A preliminary evaluation of the distribution pattern of sea cucumbers in the semi-closed waters of the Amami Islands

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Abstract: With a focus on building an inventory of subtropical species of epifaunal holothurians and completing an environmental assessment, SCUBA surveys were carried out in the Amami Islands of Kagoshima Prefecture in southern Japan. The following 12 nominal species belonging to seven genera (subgenera), as well as two as yet undescribed species belonging to two genera, were observed: Bohadschia argus Jäger, 1833; B. bivittata Mitsukuri, 1912; B. vittienisis (Semper, 1867); Holothuria (Halodeima) atrae Jäger, 1833; H.(H.) edulis Lesson, 1830; Holothuria (Microthele) nobilis (Selenka, 1867); Personothuria graeffei (Semper, 1867); Stichopus chloronotus Brandt, 1835; S. hermanni Semper, 1867; S. nasso Semper, 1867; Thelenota anax H.L. Clark, 1921; Euapta sp.; Synapta maculata (Chamisso et Eysenhardt, 1821); and Opheodesoma sp. In the semi-closed waters around the Amami Islands, epifaunal holothurians showed what seemed to be species-specific distribution patterns related to topographical features. Furthermore, ignition loss values of feces and sediments suggested that selective deposit feeding may be predominant in at least several of the species sampled.

Key words: Amami, distribution, environment, holothurian, subtropical

Introduction

It is well known that sea cucumbers (class Holothuroidea) play important roles in cleaning up the sea floor in the semi-closed waters of temperate regions (Purcell et al. 2016). However, in recent years, the populations of such sea cucumbers have decreased drastically due to ocean warming and overfishing (Akamine 2004), whereas subtropical holothurians are rapidly extending their habitats (Nomura 2004); thus, the current circumstances for benthic ecosystems are believed to be critical. Therefore, studies on the role of subtropical holothurians in the maintenance of subtropical ecosystems are important to explain future changes in the temperate benthic ecosystems.

For example, in Japan, the common sea cucumber Apostichopus japonicus (Selenka, 1867) was once the only dominant species in the whole district. Unfortunately, this sea cucumber species is one of the most economically valuable holothurians worldwide (Yang et al. 2015), thereby causing severe overfishing, which has now posed a serious threat to the survival of the species in various areas (Hamel and Mercier 2013). Furthermore, some holothurian species are considered to be vulnerable to recent ocean water warming (Toral-Granda et al. 2008); A. japonicus will be affected by water warming as it exhibits aestivation (summer sleep) (Choe 1963).

To anticipate what can be expected in the future, we must know and understand the precise conditions that underlie the distribution patterns of subtropical holothurians, allowing us to elucidate the replacement of species in different areas. Thus, to enrich our basic knowledge of Japanese subtropical holothurians in semi-closed waters, we conducted SCUBA surveys around the Amami Islands of Kagoshima Prefecture in southern Japan, with the aim of building a species inventory and completing an environ-
mental assessment of sampled individuals, focusing on the following three questions: 1) What kinds of species are present? 2) What are the outstanding topographic features of the sea floor around the Islands? 3) What are the prevailing sediment conditions?

Materials and Methods

We conducted our surveys in eight sites in the following three semi-closed waters in the Amami Islands (Fig. 1): KB four sites in the Kasari Bay on the northern end of the Amamioshima Island, OS) two sites in the Oshima Strait on the southern end of the main island, and US) two sites in the Ukeshima Strait on the southern end of Kakeromajima Island. All these study sites were selected based on the low degree of overfishing damage caused in recent years; thus, details of the localities have been kept confidential in the interests of the conservation of the environment and holothurians.

We carried out the SCUBA surveys over the period of 12–15 November 2018, with the permission of the Governor of the Islands and the local fisheries corporations. We searched for epifaunal holothurians and recorded individual data for the species, including body length and width, depth, substrate of attachment, and feeding deposits. For the environmental assessment, we recorded the topographic features and animals by using an underwater camera (SCUBAPRO Co. Ltd., CHROMIS), which enabled us to easily record individual substrates, water depth, and water temperature. Furthermore, when we had sufficient air in the tanks and time allowed it, we sampled small amounts of substrates and feces around the individuals.

For the inventory survey, one or two individuals of each species were collected by hand, and fixed and preserved in 70% ethyl alcohol after anaesthetization in a menthol solution (0.37 g of menthol dissolved into 100 mL of 99% ethanol, which was then diluted to 3.0% with seawater) for 30 minutes. All specimens were dissected and examined, and ossicles were observed. To extract ossicles, small pieces of tissue were isolated and dissolved using a sodium hypochlorite solution (NaClO, 5%). Ossicles were mounted on glass slides and observed under a microscope (Nikon Co Ltd., OPTIPHOT XF-NT). Generally, holothurians can be identified by morphological examination of the body walls on the ossicles. The identification and family assignment of the species were done mostly according to Semper (1867–1868) and Clark and Rowe (1971), while Japanese naming was done according to Motokawa et al. (2003). Dissected specimens and glass slides were deposited in the Invertebrate Collection of the Wakayama Prefectural Museum of Natural History (WMNH) in Kainan, Wakayama, Japan.

Ignition loss (IgL) and approximate grain size were measured from the sediments taken from within approximately 1 cm of the sea floor, and from holothurian feces. The substrates and feces were sampled using small plastic bags, collected from the sea floor nearest to the anterior tip and posterior tip of individuals, respectively, and preserved by the addition of a small amount of 70% ethyl alcohol. However, when individuals were attached on large rocks or coarse gravels, we could not collect the substrates or feces. Before measurement of ignition loss, samples were oven-dried and cooled in a desiccator before transfer to a porcelain vaporizer for measurement of weight on an electronic scale (SARTORIUS Co Ltd., CPA224S) before and after burning for one hour at 550°C in a muffle furnace (YAMATO Co Ltd., FM-26). We used a sieving machine (AS-ONE Co Ltd., MVS-1N) to divide all samples into three grain classes: gravel (>, 2000 µm), sand (63–2000 µm), and silt (<63 µm), and measured the weight of each class using an electronic scale (SARTORIUS Co Ltd., CPA224S). Before sieving, samples were desalted by repeated washing with fresh water, and then dried in a desiccator.

To characterize the similarity pattern of the holothurian micro-habitat in the semi-closed waters around the Amami Islands, Principle Component Analysis (PCA) was performed using the R package to assess the multivariate relationships among and between the depth, ignition loss, and approximate grain size of substrate (percentages of gravel, sand, and silt) in each individual micro-habitat. Prior to analyses, environmental variables were normalized by square root transformation, and then we checked the multicollinearity among environmental variables using pairwise correlation analysis. As a result, we accepted the four variables as water depth, ignition loss, and percentages of sand and silt. Subsequently, we separated out each group regarding similarity of micro-habitat using k-means

Fig. 1. Maps showing the study sites, located in the semi-closed waters around the Amami Islands, Japan, for the survey to specify the environmental characteristics of the habitats of epifaunal holothurians. Abbreviations KB, OS, and US indicate Kasari Bay, Oshima Strait, and Ukeshima Strait, respectively.

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clustering based on the maximum of the Calinski–Harabasz pseudo-$F$ statistics. Finally, both results of PCA and k-means clustering were synthesized on same figure by using the MS PowerPoint.

## Results

In the present study, the following 12 nominal species belonging to seven genera (subgenera) and two as yet undescribed species belonging two genera were observed (Fig. 2a–n): *Bohadschia argus* Jäger, 1833 (family: Holothuriidae, Japanese name: Janome-namako); *B. bivittata* Mitsukuri, 1912 (family: Holothuriidae, Japanese name: Futasuji-namako); *B. vitiensis* (Semper, 1867) (family: Holothuriidae, Japanese name: Kuroeri-namako); *H. chloronotus* (Halodeima) atra Jäger, 1833 (family: Holothuriidae, Japanese name: Kuro-namako); *H. (H.) edulis* Lesson, 1830 (family: Holothuriidae, Japanese name: Aka-mishikiri); *Holothuria* (Microthelae) *nobilis* (Selenka, 1867) (family: Holothuriidae, Japanese name: Ishi-namako); *Personothuria graeffei* (Semper, 1867) (family: Holothuriidae, Japanese name: Kuroeri-namako); *Stichopus chloronotus* Brandt, 1835 (family: Stichopodidae, Japanese name: Shikaku-namako); *S. hermanni* Semper, 1867 (family: Stichopodidae, Japanese name: Yokosuji-ohnamako); *S. naso* Semper, 1867 (family: Stichopodidae, Japanese name: not proposed); *Thelenota anax* H.L.Clark, 1921 (family: Stichopodidae, Japanese name: Adeyakabaika-namako); *Euapta* sp. (family: Synaptidae, Japanese name: not proposed); *Synapta maculata* (Chamisso et Eysenhardt, 1821) (family: Synaptidae, Japanese name: Ohikari-namako); and *Opheodesoma* sp. (family: Synaptidae, Japanese name: Kurenai-ohikari-namako).

It is well known that typical reef constructions have several characteristic topographical features, such as the reef crest, back reefs, and reef flats (e.g. Sorokin, 1989). However, in the three semi-closed waters around the Amami Islands, we did not find such typical reef constructions. Instead, peculiar topographical features (possibly related to the sharply inclined seashore) were observed, which we named in correspondence with four clearly defined topography sections: 1) Basal flat, deepest sea floor consisting of the substrates of sand and silt with a flat or gentle slope; 2) Basal slope, sharply sloped sea floor adjoining to the basal flat; 3) Step, a flat or gently sloped sea floor adjoining to the upper part of the basal slope; and 4) Coastal slope, a sharply or gently sloped sea floor lying between the waterside and the step. Furthermore, the basal and coastal slopes were subdivided into three subparts, based on the approximate gradient of the slope: a) nearly constant slope (middle part), b) slope gradually becoming steep, and c) gentle slope (upper and lower parts).

In the four study sites at Kasari Bay (KB-1–4), typical examples of the topographical features and the distribution of holothurians are summarized as follows (Fig. 3a, Table 1): Coastal slope, mostly consisting of rock and gravel substrates with a gentle slope, in which large corals and rocks were distributed in a wide range, where *S. chloronotus* and *H. (H.) atra* were frequently observed in the upper part, *H. (H.) edulis* and *S. maculata* were frequently observed among the coral rocks in the middle part, while *B. argus* and *P. graeffei* were sporadically observed in the middle and lower parts of the coastal slope; Step, mostly consisting of gravel and sand substrates in the upper part with a gentle slope, sand and silt in the lower part with a gentle slope, and mostly sand and silt in the middle part with a sharp slope, and where holothurians were rare in the upper part, *H. (M.) nobilis* and *B. bivittata* were observed burying gravel and sand substrates in the middle part, *S. hermanni* was observed laying quietly in the middle and lower parts, and *S. naso* was frequently observed in the lowest part of the slope; and Basal flat, consisting of sand and silt substrates (silt dominated) with a flat or very gentle slope where holothurians were quite rare, and *Euapta* sp. were observed rarely—only one solitary-dwelling individual was noted.

At the two study sites in Oshima Strait (OS-1, 2), typical examples of the topographical features and the distribution of holothurians (only observed in OS-1) are summarized as follows (Fig. 3b, Table 1): Coastal slope, mostly consisting of gravel and sand substrates (sand dominated) with a sharp slope, in which massive corals were distributed over a wide range, but nevertheless, holothurians were rare in this entire region; Step, mostly consisting of gravel and sand substrates (sand dominated), in which small corals were sporadically distributed and holothurians were rare; Basal slope, mostly consisting of gravel and sand substrates in the upper part with a gentle slope, mostly sand and silt in the sharp sloped middle part, mostly sand and silt in the lower part with a gentle slope in which holothurians were rare in the upper and middle part, and *S. hermanni* was observed in the lower part, but only sporadically distributed around small coral patches; and basal flat, consisting of sand and silt substrates (silt dominated) with flat or very gentle slope, where *Opheodesoma* sp. was sporadically observed to be dwelling.

At the two study sites in Ukeshima Strait (US-1, 2), typical examples of the topographical features and the distribution of holothurians are summarized as follows (Fig. 3c, Table 1): Coastal slope, mostly consisting of rock and gravel substrates with a gentle slope in which large corals and rocks were distributed over a wide range, and in this case, *H. (H.) edulis* was observed in the middle part; Step, mostly consisting of gravel and sand substrates (sand dominated) in which massive corals were distributed and *B. vitiensis* dwelled here in solitary; Basal slope, mostly consisting of gravel and sand substrates in the upper part with a gentle slope, mostly sand and silt in the middle part with a sharp slope (especially in US-2, partially dropped...
Fig. 2. Photographic documentation of epifaunal holothurians in the semi-closed waters around the Amami Islands: a) *Bohadschia argus* Jäger, 1833 (family: Holothuriidae, Japanese name: Janome-namako); b) *B. bivittata* Mitsukuri, 1912 (family: Holothuriidae, Japanese name: Futasuji-namako); c) *B. vitiensis* (Semper, 1867) (family: Holothuriidae, Japanese name: Chizu-namako); d) *Holothuria (Halodeima) atra* Jäger, 1833 (family: Holothuriidae, Japanese name: Kuro-namako); e) *H.(H.) edulis* Lesson, 1830 (family: Holothuriidae, Japanese name: Aka-mishikiri); f) *Holothuria (Microthele) nobilis* (Selenka, 1867) (family: Holothuriidae, Japanese name: Ishi-namako); g) *Personothuria graeffei* (Semper, 1867) (family: Holothuriidae, Japanese name: Kuroeri-namako); h) *Stichopus chloronotus* Brandt, 1835 (family: Stichopodidae, Japanese name: Shikaku-namako); i) *S. hermanni* Semper, 1867 (family: Stichopodidae, Japanese name: Yokosuji-ohnamako); j) *S. naso* Semper, 1867 (family: Stichopodidae, Japanese name: not proposed); k) *Thelephoreta anax* H.L.Clark, 1921 (family: Stichopodidae, Japanese name: Adeyakabaika-namako); l) *Euapta* sp. (family: Synaptidae, Japanese name: not proposed); m) *Synapta maculata* (Chamisso et Eysenhardt, 1821) (family: Synaptidae, Japanese name: Ohikari-namako); and n) *Opheodesoma* sp. (family: Synaptidae, Japanese name: Kurenai-ohikari-namako).
vertically), mostly sand and silt in the lower part with a gentle slope, and none of the holothurians were observed; and lastly, basal flat, consisting of sand and silt substrates with a flat or very gentle slope, in which solitary-dwelling *Opheodesoma* sp. were present.

With respect to the topographical features (Fig. 4, Table 1), several species were always observed in a specific topography section, regardless of the sites or the water depth range. For example, *T. anax* was found in the step, *S. naso* in the lower part of the basal slope, and *Opheodesoma* sp. in the basal flat. Other than these species, most epifaunal species observed were detected only in certain limited sections within two or three adjacent sections.

With respect to sediments (Table 1), several species
### Table 1. Holothurians detected and their environment assessed by SCUBA surveys in Amami Islands of Kagoshima Prefecture.

| Holothurians | Habitats | Sediment | Feces |
|--------------|----------|----------|-------|
| **Sp** | **ID** | **INV No.** | **Body size (mm)** | **Length** | **Width** | **Date** | **Site** | **Dep. (m)** | **WT (°C)** | **TS** | **ST** | **IgL (%)** | **Composition (%)** | **IgL (%)** | **Composition (%)** |
| HE | 2018-112 | 153 | 32 | 12, am | KB-2 | 8.3 | 24 | 7 | G-Sa | 3.9 | 2.3 | 94.5 | 3.2 | 4.1 | 0.0 | 93.6 | 6.4 |
| HE | 2018-113 | 119 | 37 | 12, am | KB-2 | 8.8 | 24 | 7 | G-Sa | 4.9 | 3.9 | 95.5 | 2.1 | 4.7 | 1.4 | 90.0 | 8.7 |
| HE | 2018-114 | 191 | 42 | 12, am | KB-2 | 11.5 | 24 | 7 | G-Sa | 5.5 | 11.4 | 70.8 | 17.8 | 5.2 | 0.6 | 72.7 | 20.5 |
| HE | 2018-11 | 238 | 44 | 12, am | KB-1 | 4.4 | 25 | 8 | G-Sa | 3.6 | 4.8 | 91.0 | 4.2 | 3.6 | 34.9 | 61.8 | 3.3 |
| HE | 2018-16 | 182 | 37 | 13, am | KB-3 | 4.9 | 25 | 7 | G-Sa | 3.5 | 5.2 | 85.0 | 6.8 | — | — | — | — |
| HE | 2018-2 | 246 | 38 | 13, am | KB-3 | 7.8 | 25 | 7 | G-Sa | 3.3 | 8.2 | 8.6 | 16.4 | 0.8 | — | — | — |
| HE | 2018-72 | 192 | 47 | 13, am | KB-3 | 3.2 | 24 | 7 | G-Sa | 4.4 | 67.6 | 34.6 | 2.0 | 4.2 | 18.4 | 75.9 | 5.7 |
| TA | 2018-72 | 84 | 15 | 14, pm | US-2 | 7.4 | 25 | 7 | R-G | — | — | — | — | — | — | — | — |
| TA | 2018-12 | 9 | 15 | 12, am | US-1 | 68.1 | 25 | 5 | G-Sa | 2.4 | 1.7 | 19.1 | 3.2 | 1.3 | 0.0 | 18.8 | 7.1 |
| TA | 2018-10 | 7 | 15 | 12, am | US-1 | 68.1 | 25 | 5 | G-Sa | 2.4 | 1.7 | 19.1 | 3.2 | 1.3 | 0.0 | 18.8 | 7.1 |
| TA | 2018-9 | 7 | 15 | 12, am | US-1 | 68.1 | 25 | 5 | G-Sa | 2.4 | 1.7 | 19.1 | 3.2 | 1.3 | 0.0 | 18.8 | 7.1 |
| TA | 2018-8 | 7 | 15 | 12, am | US-1 | 68.1 | 25 | 5 | G-Sa | 2.4 | 1.7 | 19.1 | 3.2 | 1.3 | 0.0 | 18.8 | 7.1 |

*Species detected, HA: Holothuria (Halodeima) atr; HE: H.(H.) edulis; BA: Bohadschia argus; BB: B. hivittata; BV: B. vitensis; HN: Holothuria (Microthelle) nobilis; PG: Personothuria graeffei; SC: Stichopus chloronotus; SH: S. hermannii; SN: S. naso; TA: Thelenota anax; ESP: Exuata sp.; SM: Synapta maculata; Osp.: Opheodesoma sp. (Fig. 2) **Identifications for analysis of the habitat selections of species (only used the individuals including the data of sediment) (Fig. 4) **Registration number of the specimens in the Invertebrate Collection (INV) of the Wakayama Prefectural Museum of Natural History (WMNH) *KB: Kasai Bay; OS: Ohshima Strait; US: Ushimashia Strait (Fig. 1) **Topography section, 1: Basal flat; 2: lower part of basal slope; 3: middle part of basal slope; 4: upper part of basal slope; 5: step; 6: lower part of coastal slope; 7: middle part of coastal slope; 8: upper part of coastal slope. *R: Rock; G: Gravel; Sa: Sand; Si: Silt **Gravel: > 2000 µm; Sand: 63–2000 µm; Silt: < 63 µm
were always observed in specific sediment types. For example, *S. naso* and *Opheodesoma* sp. were only observed in sand and silt substrates. In the present study, sediment type was classified by its appearance underwater. Grain size analysis showed that in sediment classified as silt, gravel made up less than 2% of the sample (Table 1). In the case of sediment classified as gravel and sand, gravel was over 2% of the sample (Table 1). In most cases, sediment types were seemingly not related to the results of grain size analysis for the feces; sediment composition was re-
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markably different among individuals (Table 1), and feces composition was also significantly different, regardless of sediment composition. However, as an exception, apparent grain-size-selective feeding was observed in several species (Table 1). For example, in the results of grain size analysis of the feces of *Opheodesoma* sp., gravel was always 0% (Table 1).

To check whether there was any main cause of species-specific distribution patterns other than the topography sections, we also experimentally applied similarity pattern analysis using the combination of PCA and k-means clustering, omitting the topography section data (Fig. 5). For the analysis, only the water depth data, ignition loss of the sediment, and grain size composition of the sediment were used (Fig. 5, Table 1). As a result, four clusters with little dispersion were observed from the k-means clustering, and the main component of each cluster was the composition of the sediment, followed by water depth, as suggested by PCA plots (Fig. 5). Although these results were considered limited in their interpretation owing to insufficient data, they helped us to better understand the actual condition of holothurian distribution patterns, which would not have been possible had we neglected the effect of topography sections (Table 1).

**Fig. 5.** Similarity pattern of holothurians’ micro-habitat. PCA plots four environmental features of the holothurians’ occurrence sites (water depth, ignition loss, and percentages of sand and silt) with k-means clustering in the semi-closed waters around the Amami Islands. Dotted lines indicate the separated cluster by k-means method. Abbreviations on the figure are as follows: sqDep: square-rooted water depth; sqIg: square-rooted ignition loss; sqSd: square-rooted percentage of sand; and sqSi: square-rooted percentage of silt. Numbers in parentheses indicate the explained proportion of each PCA-axis. Abbreviations for species detected: BA: *Bohadschia argus*; BB: *B. bivittata*; BV: *B. vitiensis*; E sp.: *Euapta* sp.; HA: *Holothuria (Halodeima) atra*; HE: *H. (H.) edulis*; HN: *Holothuria (Microthele) nobilis*; O sp.: *Opheodesoma* sp.; PG: *Personothuria graeffei*; SC: *Stichopus chloronotus*; SH: *S. hermanni*; SM: *Synapta maculata*; SN: *S. naso*; and TA: *Thelenota anax*.

Discussion

Our findings for the holothurian fauna agreed with the information from the local fisherman and SCUBA divers on the holothurians in the Amami Islands. However, the most expensive species in the Amami Islands, *Thelenota ananas* (Jäger, 1833) (family: Stichopodidae, Japanese name: Baika-namako), could not be confirmed at all. This may be due to overfishing and a lack of recovery.

In the semi-closed waters around the Amami Islands, epifaunal holothurians showed species-specific distribution patterns related to sea-floor topographical features. However, the disposition of topographical features is related with water depth, and water depth has direct effects upon many environmental factors such as irradiance and calmness, which likely have a significant impact in addition to the effect of water depth itself. Therefore, the factor responsible for the observed distribution patterns of holothurians cannot be confirmed easily and requires future study.
Although a detailed analysis was not possible, the discovery of holothurian distribution patterns related to topographical features of the sea floor is a remarkable finding in this study. Compared with the temperate species of Japanese common sea cucumber Apostichopus japonicus, which is distributed over a wide water depth range from the intertidal zone down to 100 m depth and from the sandy to the rocky bottom (Choe 1963), the subtidal holothurians of the Amami Islands have a relatively narrow zonation pattern. If A. japonicus should become extinct due to ocean warming, the occurrence of such a broad emptiness in the ecological niche will surely invite invasion by subtropical holothurians. Although A. japonicus has extended over a wide area, there are no other species known for such broad spectrum distribution; consequently, this could result in an invasion by multiple species. Our results are useful for assessing the influence of ocean warming, and these results can be widely applied in the advancement of technology for holothurian fishery management and engineering.

In the present study, the values of ignition loss ranged from 3.0% to 5.5% (Table 1), which are considered as oligotrophic sediment values according to the usual criterion for evaluation. It is well known that holothurians take in the organic matter present in the sediment (e.g. Kitano et al. 2003), and this organic matter content can be indicated by the ignition loss value, which generally tends to increase as the sea floor deepens and/or water confinement increases. Consistent with these general trends, the highest three ignition loss values (4.8%, 4.9%, and 5.5%) were recorded at the KB-2 site, i.e., the most enclosed waters in the present study (Fig. 1). Consequently, the other general trend related to water depth was also an expected result based on the sites selected for conducting this study.

Generally, holothurians are considered to absorb nutrients from sediments (e.g. Purcell et al. 2016); therefore, we can expect ignition loss values to be lower in feces than in sediments. However, in this study, the results of many individuals are not consistent with this expectation (Table 1); For example, the IgL value of the feces of ID 25 increased by about 1.7 times that of the sediment. Thus, the following inference can be drawn: holothurians are not non-selective deposit feeders, although this concept has hitherto been widely accepted (e.g. Choe 1963), and there is no doubt that holothurians selectively feed in sections where organic matter content is higher than anywhere else. While this is a conjecture, such a nutrient-rich section is probably present in the thin layer of sediment on the sea floor surface, or in the small gap between gravels and rock surface; however, the method of sampling sediment (extracted within approximately 1 cm of the surface) used here was not suited to the analysis of absorption rate of organic matter.

IgL values of feces and sediments indicated that several species can be considered as selective deposit feeders, such as Opheodesoma sp. and S. hermanni (Table 1), based on the fact that all the IgL values of their feces were higher than that of the sediment. This result significantly explains habitat selection: some of the epifaunal holothurians possibly dwell in locations with specific sediment type for longer than that in adjoining locations with differing sediment types. In the results of grain size analysis of the feces of Opheodesoma sp., gravel was always 0%. Other than this species, grain-size-selective feeding was also expected in S. naso because its topography sections were found adjoining to those of Opheodesoma sp. and its sediment types were quite possibly similar to those of Opheodesoma sp.; however, we cannot support this conjecture, as our data are insufficient.

This assumption might be supported by the similarity pattern analyses (Fig. 4). If sediment selection for feeding is important, the deviation of the topographical features observed can be considered as a necessary consequence of deviation of the sediment types related to the specific topographical features, and/or related to the general trend as the sea floor deepens. It is not known what factor may preferentially drive habitat selection; however, this is an issue that must be the subject of future studies.

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