

Vertical distribution and population structure of the three dominant planktonic ostracods (*Discoconchoecia pseudodiscophora*, *Orthoconchoecia haddoni* and *Metaconchoecia skogsbergi*) in the Oyashio region, western North Pacific

HIDEKI KAERIYAMA & TSUTOMU IKEDA

Marine Biodiversity Laboratory, Graduate School of Fisheries Sciences, Hokkaido University, 3-1-1, Minato-cho, Hakodate, Hokkaido 041-0821, Japan

Received 19 November 2001; accepted 4 April 2002

Abstract: Diel and seasonal vertical distribution and population structure of *Discoconchoecia pseudodiscophora* (Rudjakov), *Orthoconchoecia haddoni* (Brady & Norman) and *Metaconchoecia skogsbergi* (Iles) were investigated in the Oyashio region during September 1996 through October 1997. Monthly samples were collected with 0.1 mm mesh closing nets hauled vertically through five contiguous discrete depths between the surface and ~2000 m. *D. pseudodiscophora* occurred predominantly from the base of the thermocline to a depth of 500 m. *O. haddoni* and *M. skogsbergi* occurred somewhat deeper at depths of 250 to 1000 m, but were also moderately abundant below 1000 m. Sampling was undertaken both by day and by night during December 1996, April and October 1997 to assess diel vertical migration activity, but revealed no appreciable day/night differences in the vertical distributions of the ostracods. All the instars sampled [instars II through VIII (adults) of *D. pseudodiscophora* and *O. haddoni*, and instars III through VIII (adults) of *M. skogsbergi*] were collected throughout the entire period of the study. All three species showed evidence of ontogenetic vertical migration—the ranges of these migrations being from 300–1000 m in *D. pseudodiscophora*, 450–800 m in *O. haddoni*, and 650–900 m in *M. skogsbergi*. This, combined with the year-round occurrence of gravid females, suggests that all three ostracods spawn continuously throughout the year. Even so, it proved possible to trace the developmental sequence of a major cohort of *D. pseudodiscophora*, which implied it has an annual life-cycle. Attempts to follow similar sequences in the other two species were unsuccessful. The annual mean of the integrated total biomass of the three ostracods in the upper 2000 m of the water column was estimated to be 171 mg dry weight m⁻², equivalent to 1.4% of the total biomass of large copepods and chaetognaths at the site. These results are compared with those from other regions.

Key words: planktonic ostracods, vertical distribution, population structure, Oyashio region

Introduction

The majority of species of oceanic holoplanktonic ostracod species belong to the Family Halocyprididae, but a few belong to the Family Cypridinidae (Cohen 1982). Despite being broadly distributed throughout the world oceans (Vinogradov 1968, Poulsen 1973, Angel 1999), biological and ecological information about them is very scarce. This

is because most of the species are quite small (mostly between 1 and 2 mm), so that their contribution to total zooplankton biomass is usually only a few percent. In addition, there is no comprehensive reference source for their identification (Deevey 1968, Angel 1983, 1999). With the notable exception of the year-round study of *D. pseudodiscophora* in the Japan Sea (Ikeda & Imamura 1992), information about their ecology and distribution in Japanese waters is incidental and limited to observations of vertical distribution patterns in Sagami Bay, central Honshu (Tachibana

1993), and off Hokkaido (Otsuka 1995).

As part of a research program to evaluate the dynamic role played by zooplankton in the energy flows and organic matter cycling in the Oyashio region, we have investigated the diel and seasonal vertical distributions, population structure and biomass of the three dominant ostracods species, based on seasonal sampling throughout a year. We compare our results with data from other oceanic regions.

Materials and methods

Sampling

Zooplankton samples were collected at approximately monthly intervals from 4 September 1996 through 5 October 1997 on board the T/S 'Oshoro-Marui' and T/S 'Hokusei-Marui' of the Faculty of Fisheries of Hokkaido University, R/V 'Tansei-Marui' of the Ocean Research Institute, University of Tokyo, R/V 'Hokko-Marui' of the Hokkaido National Fisheries Research Institute, and R/V 'Hokusin-Marui' of the Kushiro Fisheries Experimental Station (Table 1). All the sampling was conducted within a one degree square in the Oyashio region off southeastern Hokkaido, delimited by latitudes 41°30' and 42°30'N and longitudes 145°00' and 146°00'E (the area is hereafter referred to as Site "H") (Fig. 1).

Zooplankton samples were collected with a closing net (60 cm mouth diameter, 0.10 mm mesh; Kawamura 1989), equipped with a Rigosha flow-meter and with a TSK depth distance recorder or RMD depth meter attached to the towing cable to record the sampling depths. The nets were hauled vertically at a speed of 1 m s⁻¹ through five discrete strata; from the surface to the base of the thermocline (Th), from Th to 250 m, 250–500, 500–1000 and 1000–≈2000 m (Table 1). When the net failed to sample the complete series of discrete strata, data for the missing stratum were interpolated from those of the nearest samplings before and after the sampling date. The majority of the sampling was carried out at night, but evidence of diel vertical migration was sought by sampling both by day and by night on 8 December 1996, 11 April 1997 and 5 October 1997. After collection, the zooplankton samples were immediately preserved in 5% formalin-seawater mixture buffered with borax. Temperature and salinity profiles were determined with a CTD system at each sampling location for zooplankton. Data on the chlorophyll *a* concentration at Site H were supplied by H. Kasai of Hokkaido National Fisheries Research Institute.

Ostracods

Back in the laboratory on land, the ostracods were sorted from the samples and counted under a dissecting microscope. Identification of the species was based on the diagnostic features described by Poulsen (1969, 1973). Specimens were designated into respective instars based on the number of pairs of claw setae on the caudal furca, as proposed for *Discoconchoecia* (formerly *Conchoecia*) *pseudo-*

Table 1. Zooplankton sampling data with closing nets at Site H in the Oyashio region, September 1996 to October 1997. Discrete sampling strata are: Surface-thermocline (Th), Th-250, 250–500, 500–1000 and 1000–<2000 m

Date	Time (local time)	Vessel
4 September 1996	1827–2023	<i>Oshoro-Marui</i>
19 September 1996	1737–1944	<i>Hokusei-Marui</i>
1 October 1996	2325–0205	<i>Hokusei-Marui</i>
8 December 1996	0110–0248, 0636–0850	<i>Hokushin-Marui</i>
13 January 1997	1000–1200	<i>Hokko-Marui</i>
20 February 1997	0230–0510 ^a	<i>Hokushin-Marui</i>
17 March 1997	0055–0330	<i>Hokko-Marui</i>
11 April 1997	0240–0440, 0820–1030	<i>Hokusei-Marui</i>
6 May 1997	2335–0320 ^b	<i>Hokko-Marui</i>
4 June 1997	1850–2009 ^c	<i>Oshoro-Marui</i>
23 June 1997	2123–2326	<i>Hokusei-Marui</i>
2 July 1997	1953–2208	<i>Hokusei-Marui</i>
17 August 1997	1945–2139	<i>Oshoro-Marui</i>
26 August 1997	1010–1201	<i>Tansei-Marui</i>
5 October 1997	2045–2220, 1505–1715	<i>Hokusei-Marui</i>

Missing stratum: ^a 500–1000, 1000–≈2000 m, ^b Th-250, 250–500 m, ^c 1000–≈2000 m.

discophora by Ikeda (1992). The incidence of gravid females was recorded, and the ratio of gravid to total females was used as an index of spawning activity. Sex ratios of adults were also recorded. Shell lengths were measured to the nearest 0.01 mm under a compound microscope using an eye-piece micrometer.

Preliminary examination showed the species had broad vertical distributions. Quantitative comparisons of vertical distributions between species were made using the $D_{50\%}$ depth i.e. the depth of the center (50%) of the population (cf. Pennak 1943).

Results

Hydrography

The Oyashio is the western boundary current of the North Pacific subarctic circulation. It flows southwestwards along the Kuril Islands and Hokkaido until it reaches the east coast of northern Honshu, Japan, where it turns eastwards at ~40°N (Kono 1997). Site H is located just south of the south-westward core of the Oyashio (Fig. 1). During the study period, surface temperatures ranged from 2°C in March–April 1997 to 18°C in September–October 1996 and 1997 (Fig. 2a). When surface temperatures exceeded 10°C (in September to November 1996 and in June to October 1997) a thermocline was well established at 20–50 m depth. Surface temperatures <3°C occurred in February–April 1997, and then the upper 150 m of the water column was well mixed vertically. Seasonal variations in temperature decreased with increasing depth, and below 300 m the temperatures remained below 3.5°C throughout the year.

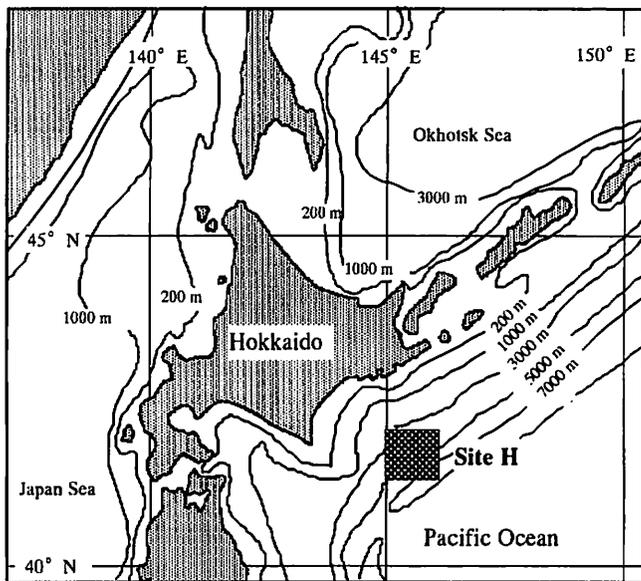


Fig. 1. Location of sampling site (Site H, shaded square) in the Oyashio region, western subarctic Pacific Ocean. Bathymetric contours are superimposed.

Surface salinities ranged seasonally from 32.2 to 34.1. Relatively high surface salinities (>33.5) occurred in December 1996–January 1997 (Fig. 2b). Oyashio Water is characterized by salinities between 33.0 and 33.5 and temperatures $<3^{\circ}\text{C}$ (Hanawa and Mitsudera 1987); this water-mass was observed at 0–150 m depth in February–April 1997. The lower salinity water (<33.0) observed near the surface during other months is considered to have been derived from the Okhotsk Sea (T. Kono personal communication). Below 500 m depth salinities varied only slightly (34.0–34.5) throughout the year.

Chlorophyll *a* concentrations, a proxy for phytoplankton biomass, showed a marked seasonality (Fig. 2c). Surface chlorophyll *a* concentrations were $\sim 0.4 \text{ mg m}^{-3}$ from August 1996 to March 1997, and then during the spring bloom, increased rapidly to $>9 \text{ mg m}^{-3}$ in May 1997. Concentrations $>2 \text{ mg m}^{-3}$ extended down to 50 m depth. Surface chlorophyll *a* concentrations once again declined to 2 mg m^{-3} by the end of June and were $<1 \text{ mg m}^{-3}$ by the end of July 1997. Chlorophyll *a* concentrations deeper than 100 m were consistently $<0.2 \text{ mg m}^{-3}$ throughout the year.

Ostracod abundance and vertical distribution

Throughout the study period, the integrated total abundance of planktonic ostracods in the upper 2000 m ranged from 5574 to 22461 individuals m^{-2} (Fig. 3a). There was no apparent relationship between ostracod abundances and chlorophyll *a* concentrations. Bathymetrically, the ostracods were distributed over broad vertical ranges. The majority were concentrated at 200–600 m depth, and their abundances in the well-mixed layer above the thermocline were low (Fig. 3b). The species identified included *Discocon-*

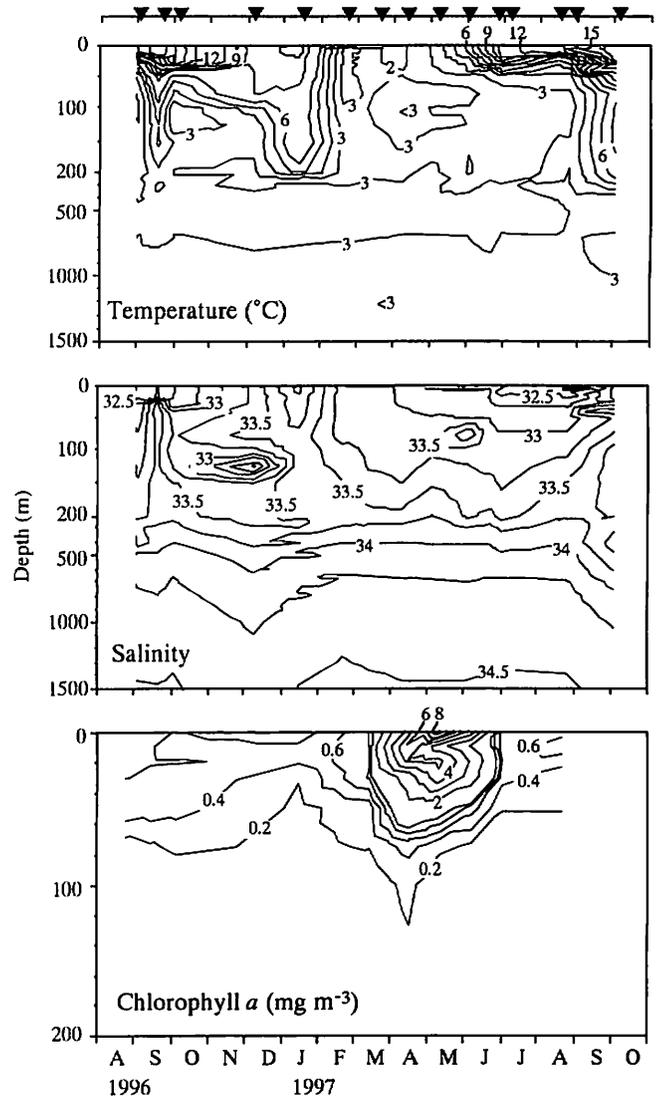


Fig. 2. Seasonal changes in vertical profiles of temperature (a), salinity (b) and chlorophyll *a* (c) at Site H, August 1996 to October 1997. Chlorophyll *a* data are from Hokkaido National Fisheries Research Institute. ▼ on top abscissa indicates the sampling date. Note that the depth scale changes at 200 m depth for top and middle panels.

choecia pseudodiscophora (Rudjakov), *Orthoconchoecia haddoni* (Brady & Norman), *Metaconchoecia skogsbergi* (Iles), *Conchoecia magna* Claus, *Conchoecilla daphnoides* Claus, *Conchoecissa imbricata* (Brady), *Mikroconchoecia curta* (Lubbock) and *Fellia cornuta* (Müller) together with a few other unidentified *Conchoecinae* and *Archiconchoecia* species. It is worth noting that most of these species were originally described from the Atlantic and Mediterranean region so a critical taxonomic review of the North Pacific species needs to be undertaken to confirm they are indeed conspecific. Such a review led to the description of *D. pseudodiscophora*, which is a species endemic to the North Pacific and was numerically the dominant species (62.4% of total ostracods) in our samples. The next most

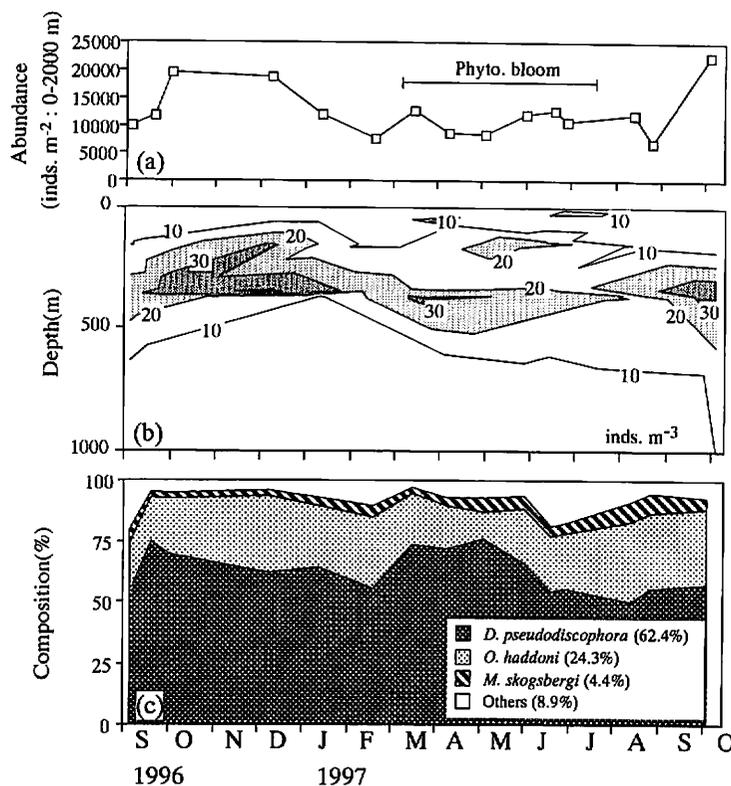


Fig. 3. Seasonal changes in total abundance of ostracods in 0–2000 m water column (a), vertical distribution patterns of abundance (b) and species composition by number (c) at Site H, September 1996 to October 1997.

abundant species were *O. haddoni* (24.3%) and *M. skogsbergi* (4.4%) (Fig. 3c). The shell lengths of adult males and females of these three dominant species were: *D. pseudodiscophora* males 0.98 ± 0.05 mm (mean \pm SD, $N=1257$), females 1.34 ± 0.06 mm ($N=2137$), *O. haddoni* males 2.63 ± 0.16 mm ($N=273$), females 3.02 ± 0.11 mm ($N=423$) and *M. skogsbergi* males 1.51 ± 0.05 mm ($N=143$), females 1.52 ± 0.03 mm ($N=317$)—note the marked sexual dimorphism in two of these species.

The seasonal vertical distributions and the $D_{50\%}$ depths of these three dominant ostracods are illustrated in Fig. 4. The majority of the populations of *D. pseudodiscophora* occurred between the base of thermocline and 500 m depth. *O. haddoni* and *M. skogsbergi* occurred mostly at 250 to 1000 m, but appreciable portions of the populations of both species were often found >1000 m (Fig. 4). Seasonal variations in the $D_{50\%}$ depths of the three species ranged from 225–495 m (annual mean: 380 m) in *D. pseudodiscophora*, 375–1279 m (588 m) in *O. haddoni*, and 443–1194 m (696 m) in *M. skogsbergi*. In none of the species were the seasonal variations in the $D_{50\%}$ values significant (one-way ANOVA, $p > 0.05$). The $D_{50\%}$ values of *D. pseudodiscophora* were much shallower than those of *O. haddoni* and *M. skogsbergi* (F-test, $F=9.819$, $p < 0.001$, d.f.=2, 42). The day and night vertical distribution patterns of all three species (observed on 8 December 1996, 11 April 1997 and 5 October 1997) showed no appreciable day/night differences (Kolmogorov-Smirnov test, $p > 0.1$; Fig. 4).

Instars

The instars sampled were, for *D. pseudodiscophora* and *O. haddoni*, II through VIII (adults), and for *M. skogsbergi* III through VIII (adults). [Note: we have assumed that the species pass through seven larval instars as demonstrated for *D. pseudodiscophora* (Ikeda 1992), which is contrary to the assumptions of other authors that there are only six, e.g. Poulsen 1973]. In the absence of seasonal differences in vertical distribution of the population of each species, annual mean $D_{50\%}$ values have been computed for each instar (Fig. 5). For *D. pseudodiscophora* the respective $D_{50\%}$ values were 1001 m for instar II, 387 m for instar III, 343 m for instar IV, 338 m for instar V, 303 m for instar VI, 299 m for instar VII, 374 m for instar VIII (male) and 362 m for instar VIII (female). For *O. haddoni* the $D_{50\%}$ depths were 790 m (instar II), 675 m (instar III), 526 m (instar IV), 447 m (instar V), 454 m (instar VI), 487 m (instar VII), 589 m (instar VIII, adult males) and 589 m (instar VIII, adult females). *M. skogsbergi* exhibited the deepest distributions with $D_{50\%}$ values of 900 m (instar III), 717 m (instar IV), 706 m (instar V), 673 m (instar VI), 668 m (instar VII), 664 m (instar VIII males) and 643 m (instar VIII females). Since the differences between the annual $D_{50\%}$ values of adult males and females did not differ significantly, the data for the two sexes have been pooled in Fig. 5.

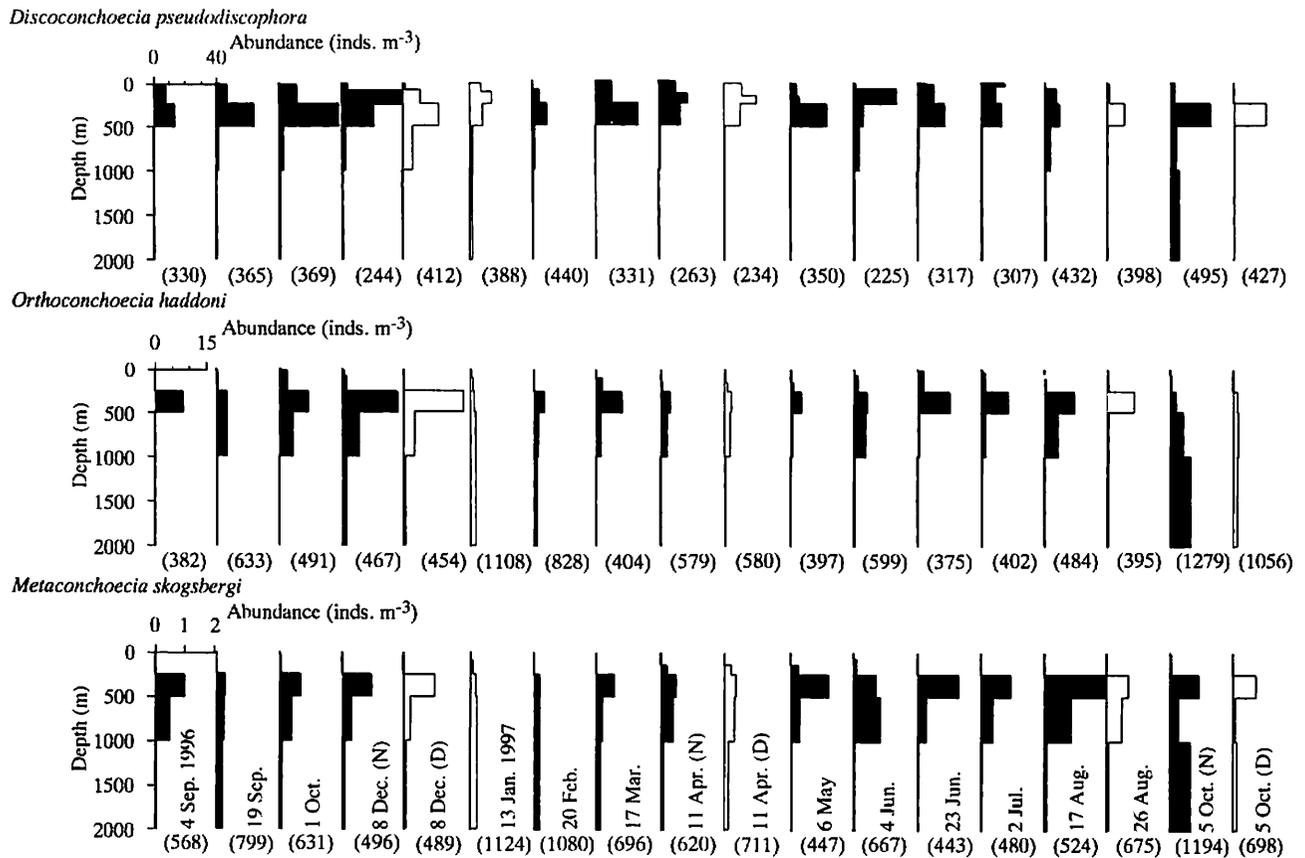


Fig. 4. Seasonal changes in vertical distribution patterns of *Discoconchoecia pseudodiscophora* (top), *Orthoconchoecia haddoni* (middle) and *Metaconchoecia skogsbergi* (bottom) at Site H. Open histograms denote day-time samplings and shaded histograms, night-time samplings. Figures in parentheses on the bottom of each panel denote $D_{50\%}$.

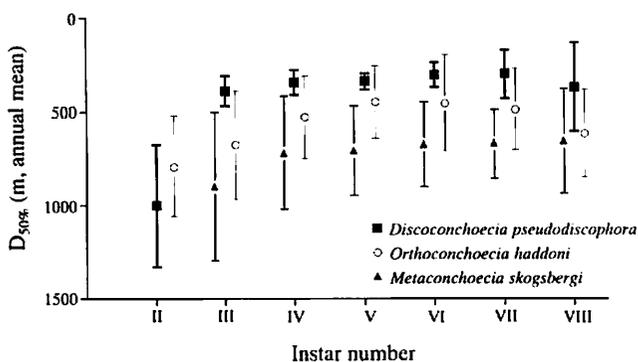


Fig. 5. Annual mean depths at which 50% of population of each instar of *Discoconchoecia pseudodiscophora*, *Orthoconchoecia haddoni* and *Metaconchoecia skogsbergi* resided at Site H. Vertical bars show the ranges of ± 1 standard deviation around means.

Population structure

All the instars sampled of all three species occurred throughout the year (Fig. 6). The sex ratios in adults (female:male) ranged from 51 to 88% (mean 68.9%) in *D. pseudodiscophora*, from 28 to 79% (mean 56.0%) in *O. haddoni*, and from 51 to 87% (66.7%) in *M. skogsbergi*. Gravid females occurred in all seasons and the ratios of

gravid:total females ranged from 31.1 to 81.4% (mean 52.1%) in *D. pseudodiscophora*, 20.0 to 42.1% (mean 31.9%) in *O. haddoni*, and 56.0 to 97.2% (mean 81.5%) in *M. skogsbergi*. These results suggest that reproduction and recruitment to the populations of all three species are continuous throughout the year. By assuming the seasonal population structure of each of the species is stable every year at Site H, it has proved possible to track the development sequence of a major cohort of *D. pseudodiscophora*; in October instars II, III and IV were dominant, in December instar V became dominant, and was succeeded by instar VI in March (some in December), instar VII in May (some in December), and adults (instar VIII) in June/July (Fig. 6). This implies that at site H, *D. pseudodiscophora* has a one-year life cycle. Its most active spawning season deduced from gravid:total female ratio is January–March, although this is not consistent with the developmental scheme. *O. haddoni* was similar to *D. pseudodiscophora* in having its early instars (II–V) dominant in October–December, but their further development could not be traced in Fig. 6. Instars III and IV of *M. skogsbergi* were abundant in August–October, but irregular seasonal patterns of the occurrence of later instars made it difficult to trace their further development.

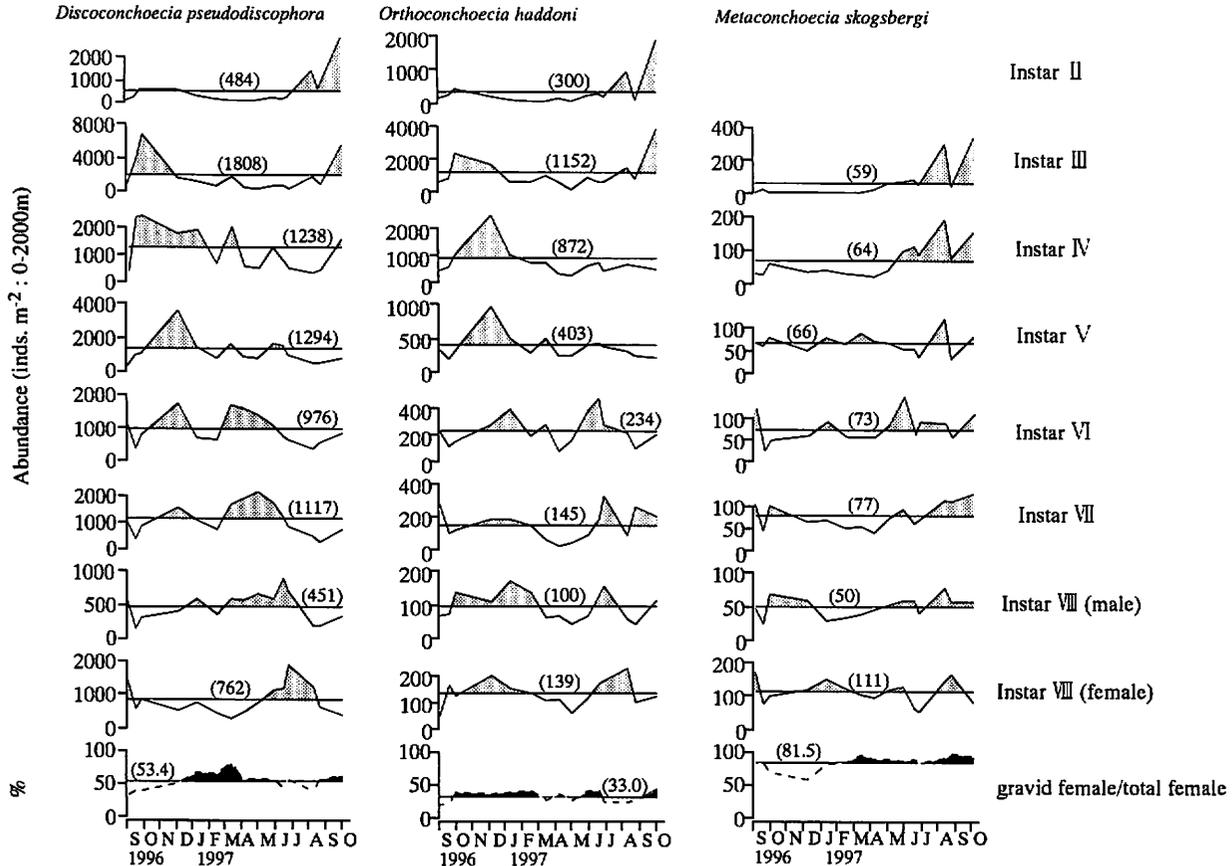


Fig. 6. Seasonal changes in abundance of instars II (or III) through VIII and percentage of gravid females of *Discoconchoecia pseudodiscophora*, *Orthoconchoecia haddoni* and *Metaconchoecia skogsbergi* at Site H. Horizontal lines and associated figures in parentheses denote annual mean abundance and percentage of gravid females, respectively. Values above (dotted area) and below (open area) the annual means are indicated to facilitate distinction of seasonal peaks of each instar.

Discussion

At two stations off Africa and off Bermuda in the North Atlantic (ca. 30°N), Angel (1979) recorded the integrated abundance of planktonic ostracods in the upper 2000 m to be in the order of 1600–2000 individuals m^{-2} , much lower than our data at Site H (5574 to 22461 individuals m^{-2} in the upper 2000 m). However, direct comparisons are misleading because of the difference in the mesh size of the nets used in the two sampling programmes [0.33 mm mesh in Angel (1979) compared with 0.10 mm in this study]. Angel (1979) observed that the early juvenile instars of most of the ostracod species he sampled are small enough to pass through the 0.33 mm mesh. Off Bermuda, Deevey (1968) observed that total ostracod abundances sampled by nets with 0.076 mm mesh were an order of magnitude higher than those sampled by nets with 0.366 mm mesh.

D. pseudodiscophora, the dominant ostracod at Site H, is also the dominant species in both the Okhotsk Sea (66% of the total ostracods; Otsuka 1995) and in Toyama Bay, southern Japan Sea (99% of the total ostracods; Ikeda & Imamura 1992). The depths at which the abundance peaks were observed varied between and within regions being

250–500 m at Site H, 200–400 m in the Okhotsk Sea (Otsuka 1995) and at 500 m in the western North Pacific (Rudjakov 1962). While our samples showed no evidence of diel vertical migration (DVM) by this species, Otsuka (1995) recorded an ascent of its population from daytime depths of 400 m to 200 m at night. The relatively coarse sampling regime used in this study (only five discrete strata between 0 and <2000 m), could well have resulted in vertical movements of this order being overlooked.

O. haddoni is reported to occur in all oceans (Angel 1999). In the Pacific Ocean, it is abundant below 1000 m in the waters around Japan, Australia and New Zealand (Poulsen 1973). In the Canary Island region, the North Atlantic, Angel (1969) noted that this species (albeit a smaller form) was most numerous at around 500 m depth and, in agreement with our observations, showed no DVM behavior. Whereas further north at 44°N Angel (1977) observed that in April the population of the typical form of *O. haddoni* was dominated by instars V and VI (note equivalent to our instars VI and VII), which were migrating from depths of 300–400 m by day to the upper 200 m at night. According to a recent review of this species in the Atlantic Ocean, its main depth range is 100–1000 m (Angel 1999).

M. skogsbergi has been recorded from bathypelagic zones of the Bering Sea, Pacific Ocean and Atlantic Ocean (Hiruta 1997) and below 500 m depth in the waters around the Antarctic Peninsula (Blachowiak-Samolyk 1999), as was observed at Site H in this study (Fig. 4). According to Angel's (1999) review on pelagic ostracods in the Atlantic Ocean, its main depth range is 250–1500 m and it does not undertake DVM (Angel 1999).

Among the three ostracods studied, the mean depths of each instar (i.e. the $D_{50\%}$) are usually well separated vertically with an exception being the near overlapping ranges of the adults (instar VIII) of *O. haddoni* and *M. skogsbergi* (cf. Fig. 5). The marked disparity in their sizes may indicate that there is little or no overlap in the resources they exploit, and the resulting lack of competition leads to overlap in their bathymetric ranges. Overall, species-specific depth distribution across all instars collected is approximately 300–1000 m for *D. pseudodiscophora*, 450–800 m for *O. haddoni*, and 650–900 m for *M. skogsbergi*. A feature common to all three species, is that instars II and III (except instar III for *M. skogsbergi*) exhibit the deepest distribution, followed by instar VIII. Instars IV–VII inhabit the shallowest depth strata. Such changes in depth distribution during life cycle (ontogenetic vertical migration OVM) have been demonstrated for many planktonic ostracod species (Angel 1979). While food sources of most pelagic ostracods are poorly defined at present, most are generally assumed to be detritivores (cf. Angel 1983). Since the amount of detritus in terms of particulate organic carbon increases exponentially with decreasing depths in the oceans (Gordon 1971; Yamaguchi et al. 2000), an apparent advantage of the OVM pattern is that pre-adult instars ensure they acquire sufficient energy for their maturation in food rich shallower layers. It is notable that the peak abundances of the early instars and adults of all three dominant ostracods were unrelated to the incidence of phytoplankton blooms (March–June) at Site H (Figs. 3 and 6).

Instar I for *D. pseudodiscophora* and *O. haddoni*, and instars I and II of *M. skogsbergi* were not found in the present samples. Assuming that the increment in shell length between instars remains near constant throughout development (1.19–1.43 for *D. pseudodiscophora*, 1.29–1.59 for *O. haddoni*, 1.28–1.36 for *M. skogsbergi*; Kaeriyama & Ikeda 2002), and shell height: shell length ratio is 0.58:1, the shell height of Instar I of the three species is estimated to be 0.12–0.15 mm. The diagonal dimension of the 0.10 mm mesh used in the nets used in this study is 0.14 mm, so it seems highly likely that all instar I specimens will have been extruded through the meshes (cf. Vannucci 1968). The shell height of missing *M. skogsbergi* instar II can similarly be estimated to be 0.17–0.18 mm, which should be large enough for specimens to be retained by the 0.10 mm mesh nets. An alternative explanation for the absence of instar I of *D. pseudodiscophora* and *O. haddoni* and instars I and II of *M. skogsbergi* is that they are distributed below depths of 2000 m.

Information about life span in planktonic ostracods is currently limited to data from laboratory rearing experiments on *Euconchoecia elongata* (Tseng 1975), near-surface dwelling subtropical species and seasonal population structure analyses of high latitude species—*D. pseudodiscophora* in the southern Japan Sea (Ikeda & Imamura 1992), and *Alacia belgicae* and *A. hettacra* off the Antarctic Peninsula (Kock 1992; Blachowiak-Samolyk 1999). Our present estimate of a one-year life span for *D. pseudodiscophora* in the cool waters at Site H is substantially longer than the life cycle of 6–8 weeks in *E. elongata* raised at 27–28°C, very similar to ≤ 1 year of *A. belgicae* and *A. hettacra* living at sub-zero temperatures, but shorter than 3 years for the same species living at about $< 1^\circ\text{C}$ in the southern Japan Sea. The prime cause for the difference between the generation length of the southern Japan Sea population and the Oyashio region (Site H) population of *D. pseudodiscophora* is considered to be the much colder habitat temperature in the former ($< 1^\circ\text{C}$) than the latter ($> 3^\circ\text{C}$). A similar contrast in life-cycle duration was reported between surface-dwelling and deep-living mysid species by Childress & Price (1978). Adult size (shell length) of slow growing southern Japan Sea specimens (female 1.56 mm; male 1.18 mm, Ikeda & Imamura 1992) are much greater than those of fast growing Oyashio region specimens (female 1.34 mm; male 0.98 mm, this study). In a variety of marine zooplankton species, it has been well documented that species living in warmer waters have shorter generation times and attain maturity at smaller body sizes; e.g. copepods (cf. review of Mauchline 1998), a chaetognath *Sagitta elegans* (Sameoto 1971), an amphipod *Themisto compressa* (formally *Parathemisto gaudichaudi*) (Shearer 1981) and an appendicularian *Oikopleura dioica* (Fenaux 1998). Our failure to resolve the life cycle patterns in *O. haddoni* and *M. skogsbergi* may partly be a result of their spawning continuing relatively constantly throughout the year—a common problem in life history analysis of deep-sea pelagic animals (cf. Mauchline 1991). Laboratory rearing as used to resolve the entire life cycle of *Euconchoecia elongata* (Tseng 1975) and the spawning and early development of *D. pseudodiscophora* by Ikeda (1992) may be the best method of overcoming this problem.

To evaluate the dynamic roles played by planktonic ostracods in pelagic ecosystems, data not only on their numerical abundances but also on their biomass are required, because most physiological rate processes are related to body mass of the animals (cf. Ikeda 1985). Based on DW data of each instar (Kaeriyama & Ikeda, unpublished) we have estimated the annual mean biomasses of *D. pseudodiscophora*, *O. haddoni* and *M. skogsbergi* to be respectively 66, 91 and 14 mg DW m^{-2} , giving a total of 171 mg DW m^{-2} at Site H. The biomasses of other components of the zooplankton assemblage have been estimated from the same time series of samples including the large copepods (*Neocalanus cristatus*, *N. flemingeri*, *N. plumchrus* and *Eu-calanus bungii*) (Kobari & Ikeda 2000, Shoden & Ikeda un-

published) and the chaetognaths (*Sagitta elegans*, *Eukrohnia hamata*, *E. bathypelagica* and *E. fowleri*; Nishiuchi & Ikeda unpublished). The mean annual biomass of the copepods in the upper 2000 m was 10,482 mg DW m⁻² and of the chaetognaths was 1,448 mg DW m⁻². Thus, the ostracods contribute only 1.4% of the total biomass of the dominant zooplankters, and since the biomasses of other zooplankters have not been taken into account, the contribution of the ostracods to the total zooplankton biomass at site H has to be even lower than 1.4%. Thus the contribution of ostracods to the total zooplankton biomass at Site H is markedly lower than the 2–5% calculated by Longhurst (1985) when compiling zooplankton biomass data for the world ocean. However, the zooplankton data analyzed by Longhurst (1985) were collected using 0.2–0.3 mm mesh nets from the upper 200–300 m, once again making direct comparisons with our results questionable. There is an almost total lack of information on physiological rates such as feeding, metabolism and growth in the ostracods, so it would be premature on the basis of their relatively low biomass to dismiss their trophic role in pelagic ecosystems as being of little or no significance. Laboratory experiments on these three dominant ostracods are currently in progress to fill these gaps in our knowledge.

Acknowledgement

We are grateful to Dr. M. Angel for his critical reading and valued comments on the manuscript.

Literature Cited

- Angel, M. V. 1969. Planktonic ostracods from the Canary Island Region; their depth distributions, diurnal migrations and community organization. *J. Mar. Biol. Ass. U.K.* **49**: 515–553.
- Angel, M. V. 1977. Studies on Atlantic halocyprid ostracods: vertical distributions of the species in the top 100 m in the vicinity of 44°N, 13°W. *J. Mar. Biol. Ass. U.K.* **57**: 239–252.
- Angel, M. V. 1979. Studies on Atlantic halocyprid ostracods: their vertical distributions and community structure in the central gyre region along latitude 30°N from off Africa to Bermuda. *Prog. Oceanogr.* **8**: 3–124.
- Angel, M. V. 1983. A review of the progress of research on halocyprid and other oceanic planktonic ostracods 1972–1982, p. 529–548. In *Applications of Ostracoda*. (eds. Löffler, H. and Maddocks, R. F.). Univ. Houston Geosciences, Houston.
- Angel, M. V. 1999. Ostracoda, p. 815–868. In *South Atlantic Zooplankton* (ed. Boltovskoy, D.). Backhuys Publishers, Leiden.
- Blachowiak-Samolyk, K. 1999. Distribution and population structure of pelagic Ostracoda near the Antarctic Peninsula in Spring 1986 (BIOMASS III, October–November 1986). *Pol. Arch. Hydrobiol.* **46**: 9–25.
- Childress, J. J. & M. H. Price 1978. Growth rate of the bathypelagic crustacean *Gnathophausia ingens* (Mysidacea: Lophogastridae). 1. Dimensional growth and population structure. *Mar. Biol.* **50**: 47–62.
- Cohen, A. C. 1982. Ostracoda. In *Synopsis and Classification of Living Organisms*. 2, p. 181–211. (ed. Parker, S. P.). McGraw-Hill, New York.
- Deevey, G. B. 1968. Pelagic ostracods of the Sargasso Sea off Bermuda: description of species and seasonal and vertical distribution. *Peabody Mus. Nat. Hist. Yale Univ. Bull.* **26**: 1–125.
- Fenaux, R. 1998. Life history of the Appendicularia. p. 151–159. In *The Biology of Pelagic Tunicates*, (ed. Bone, Q.). Oxford University Press, Oxford.
- Gordon, D. C. Jr. 1971. Distribution of particulate organic carbon and nitrogen at an oceanic station in the central Pacific. *Deep-Sea Res.* **8**: 1127–1134.
- Hanawa, K. & H. Mitsudera 1987. Variation of water system distribution in the Sanriku coastal area. *J. Oceanogr. Soc. Jpn.* **42**: 435–446.
- Hiruta, S. 1997. Ostracoda, p. 625–648. In *An Illustrated Guide to Marine Plankton in Japan*. (eds. Chihara, M. and Murano, M.). Tokai University Press, Tokyo.
- Ikeda, T. 1985. Metabolic rates of epipelagic marine zooplankton as a function of body mass and temperature. *Mar. Biol.* **85**: 1–11.
- Ikeda, T. 1992. Laboratory observations on spawning, fecundity and early development of a mesopelagic ostracod, *Conchoecia pseudodiscophora*, from the Japan Sea. *Mar. Biol.* **112**: 313–318.
- Ikeda, T. & A. Imamura 1992. Population structure and life cycle of the mesopelagic ostracod *Conchoecia pseudodiscophora* in Toyama Bay, southern Japan Sea. *Mar. Biol.* **113**: 595–601.
- Kaeriyama, H. & T. Ikeda 2002. Body allometry and developmental characteristics of the three dominant pelagic ostracods (*Discoconchoecia pseudodiscophora*, *Orthoconchoecia haddoni* and *Metaconchoecia skogsbergi*) in the Oyashio region, western North Pacific. *Plankton Biol. Ecol.* **49**: 97–100.
- Kawamura, A. 1989. Fast sinking mouth ring for Closing Norpac net. *Bull. Jap. Soc. Scient. Fish.* **55**: 1121.
- Kobari, T. & T. Ikeda 2000. Life cycle of *Neocalanus* species in the Oyashio region. *Bull. Plankton Soc. Jpn.* **47**: 129–135. (In Japanese with English abstract.)
- Kock, R. 1992. Ostracods in the epipelagic zone off the Antarctic Peninsula—a contribution to the systematics and to their distribution and population structure with regard to seasonality. *Ber. Polarforsch.* 1–209.
- Kono, T. 1997. Modification of the Oyashio Water in the Hokkaido and Tohoku areas. *Deep-Sea Res.* **144**: 669–688.
- Longhurst, A. R. 1985. The structure and evolution of plankton communities. *Prog. Oceanogr.* **15**: 1–35.
- Mauchline, J. 1991. Some modern concepts in deep-sea pelagic studies: patterns of growth in the different horizons. In *Marine Biology, Its Accomplishment and Future Prospects*. p. 107–130. (eds. Mauchline, J. and Nemoto, T.). Hokusen-Sha, Tokyo.
- Mauchline, J. 1998. The Biology of Calanoid Copepods. *Adv. Mar. Biol.* **33**: 1–710.
- Otsuka, H. 1995. A study of taxonomy and vertical distribution of planktonic ostracods in the Sea of Okhotsk and western North Pacific. *Master thesis of Hokkaido University*, 17 pp. (In Japanese.)
- Pennak, R. W. 1943. An effective method of diagramming diurnal movements of zooplankton organisms. *Ecology* **24**: 405–407.
- Poulsen, E. M. 1969. Ostracoda-Mydocopida. IIIa. Halocyprid-

- formes-Thaumatocipridae and Halocypridae. *Dana Report* **75**: 1–100.
- Poulsen, E. M. 1973. Ostracoda-Mydocopida. IIIb. Halocypriformes-Halocypridae Conchoecinae. *Dana Report* **84**: 1–224.
- Rudjakov, J. A. 1962. Ostracoda Mydocopa of the family Halocypridae from the northwestern Pacific. *Trudy Inst. Okeanol.* **58**: 172–201 (In Russian).
- Sameoto, D. D. 1971. Life history, ecological production, and an empirical model of the population of *Sagitta elegans* in St. Margaret's Bay, Nova Scotia. *J. Fish. Res. Bd. Canada* **28**: 971–985.
- Shedder, M. 1981. Development and growth in laboratory-maintained and field population of *Parathemisto gaudichaudi* (Hyperperiidea: Amphipoda). *J. mar. biol. Ass. U.K.* **61**: 769–787.
- Tachibana, K. 1993. A study of taxonomy and vertical distribution of planktonic ostracods in Sagami Bay, central Honshu. *Master thesis of Tokyo University of Fisheries* 48 pp. (In Japanese).
- Tseng, W. Y. 1975. Biology of the pelagic ostracod *Euconchoecia elongata* Muller. *Taiwan Fish. Res. Inst. Lab. Fish. Biol. Rep.* **27**: 1–183.
- Vannucci, M. 1968. Loss of organisms through the meshes. p. 77–86. In *Zooplankton Sampling* (ed. Tranter, D. J.). The Unesco Press, Paris.
- Vinogradov, M. E. 1968. Vertical distribution of oceanic zooplankton. Israel Program for Scientific Translations, Jerusalem.
- Yamaguchi, A., J. Ishizaka and Y. Watanabe 2000. Vertical distribution of plankton community in the western North Pacific Ocean (WEST-COSMIC) *Bull. Plankton Soc. Jpn.*, **47**: 144–156 (In Japanese with English abstract).