

Macrobenthic abundance in the vicinity of spreading ridge environment in Central Indian Ocean

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Macrofaunal communities of the Central Indian Ocean were evaluated for their composition, distribution, abundance and biomass. The fauna comprised of 24 major groups belonging to 15 phyla. The density of macrofauna varied from 30 to 1430 ind.m⁻² (mean = 376.39 ± 345.97 SD; n = 56) and biomass varied from 0.11 to 12.75 g wet wt m⁻² (mean = 1.02 ± 1.85 SD; n = 56). The results indicate that faunal density was negatively correlated with water depth ($Y = -0.204x + 1204.5$; $r = -0.601$; $n = 56$; $P < 0.001$). Exponential increase in benthic standing stock (density and biomass) from eastern to western region ($Y = 2.3328x^2 - 328.8x + 11640$; $r = -0.712$; $n = 56$; $P < 0.001$; $n = 56$) suggests the direct relationship between the mid-ocean ridge environment and macrobenthic abundance. The recent discovery of hydrothermal activity in the Indian Ocean strongly suggests the possibility of many more such activities in the region and hence the mid-ocean ridge systems in the Indian Ocean make them a very attractive environment for benthic biological studies.

UNTIL the discovery of hydrothermal vents and their attendant fauna¹, benthic ecosystem of the abyssal depths was considered to be a food-limited environment, one of the poorest on earth in terms of benthic biomass and a desert deprived of local primary production. However, only a very small fraction (1% or less) of surface productivity reaches the deep ocean floor² and therefore the deep-sea benthos may not necessarily depend on the surface primary productivity as was generally argued³⁻⁶. Tight coupling of bacteria and benthic biomass in the deep-sea sediment indicate that bacteria and organic detritus are the major source of food for deep-sea benthos⁷⁻¹⁰. Although information on the abyssal environment has increased considerably in the last few years, our knowledge of the deep-sea benthos of the Indian Ocean is still in its infancy. Only a few investigations have recently directed to a quantitative evaluation of the benthic stocks¹¹⁻¹³.

The Central Indian Ocean Basin (CIOB) located between the Central Indian Ridge and the Ninety East Ridge receives sediments from the runoff of major rivers (Ganga

and Brahmaputra), dispersed far south of the equator by turbidity currents¹⁴. Recent biological studies conducted in the Central Indian Basin (CIB) suggested remarkably rich microbiota^{9,15} and abundant and diverse meio-, macro- and megabenthic communities¹⁶⁻²⁰ on the deep-sea floor. However, the above investigations were conducted in a limited area, with a specific objective (assessing the impact of deep-sea mining) and hence the inferences from CIB studies may not necessarily reflect the patterns of benthic standing stock for the entire Central Indian Ocean (CIO). Further, as mentioned by Lindsay *et al.*²¹; there is an urgent need to conduct detailed benthic investigation of the Indian Ocean, particularly to understand the species composition and ecological interactions of the benthic communities.

Deep-sea sediments of the World Oceans are considered as reservoirs of biodiversity, harbouring 10–100 million species of worms, crustaceans, echinoderms and molluscs^{22,23}. The discoveries of hydrothermal vent fields and associated life forms¹ suggest that 'Mother Earth' hosts a subsurface biosphere of microbial life and presently we do not have enough information of its nature and extent. The recent discovery of hydrothermal activity in the Indian Ocean²⁴ strongly suggests the possibility of many more such activities in the region and hence the mid-ocean ridge systems in the CIOB make them a very attractive environment for benthic biological studies. As suggested by Lonsdale¹, searching for local clusters of filter feeding animals might be one of the simplest methods for locating the precise sites of active hydrothermal vent. Therefore, the present study has been undertaken with this objective. Data on the distribution and abundance of macrofauna in the CIOB, collected from abyssal depths during various deep-sea cruises^{12,13}, have been re-analysed and discussed in relation to the spreading ridge environment.

Materials and methods

Data presented in this article are based on the sediment samples collected on-board four different research vessels, during 1982–1987. The water depth of the sampling sites ranged between 2220 and 6005 m (Figure 1). Sediment

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samples were collected with the help of Peterson grab (0.2 m²); van Veen grab (0.7 m² area, 40 cm depth) and box core (50 × 50 × 50 cm size). Details of the sampling locations and sampler used are given in Table 1 and Figure 1. Sub-sampling for macrofauna was done with 15 × 15 × 10 cm size quadrant and 2–3 quadrants were taken at each location. The samples were washed through a 0.5mm mesh sieve and preserved in 5% seawater formalin – Rose Bengal solution.

All the sub-samples were washed through a 0.5-mm mesh sieve in running water to clear adhering sediments. The organisms were sorted into major groups and preserved in 90% alcohol. Subsequently specimens were identified and counted group-wise under stereo-zoom microscope. For some of the taxa, identification could not be done up to species level and hence they were put under a generic group. All unidentified species are referred by their generic/family names and are considered single taxonomic categories. Biomass (wet weight) of all the sorted specimens was taken group-wise. All the nodules collected with individual grab samplers were sorted carefully to determine the nodule abundance (kg/m²). Any sedentary animals attached to nodule surface were removed and preserved in 5% formalin.

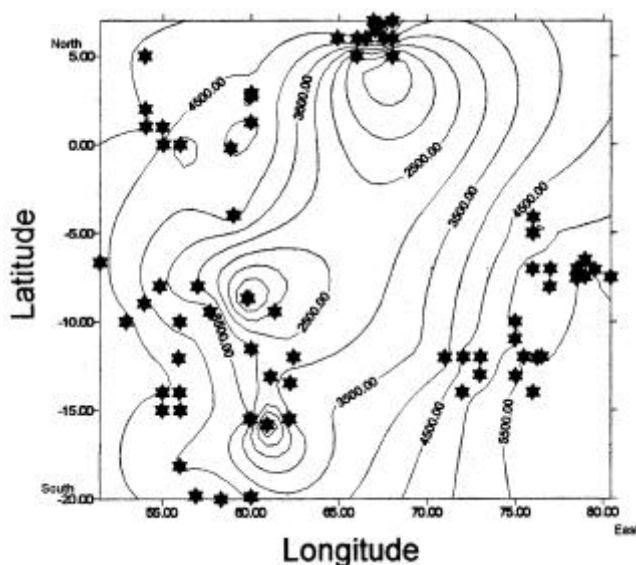


Figure 1. Location of sampling stations.

Results and discussion

Composition and abundance of macrofauna

Macrofauna of the CIO comprised 24 major groups belonging to 15 phyla. The fauna was mainly constituted by Protozoa, Nematoda, Mollusca, Polychaeta, Crustacea and Echinodermata. Polychaeta was the most dominant group in terms of number of individuals, contributing over 33% to the total macrofaunal population (Figure 2). Their density varied from 20 to 649 no.m⁻² with a mean value of 124.18 ± 40.33 SD (Table 2). Crustacea (23%) was the most diversely represented group and dominated the fauna in number of taxa (10 taxa, Table 2; Figure 2). Amphipods (7.11%), isopods (5.33%), ostracods (4.03%) and harpacticoid copepods (3.76%) were major groups with higher per cent prevalence. Paracaridean shrimps (0.87%), thalassinoid decapods (0.79%), cumaceans (0.64%), brachyuran crabs (0.33%), pagurid crabs (0.15%) and Tanaidacea (0.11%) were the other macrobenthic taxa. Gastropods and bivalves were the main constituents of molluscs and together formed over 15% of macrofaunal density. Protozoa (5%) was represented by foraminiferans (3.50%) and radiolarians (1.14%). Echinoids (1.73%), ophiuroids (1.22%) and holothurians (0.59%) represented Echinodermata (4%). Bryozoa (2%), Nemertinea (1%), Echiurida (1%) and Brachiopoda (1%) were the other faunal groups contributing over 1% to the macrofauna. Miscellaneous forms such as turbellarians, hydrozoans, sponges, sipunculid worms, siphonophores and fish larvae contributed about 7% to the faunal composition.

Distribution of density and biomass

As shown in Figure 3, the values for the macrobenthic density fluctuated very widely and were considerably higher at some of the stations. The density of macrofauna varied from 30 to 1430 no.m⁻² (mean = 376 ± 346 SD; *n* = 56; Table 2) and biomass (wet wt) varied from 0.11 to 12.75 g m⁻² (mean = 1.02 ± 1.85 SD; *n* = 55; Table 2). Remarkably high (7085 no.m⁻²) density was observed at one of the sampling stations located in the western region (lat. 08°42'644'S; long. 59°50'207'E). However, being a shallower (500 m) station, this was not included for estimating the mean abundance. In general, the density values were higher in the western sector compared to the eastern

Table 1. Details of the macrobenthic sampling in the Central Indian Ocean (CIO)

Research vessel and cruise nos	Duration	No. of samples	Depth range (m)	Sampling gear	Sampling area
<i>MV Skandy Surveyor</i> (SS-2)	29.09.1982 to 10.11.1982	9	3700–6005	Peterson grab	Eastern sector CIO
<i>MV Fernella</i> (F-3)	30.03.1983 to 13.05.1983	11	4492–5800	Peterson grab	Eastern Sector CIO
<i>RV Gaveshani</i> (RV-133-134)	21.02.1984 to 11.05.1984	25	1254–5040	Peterson grab	CIO
<i>ORV Sagar Kanya</i> (SK-20)	28.11.1985 to 11.01.1986	4	5170–5420	Van Veen grab and Box corer	CIO
<i>ORV Sagar Kanya</i> (SK-35)	22.08.1987 to 23.10.1987	18	2200–4556	Van Veen grab and Box corer	CIO

sector and there was gradual increase in the density values from east to west. The mean maximum values were observed between 8–9°S latitude and 57–62°E longitude (Figure 4). The western region has relatively shallower depths compared to the eastern region (Figure 1). As assessed from the regression coefficients, abundance (density)

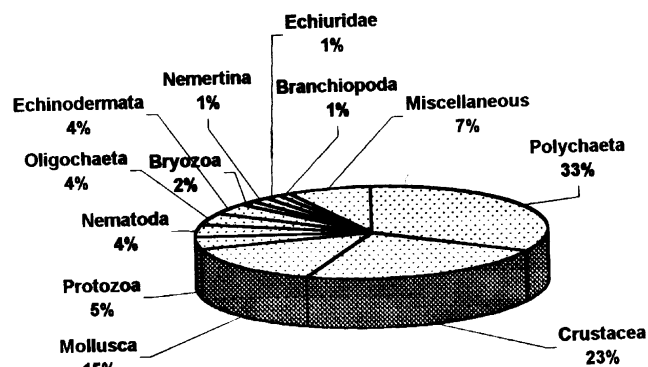


Figure 2. Composition (%) of the macrofauna.

Table 2. Abundance (no. of ind.m⁻²) of macrofauna in the Central Indian Ocean, arranged in descending order of dominance

Taxa	Range	Mean	SD	%
Polychaeta	20–649	124.18	40.33	32.97
Gastropoda	29–177	35.21	47.09	9.34
Amphipoda	20–203	26.8	6.33	7.11
Isopoda	20–180	20.1	13.04	5.33
Bivalvia	29–116	16.52	23.48	4.39
Unidentified	0–174	15.77	24.17	4.19
Ostracoda	20–295	15.19	26.32	4.03
Nematoda	29–118	14.88	14.51	3.95
Oligochaeta	20–319	14.8	25.63	3.93
Harpacticoida	20–177	14.29	11.86	3.79
Foraminifera	20–236	13.19	21.64	3.5
Echinoidea	20–300	6.51	11.28	1.73
Bryozoa	0–89	5.87	4.19	1.56
Nemertina	0–30	5.51	5.36	1.46
Echiurida	20–89	5.46	6.87	1.45
Branchiopoda	0–148	4.67	8.08	1.24
Ophiuroidea	0–60	4.6	5.94	1.22
Radiolaria	0–59	4.28	7.41	1.14
Paracaridean shrimp	0–60	3.27	2.83	0.87
Turbellaria	15–78	3.24	5.61	0.86
Hydrozoa	20–118	3.17	5.61	0.84
Sipuncula	30–59	3.04	2.76	0.81
Thalassinid decapods	15–59	2.96	5.12	0.79
Cumacea	29–59	2.42	2.4	0.64
Holothuroidea	20–60	2.22	3.85	0.59
Fish larvae	0–30	1.8	3.12	0.48
Dentatiidae	0–58	1.6	2.77	0.42
Brachyuran crab	0–90	1.25	2.16	0.33
Monoplacophora	0–60	0.83	1.44	0.22
Pagurid crab	0–20	0.55	0.96	0.15
Siphonophora	0–29	0.53	0.93	0.14
Soft coral	0–30	0.42	0.72	0.11
Sponges	0–30	0.42	0.72	0.11
Pteropoda	0–30	0.42	0.72	0.11
Tanaidacea	0–30	0.42	0.72	0.11
Total density (no.m ⁻²)		376.39	345.97	99.92
Total biomass (g m ⁻² wet wt)	0.11–12.75	1.02	1.85	–

of macrofauna decreased steadily with increasing water depth ($Y = -0.204x + 1204.5$; $r = -0.601$; $n = 56$; $P < 0.001$; Figure 5 a). The longitudinal distribution of macrobenthic density showed exponential increase in the western sector ($Y = 2.3328x^2 - 328.8x + 11640$; $r = 0.712$; $P < 0.001$; $n = 56$; Figure 6); this suggest the possibility of biological colonization in this region. According to Lonsdale¹, each hydrothermal convection cell may have a diameter in the range of kilometers. It has been suggested that bacteria are the main food source of abyssal filter-feeding organisms²⁵. Since rapid growth of chemoautotrophic bacteria occurs at many subaerial and abyssal hydrothermal vents¹, they could provide a local source of food for the filter-feeding benthic organisms and also possibly a significant input of organic matter to the deep sea. Thus, we can expect a clear zonation of benthic animals in the vicinity of hydrothermal activity. If this is true then the extent of each benthic community may provide useful information on the horizontal scale of convective cells. The presence of mid-ocean ridge and seamounts in and around the study region make certain the continuous supply of sedimentary organic material that could act as attractive force for macrofaunal congregation. While discussing the influence of sediment transport on short-term recolonization of benthic fauna, Levin and DiBacco²⁶ considered the passive transport of bedload as dominant factor for colonization of seamount infauna. The simplest explanation for clustering around a vent is that entrainment of bottom water by the rising buoyant plume creates local inflowing bottom currents that deliver food for the benthic animals¹. Thus, the biomass generated in hydrothermal plumes may represent a significant fraction of the organic matter in the deep ocean²⁷.

The macrobenthic biomass varied between 0.11 and 12.75 g m⁻² (mean = 1.02 ± 1.85 SD; $n = 56$) and the values were much higher than previously reported from comparable depths¹¹. Biomass values also decreased with increasing water depths, but the regression analysis did not show significant correlation between water depths and

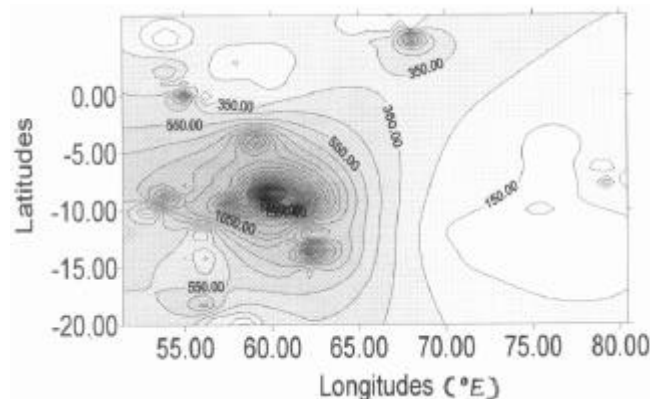


Figure 3. Distribution of macrobenthic density in the Central Indian Ocean.

biomass (Figure 5 b). Total density and biomass of benthic assemblages are known to decrease with increasing depth¹⁰, whereas a close binding between surface productivity and benthic standing stocks has been reported by several workers^{12,28-30}. This clearly suggests that food supply is one of the main factors controlling the distribution of benthic fauna. Input of food to the deep-sea fauna of the World Ocean is in the form of large seasonal pulses of phytodetrital material⁴⁻⁶. Many deep-sea organisms including foraminiferans, cnidarians, polychaetes and echinoderms ingest phytodetritus. The relative amount of organic matter that reaches the seafloor could be seasonal^{28,31} and the supply of particulate organic material from plankton to benthos decreases with depth⁴. The surface water productivity is much lower in the CIB area than in the surrounding equatorial region³². The major food source for abyssal macrofauna of the CIO therefore, could be the lower trophic level organisms such as bacteria, microfauna and meiofauna^{3,8}. Tight coupling between bacteria and meiobenthos reported for the CIB sediment^{9,15}, indicate that bacteria and organic detritus are the major source of food for deep-sea benthos. The significant contribution of bacterial (47%) biomass to the sediment organic carbon⁹ may also ensure the uninterrupted supply of food material for higher organisms.

Benthic biology of the spreading ridge of the Indian Ocean is relatively less known (Table 3). Only 20 species of vent-specific organisms are known from the Indian Ocean²⁴ out of the ≈ 500 known hydrothermal species³³. Most of the hydrothermal systems studied by biologists so far, are located either in the Pacific or in the north central Atlantic Ocean. Therefore, to understand the diversity and benthic ecology one needs to explore the vast mid-ocean ridges. The Central Indian Ridge (CIR) is also very important from the biogeographical and evolutionary point, as it is in the main propagation pathway between the Atlantic and the Pacific vent faunas²⁴. This makes the CIR system an attractive target for Mid-Ocean Ridge studies. As a consequence of lower input of phytodetritus from water column productivity, the benthic communities at deep-sea level have to depend on other food sources.

The continuous supply of dissolved organic matter from nearby sulphide-rich systems (Black Smokers) and other hydrothermal activities could be the alternative food sources. Hydrogen sulphide (H₂S) has been identified as the most important potential energy source for microbial growth²⁷ and microorganisms are inferred to be the principal dietary item of hydrothermal vent-associated invertebrates³⁴. These vents are oases for unique life forms based on chemosynthesis where organisms derive energy by mediating chemical reactions within the hydrothermal fluids. Further, the macrofaunal abundance and biomass measured from the vent environment could be 500 to 1000 times higher than that of the surrounding deep-sea environment³⁵. Under the present setting, high abundance and biomass of macrofauna recorded at a few locations in the western area of CIOB (Figure 4), may be

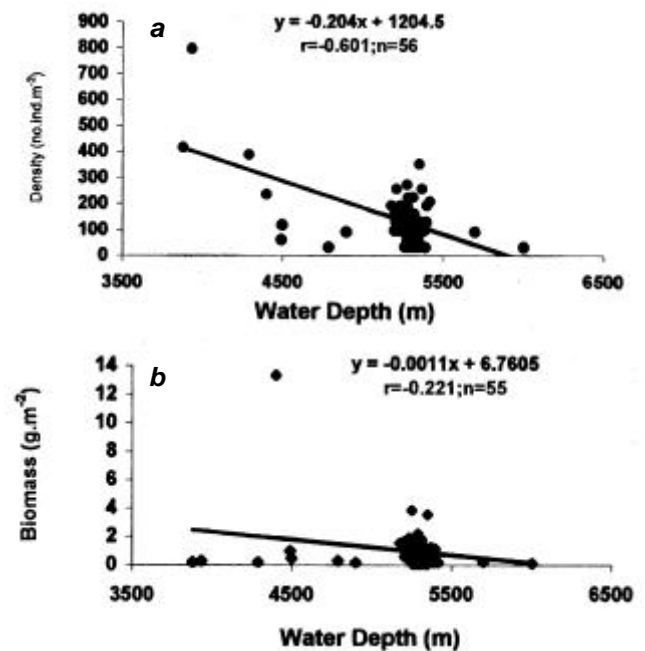


Figure 5. Relationship between water depths and macrobenthic abundance. a, Density; b, Biomass.

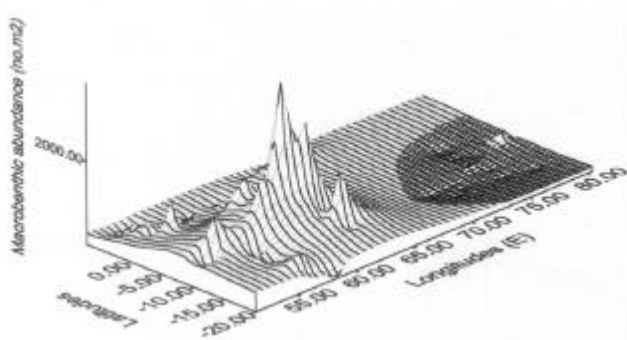


Figure 4. 3D view of the macrobenthic density distribution in the Central Indian Ocean.

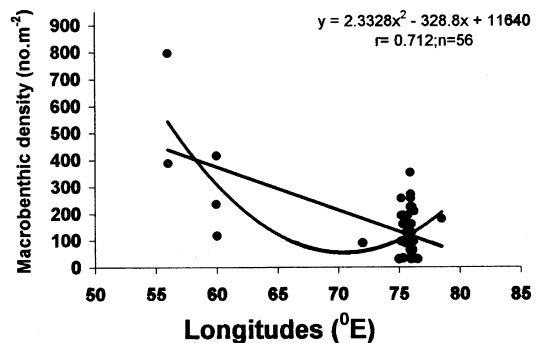


Figure 6. Longitudinal variation in macrobenthic density.

Table 3. Macrobenthic species recorded from the spreading ridge of the Indian Ocean (Source: Hashimoto *et al.*²⁴)

Phylum	Genus	Locations/Status
Coelenterata Actinostolid (sea anemone)		Beds on the bare rocks as close as 1–2 m from black smokers
Mollusca Bivalvia	Calyptogena	North of triple junction (heap of dead shells)
	Bathymodiolus	Dense beds
Gastropoda	Alviniconcha	Around the base of active chimneys
	<i>Phymorhynchus</i>	Around the base of active chimneys
	Lepetodrilus	Around the base of active chimneys
Annelida: Polychaeta	Branchipolynoe	In the mantle cavity of the deep-sea mussels
	Ophryotrocha	Around the base of active chimneys
Arthropoda: Crustacea	Austinograea	Around the base of active chimneys
	<i>Rimicaris</i>	Swarms on the surface of active chimneys
	Chorocaris	Near active vent field
	Munidopsis	On and around mussel beds
	Neolepas	On the basal rocks 3–10 m from active chimneys
	Munidopsis	Near the vent field
Chordata: (family Zoarcidae) Zoarcid fish		Around the base of active chimneys

related to the very recent finding of hydrothermal vents over the Central Indian Ridge System. The discovery of 'Kairei' hydrothermal field near Rodriguez Triple Junction²⁴ and Edmond field near 23°52'S suggests that the mid-ocean ridge systems in the Indian Ocean are potential sites for hydrothermal mineralization and active vent field. Substantially high abundance of macrobenthos around Carlsberg Ridge (CR) and CIR observed during the present study point toward the possibility of more unexplored hydrothermal vent sites in this region.

Today biological exploration of the deep-sea is gaining momentum. The hydrothermal vents rightly known as the 'Oases of the abyssal' (Pierre Chevaldonne) are a unique system in the deep-sea, which is found in the entire world ocean. Hydrothermal vents are one of the most spectacular features on the seafloor. They form in places where there is volcanic activity. These specialized ecosystems are considered as highly productive with low species diversity³⁶. Over 500 new animal species have been described from the hydrothermal environment, and most of them are endemic^{2,33}. Secondly, the abundance of chemoautotrophic and hyperthermophilic microbes in hydrothermal vent waters has stimulated new theories of the origin of life on Earth³³. This system has already been explored in much greater detail for biological approach in the Pacific and the Atlantic, whereas, the investigation of the Indian Ocean Ridge System has just started. The presence of diverse macrofaunal groups such as shrimps, ophiuroids, asteroids, crinoids, holothurians, fishes, polychaetes and bivalves with relatively higher abundance in and around Carlsberg Ridge (CR) and CIR strengthen the speculations of having a continuous supply of organically rich sediment that can support high benthic abundance. Also, in the absence of high surface primary productivity, ben-

thic fauna has to rely on the available organic material at the benthic zone itself. This led to consider the possibility of a continuous supply of dead organic matter from nearby mid-ocean ridge, which can support the observed high benthic abundance (> 7000 organisms m⁻²). However, no investigation on bacteria or any other sulphide-related benthic organism has been reported so far from CIR. It is well established that animal assemblage at abyssal depths depends on chemoautotrophic production associated with a variety of continental margin 'seeps'. As suggested by Gage and Tyler³⁷, seeped fluids exhibit a fauna taxonomically similar to that of hydrothermal vents such as tubeworms, vesicomid and mytilid bivalves, which can use the carbon from dissolved methane through symbiotic bacteria. Future studies, therefore, need to be directed towards finding the chemoautotrophic production with close grid seabed sampling that could give substantial clues for possible hydrothermal activities.

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