed compared to other stations around the island and on the northeastern coast of Taiwan. In addition, the proportion of calanoid copepods (71% of the abundance of copepods) was lower at this station compared to other stations. Skebo et al. (2006) also found that poecilostomatoids (mostly *Oncaea* spp.) were well represented in waters surrounding vents. In areas of volcanic activity in Matupi Harbor (Papua New Guinea), it was reported that cyclopoids were the dominant copepods (Tarasov et al. 1999). However, it was noted that Tarasov et al. (1999) included species of the genus *Corycaeus* (which were dominant in their study) with *Oithona hamata* in the order Cyclopoida, whereas this genus is included in the order Poecilostomatoida in this present study. All these observations seem to suggest that poecilostomatoids are fond of waters surrounding vents. The high abundance of copepods in waters adjacent to hydrothermal vents is suggested to be linked to aggregation behavior created by the avoidance of extreme living conditions at the vents (Skebo et al. 2006). In our study, the abundance of the other mesozooplankton taxa (mainly copepod predators) at St. 7 was probably linked to an attraction to copepod aggregation and avoidance of vent effluents as suggested for jellyfish in other studies (Burd et al. 2000, Skebo et al. 2006).

The positive effect of hydrothermal vents on zooplankton communities may also be linked to the fact that hydrothermal fluids are positively enriching to surface-layer waters, thus contributing to primary production (Tarasov et al. 1999 2005). This is reinforced by the high contribution of chemosynthesis at shallow depths which can be very high (Sorokin et al. 1998, Tarasov et al. 1999). Tarasov et al. (2005) reported that diatoms, algal-bacterial, and bacterial mats were the 3 main types of mats which could be distinguished at shallow vents. This primary production could support high abundances of mesozooplankton communities in areas nearest to hydrothermal vents as was the case in the present study.

This study found a high diversity and species richness in northeastern coastal waters of Taiwan. Most of the observed species were commonly associated with Kuroshio waters. In addition, our findings suggest a positive effect of the hydrothermal vents located around Kueishan I. on mesozooplankton communities in terms of their increased abundances. However, further investigations are needed to define patterns of mesozooplankton distribution and diversity in different seasons in order to develop an understanding of various processes of hydrothermal vents on the northeastern coast of Taiwan.

Acknowledgments: We are grateful to the National Science Council, Taiwan (grant nos. NSC96-2611-M-019-006 and NSC97-2611-M-019-004) and the Center for Marine Bioenvironment and Biotechnology of National Taiwan Ocean Univ., Keelung, Taiwan for financial support to J.S. Hwang. We thank 2 anonymous referees for their valuable comments and constructive suggestions on the 1st version of the manuscript.

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