

Meiofauna in a Cold-Seep Community off Hatsushima, Central Japan*

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Abstract: The community structure of the bathyal meiofauna of a cold-seep community found off Hatsushima in Sagami Bay, central Japan, was compared with the community composition outside the influence of the seep, using sediments collected during dives 226 and 227 of the deep-sea submersible *Shinkai 2000*. The sediment from the Hatsushima seep site (HSS) was very coarse, black in color, and with an odor of hydrogen sulfide, suggesting reduced thiobiotic conditions. The sediment from the control area was well-oxygenated, fine silt. Despite the differences in the characteristics of the sediments, the abundance of meiofauna in the HSS was not very different from that in the control area. However, its composition even at the major taxonomic group level was distinct; for example, a high nematode/copepod ratio occurred in one of the samples collected at the HSS. At the species level, nematodes were less diverse at the HSS than at the control area. The composition of the nematode fauna at the HSS showed stronger affinity with that collected at the adjacent control area than with a community sampled from other deep-sea environments or another seep community in shallow water. This emphasizes that the adaptation of nematodes to the thiobiotic condition is controlled by local conditions.

1. Introduction

In addition to the hydrothermal vent system (Hessler and Smithey, 1984), another type of ecosystem supported by chemosynthesis—namely the cold seep—has been discovered in various parts of the deep sea (Paull *et al.*, 1984; Suess *et al.*, 1985; Kulm *et al.*, 1986; Ohta and Laubier, 1987). There have been numerous studies of the macro- and megabenthos in this type of ecosystem, but none for the meiofauna (Grassle, 1986).

At depths of between 1,100 and 1,200 m off Hatsushima Island in Sagami Bay, central Japan, occurs an extensive cold-seep community (Hashimoto *et al.*, 1989). An intensive survey of this community was carried out in 1986 and 1987 using the submersible *Shinkai 2000* of the Japan Marine Science and Technology Center (JAMSTEC). The results of this multidisciplinary study have been summarized by Ohta *et al.* (1987) and Sakai *et al.* (1987).

Two sediment cores were collected for the study of meiofauna within the area where the giant clam, *Calyptogena soyoeae*, is abundant. Another sediment core was collected outside the area. Preliminary results were reported by Shirayama (1987). Here, quantitative data were presented concerning the community structure of the meiofauna—especially nematodes—in these sediments, and they were compared with meiofauna of the other area with a similar environment.

2. Materials and methods

Three sediment cores, 3.6 cm in inner diameter and 30 cm in length, were collected at the Hatsushima seep site (HSS; 34°59.91'N, 139°13.59'E, 1,170 m: Fig. 1), using a core sampler operated by the manipulator of the *Shinkai 2000*. At HSS, the giant clam, *Calyptogena soyoeae*, established a dense bed, and one core was collected during dive 227 at the center of the bed (D227 core). Another core was collected from the middle point between the center and the margin of the bed during dive 226 (D226 core). About 30 m away from the margin of the bed,

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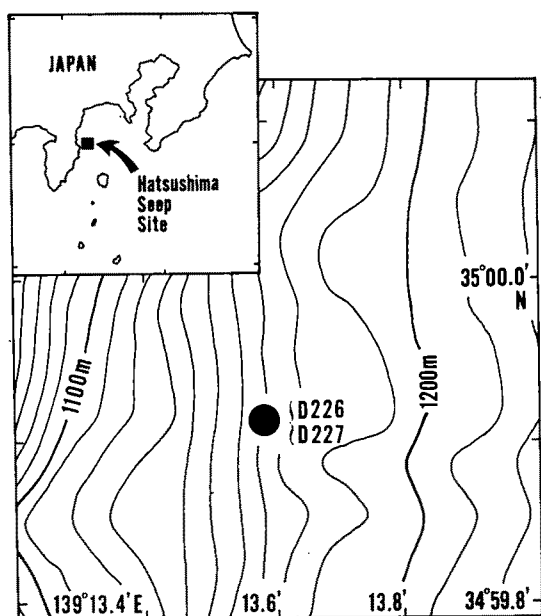


Fig. 1. A map showing the locality of the dives 226 and 227 of the deep-sea submersible, *Shinkai 2000*.

Table 1. Density (No. of individuals per 10 cm²) of meiofauna at the Hatsushima seep site and the control area.

	Foraminifera	Nematoda	Copepoda	Others	Total
Hatsushima seep site					
Dive 226					
Total	23	384	2	*5	414
Dive 227					
^a 0-2 cm	56	100	36	**44	236
2-4 cm	0	93	12	20	125
4-6 cm	0	13	1	2	16
6-8 cm	0	1	0	0	1
Total	56	207	49	66	378
Control area					
^b 0-2 cm	46	142	24	***20	232
2-4 cm	0	22	0	4	26
Total	46	164	24	24	258

* Others include unidentified phyla.

** Others include turbellarians, annelids, molluscs and unidentified phyla.

*** Others include turbellarians, kinorhynch, annelids, ostracods, molluscs, and unidentified phyla.

^a Estimated from 2.5 cm² sediment.

^b Estimated from 5.0 cm² sediment.

Table 2. List of nematode species found in the D 227 core collected at the Hatsushima seep site. CH:Chromadorida; EN:Enoplida; MO:Monhysterida.

Order	Family	Genus and species	No. of individuals				
			0-2	2-4	4-6	6-8 (cm)	Total
CH	Chromadoridae	<i>Chromadorita</i> sp. 1	8	11	1		20
CH	Chromadoridae	<i>Hypodontolaimus</i> sp. 1		1			1
CH	Chromadoridae	<i>Innocuonema</i> sp. 1		1			1
CH	Chromadoridae	<i>Neochromadora</i> (?) sp. 2	3	4			7
CH	Chromadoridae	gen. 1 sp. 1		1			1
CH	Chromadoridae	gen. 2 sp. 1		1			1
CH	Chromadoridae	gen. 3 sp. 1		1			1
CH	Chromadoridae	gen. 4 sp. 1		1			1
CH	Comesomatidae	<i>Sabatieria</i> sp. 1		6			6
CH	Cyatholaimidae	gen. 1 sp. 1		1			1
CH	Desmodoridae	<i>Desmodora</i> sp. 1	1				1
CH	Desmoscolecidae	<i>Tricoma</i> sp. 1		1			1
CH	Ethmolaimidae	<i>Gomphionchus</i> sp. 1		2	6		8
CH	Plectidae	<i>Setoplectus</i> (?) sp. 1		3			3
CH	Selachinematidae	<i>Halichoanolaimus</i> sp. 1	1	6	1		8
EN	Anticomidae	<i>Anticoma</i> sp. 1		1			1
EN	Eurystominidae	<i>Bathyeurystomina</i> sp. 1		1			1
EN	Oxystominidae	<i>Halalaimus</i> sp. 1	1				1
EN	Oxystominidae	<i>Thalassoalaimus</i> sp. 1	1				1
MO	Linhomoeidae	<i>Linhomoeus</i> sp. 1		1			1
MO	Linhomoeidae	gen. 1 sp. 1		4			4
MO	Xyalidae	<i>Daptonema</i> sp. 1	7	24	2		33
MO	Xyalidae	<i>Steineria</i> sp. 1		1			1
MO	Xyalidae	gen. 1 sp. 1	3	5			8
MO	Xyalidae	<i>Daptonema</i> (?) sp. 3		20	1		21
MO	Xyalidae	gen. 5 sp. 1		7			7
MO	Xyalidae	<i>Elzalia</i> (?) sp. 1		7			7
	unknown order		2	13	0	1	16

the third core was collected as a control during dive 227 (control core).

Each sediment core was sliced into 2 cm horizons on board and kept in a refrigerator until further processing. Some of the sediment slices were divided into two or four parts to share the sample with other scientists.

In the laboratory on land, each sediment sample was washed through a 63 μm mesh sieve, the material retained on the mesh was fixed with 5% sea-water formalin. Meiofaunal organisms were sorted under a binocular dissecting microscope, counted, and identified to the level of major taxonomic groups. Nematodes were transferred to anhydrous glycerol, and identified under the compound microscope using Nomarsky optics.

3. Results

The sediments collected at the HSS were very coarse. In addition, they were black in color and bore an odor of hydrogen sulfide, suggesting reduced conditions. The sediment of the control core was well-oxygenated fine silt.

The density of the meiofauna at the HSS was 1.5 to 1.6 times greater than at the control area (Table 1). In the D226 core, the density of nematodes was 2.3 times greater than in the control core. This leads to the higher density of total meiofauna in the former core, though other taxonomic groups were less abundant than in the latter. In the D227 core, on the other hand, all taxonomic groups including not only nematodes but also foraminifers, copepods and others showed a higher density of individuals than in the control core.

There was little difference in the composition of major meiofaunal taxa between the D227 and the control core. In both cores, nematodes were the most dominant group, occupying around 60% of the total, and the rest were shared by foraminifers, copepods and others at the similar percentage. In the D226 core, nematodes accounted for as high as 94% of the total meiofauna, whereas copepods occupied only 0.5%. Within the taxa sorted as others, it was noteworthy that kinorhynchs and ostracods were found only in the control core but not in either the D226 or the D227 cores.

The nematodes in the D227 core were classified into 13 families, 26 genera and 27 species

(Table 2). Most species belonged to the orders Chromadorida and Monhysterida, and only a few to Enoplida. The families Chromadoridae and Xyalidae were conspicuous, consisting of eight and six genera, respectively. Two *Daptonema* and one *Chromadorita* species were the dominants, occupying 20.2, 12.9 and 12.3% of the total nematodes, respectively.

A total of 15 families, 35 genera and 44 species was found in the control core (Table 3). A variety of species could be seen in the families Oxystominidae and Xyalidae. Chromadoridae was not as diverse as in the D227 core. A species of *Microlaimus* predominated over the other species and accounted for 25.2% of the total. Another species belonging to the same family (Microlaimidae) followed (5.8%) the *Microlaimus* species. No species was found that was common to both areas within and outside the HSS, although four genera resided in both areas.

The species diversity, measured using Shannon-Weaver's H' (Margalef, 1958), was considerably lower at the HSS than at the control area (Table 4). The nematode diversity within the HSS was lower in the surface layer than in the subsurface layer, but this may be caused by the fewer number of specimens collected from the surface layer.

At the HSS, five species out of eight (62.5%) found within the surface layer, were found also in the subsurface layer (see Table 2). At the control area, in contrast, only 14.7% (five out of 34) of the species inhabited in the surface layer penetrated into the subsurface layer (see Table 3). The similarity index (C_{π} ; Kimoto, 1967) between the surface and the subsurface layers was lower at the control area than at the HSS (see Table 4), suggesting the presence of a distinct vertical structure of the nematode assemblage in the former core.

4. Discussion

The density of meiofauna at the hydrothermal vent area has been reported one to two orders of magnitude lower than the figure in the ordinal deep sea (Dinet *et al.*, 1988). It was not the case in this study. At the HSS the meiofauna was slightly (1.5 to 1.6 times) more abundant than at the control area. This is distinct from the huge biomass of megafauna at the HSS.

Table 3. List of nematode species collected at the control area adjacent to the Hatsushima seep site. CH:Chromadorida; EN:Enoplida; MO: Monhysterida.

Order	Family	Genus and species	No. of individuals		
			0-2	2-4 (cm)	Total
CH	Aegialoalaimidae	<i>Southerniella</i> sp. 1	1		1
CH	Ceramonematidae	<i>Pselionema</i> sp. 1	2		2
CH	Chromadoridae	<i>Neochromadora</i> sp. 1	7		7
CH	Chromadoridae	<i>Rhyps</i> sp. 1	4		4
CH	Chromadoridae	gen. 5 sp. 1	2		2
CH	Comesomatidae	<i>Pierrichia</i> sp. 1	2		2
CH	Comesomatidae	<i>Sabatieria</i> sp. 2		2	2
CH	Comesomatidae	gen. 1 sp. 1		2	2
CH	Comesomatidae	gen. 2 sp. 1		1	1
CH	Cyatholaimidae	<i>Longicyatholaimus</i> sp. 1		1	1
CH	Desmoscolecidae	<i>Antarcticonema</i> sp. 1	1		1
CH	Desmoscolecidae	<i>Desmoscolex</i> sp. 1	1	1	2
CH	Desmoscolecidae	<i>Desmoscolex</i> sp. 2	1		1
CH	Desmoscolecidae	<i>Desmoscolex</i> sp. 3	1		1
CH	Ethmolaimidae	gen. 1 sp. 1		3	3
CH	Leptolaimidae	<i>Leptolaimus</i> sp. 1	4		4
CH	Leptolaimidae	gen. 1 sp. 1	1		1
CH	Microlaimidae	<i>Microlaimus</i> sp. 1	31	4	35
CH	Microlaimidae	gen. 1 sp. 1	8		8
EN	Enchelidiidae	<i>Symplocostoma</i> sp. 1	1		1
EN	Oxystominidae	<i>Halalaimus</i> sp. 2	1		1
EN	Oxystominidae	<i>Halalaimus</i> sp. 3	1		1
EN	Oxystominidae	<i>Halalaimus</i> sp. 4	4		4
EN	Oxystominidae	<i>Halalaimus</i> sp. 5	1		1
EN	Oxystominidae	<i>Halalaimus</i> sp. 6	1		1
EN	Oxystominidae	<i>Litinium</i> sp. 1		1	1
EN	Oxystominidae	gen. 1 (<i>Oxystomina</i> ?) sp. 1	2		2
EN	Oxystominidae	gen. 2 sp. 1	1		1
EN	Oxystominidae	gen. 3 sp. 1	2		2
EN	Unknown Family		1		1
MO	Axonolaimidae	<i>Parodontophora</i> sp. 1	1		1
MO	Diplopeltidae	<i>Campylaimus</i> sp. 1	1		1
MO	Diplopeltidae	<i>Campylaimus</i> sp. 2		1	1
MO	Linhomoeidae	gen. 2 sp. 1	2		2
MO	Linhomoeidae	gen. 3 sp. 1	1		1
MO	Linhomoeidae	<i>Terchellingia</i> sp. 1		1	1
MO	Xyalidae	<i>Daptonema</i> sp. 2	3	1	4
MO	Xyalidae	<i>Rhynchonema</i> sp. 1	1		1
MO	Xyalidae	<i>Theristus</i> sp. 1	3		3
MO	Xyalidae	<i>Theristus</i> sp. 2	2	1	3
MO	Xyalidae	gen. 2 sp. 1	4	1	5
MO	Xyalidae	gen. 3 sp. 1	1		1
MO	Xyalidae	gen. 7 sp. 1	1		1
MO	unknown family		2		2
	unknown order		12	4	16

The giant clam, *Calyptogena soyoeae*, constructed a dense bed and consequently the mega-faunal biomass there reached to as high as 10 kg m⁻² (Hashimoto *et al.*, 1989). The giant

clam as well as other peculiar species found in both the hydrothermal vent and the cold seep communities (*e.g.* Vestimentifera) depend for their life on the chemosynthetic energy available

only at these habitats. The lack of dominant meiofaunal taxa at the HSS suggests that the organisms belonging to this smaller size fraction have not adapted as well as the megafauna had to utilize the geotectonically-supplied sparse energy source.

The characteristics of the sediment at the HSS suggest a reduced condition. Those species which

Table 4. The species diversity (Shannon-Weaver's H' ; Margalef, 1958) and the similarity (Kimoto's $C\pi$; Kimoto, 1967) of nematode assemblages for the D 227 core at the Hatsushima seep site and the control core.

	D 227	Control
Diversity (H')		
surface layer	2.52	4.16
subsurface layer	3.75	3.37
total	3.77	4.53
Similarity ($C\pi$)		
between surface and subsurface layers	0.634	0.555

adapted to this environment seem to construct the meiofauna community at the HSS, because its structure shared the general characteristics of the meiofauna usually found at the anaerobic habitat of the shallow water (Shirayama, 1988). For example, the meiofauna at the HSS was devoid of the kinorhynchs (Fleeger *et al.*, 1983), its nematode/copepod ratio was high (especially in the D226 core: Warwick, 1981), and the nematode species diversity was lower than the adjacent area (Shaw *et al.*, 1983).

The constant response of the meiofauna to such an anaerobic condition disregarding the water depth might imply the presence of a special taxonomic group that prefers the reduced environment and has a wide geographic distribution. To discuss this possibility within nematodes, taxa reported to be dominant at other hydrogen-sulfide rich environments were compared with the nematodes at the HSS. Dinert *et al.* (1988) reported dominant nematode families at the deep-sea hydrothermal vent found at the East Pacific

Table 5. List of dominant nematode families at the Hatsushima seep site, the control area, the East Pacific Rise (deep-sea hydrothermal vent: Dinert *et al.*, 1988) and the East Flower Garden (shallow-water cold seep: Jensen, 1986).

Hatsushima seep site		Control area		East Pacific Rise		East Flower Garden	
Family name	% of total	Family name	% of total	Family name	Abundance	Family name	% of total
Xyalidae	47.2	Microlaimidae	30.9	Microlaimidae	+++++	Linhomoeidae	69.9
Chromadoridae	20.2	Xyalidae	12.9	Epsilonematidae	+++	Xyalidae	6.1
Selachinematidae	4.9	Oxystominidae	10.1	Draconematidae	+++	Thoracostomopsidae	5.0
Ethmolaimidae	4.9	Chromadoridae	9.4	Cyatholaimidae	++	Chromadoridae	4.5
Comesomatidae	3.7	Comesomatidae	5.0	Chromadoridae	++	Cyatholaimidae	4.2
Linhomoeidae	3.1	Leptolaimidae	3.6	Linhomoeidae	++	Monhysteridae	3.5
		Desmoscolecidae	3.6				
		Linhomoeidae	2.9				

Table 6. List of dominant nematode genera at the Hatsushima seep site, the control area and the East Flower Garden (shallow-water cold seep: Jensen, 1986).

Hatsushima seep site		Control area		East Flower Garden	
Genus name	% of total	Genus name	% of total	Genus name	% of total
<i>Daptonema</i>	33.1	<i>Microlaimus</i>	25.2	<i>Desmolaimus</i>	66.5
<i>Chromadorita</i>	12.3	Microlaimidae gen. 1	5.8	<i>Mesacanthoides</i>	4.5
<i>Halichoanolaimus</i>	4.9	<i>Halalaimus</i>	5.8	<i>Marylynnia</i>	3.7
<i>Gomphonchus</i>	4.9	<i>Neochromadora</i>	5.1	<i>Monhystera</i>	3.5
Xyalidae gen. 1	4.9	<i>Theristus</i>	4.3	<i>Gonionchus</i>	3.4
<i>Neochromadora</i> (?)	4.3	Xyalidae gen. 2	3.6	<i>Linhomoeus</i>	3.1
<i>Elzalia</i> (?)	4.3	<i>Rhyps</i>	2.9		
Xyalidae gen. 5	4.3	<i>Leptolaimus</i>	2.9		
<i>Sabatieria</i>	3.7	<i>Desmoscolex</i>	2.9		
Linhomoeidae gen. 1	2.5	<i>Daptonema</i>	2.9		

Rise (EPR). The specimens were sorted out from the subcores taken from the box-cored sediment, which was sampled using *Alvin* at a site about 800 m distant from the center of the principal chimney. Jensen (1986) carried out an extensive survey on the nematode fauna of the shallow-water seep ecosystem at the East Flower Garden (EFG), off Louisiana, U.S.A.

At the family level (Table 5), four out of six families dominant (defined here as those which accounted for more than 2% of the total) at the HSS were also dominant at the control area. Only two families were found to be common between the HSS and the EPR, and a half (three out of six) of the dominant HSS families also took more than 2% of the total at the EFG. The percentage of each family, however, was very different between the two localities. The family occupied about 70% of the total EFG nematodes (Linhomoeidae) was ranked at the fifth place (only 3.1%) at the HSS, whereas the most dominant (47.7%) family at the HSS (Xyalidae) was as low as 6% at the EFG.

There was no common dominant genus between the HSS and the EFG nematodes (Table 6). Between the HSS and the adjacent control area, however, two genera (*Daptonema* and *Neochromadora*) out of ten, which were dominant in the former community, were also dominant in the latter. In addition, two other genera, *Halalaimus* and *Sabatieria*, resided in both HSS and the control area.

The above comparisons lead to the conclusion that the nematode assemblage at the HSS had little relationship with the assemblage at a distant place, though its environmental condition was similar. On the other hand, it had a strong affinity with the assemblage at the adjacent locality disregarding the distinct environmental difference. The conclusion did not support the concept that certain nematode taxa are specialized to have their life in the thiobiotic condition and have a cosmopolitan distribution. It rather favors the idea (Reise and Ax, 1979; Jensen, 1986) that the meiofauna existing in the thiobiotic condition had been originally oxybiotic species which eventually adapted at each place to live in its own local reduced environment.

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初島沖遺留水生生態系のメイオベントス

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要旨: 相模湾初島沖にみられる, 漸深海帯遺留水生生態系に生息するメイオフauナの群集構造と, 湧水の影響を受けていない群集の組成とを, 深海潜水艇“しんかい2000”のdive 226と227の際に採集された堆積物を用いて比較した。初島遺留水生生態系(HSS)内の堆積物は, 粗く黒色を呈し, また硫化水素臭を有しており, 還元的環境であることを示唆していた。対照区の堆積物は, よ

く酸化された細泥であった。堆積物の特色の差にもかかわらず, メイオフauナの密度は, HSS内部と対照区とで大差無かった。しかし, その群集組成は大きく異なり, 例えば線虫類/橈脚類比がHSS内部では非常に高かった。種のレベルでは, HSS内部の線虫類の多様度は対照区よりもかなり低かった。またHSS内部の線虫相は, 他の海域の類似の環境のものよりも, 近傍の対照区のものにより関係が深かった。このことは, 線虫類の還元的環境への適応が主に地理的な条件に支配されていることを示している。

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