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FIRST FINDINGS OF SOFT-WALLED MONOTHALAMOUS FORAMINIFERA AND GROMIIDS IN THE MEIOBENTHIC COMMUNITIES OF THE SOUTH CHINA SEA

© 2026 **N. Sergeeva[1], O. Anikeeva[1], and H. Q. Tran[2]**

[1]A. O. Kovalevsky Institute of Biology of the Southern Seas of RAS, Sevastopol, Russian Federation
[2]Joint Vietnam–Russia Tropical Science and Technology Research Center, Hanoi, Vietnam
E-mail: *alegria@ibss-ras.ru*

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As a group of marine Protozoa, foraminifera play an important role in marine ecosystems. The data about hard-shelled foraminiferans from the Spratly Islands was reported in results of geological surveys. So far, there is no information on soft-walled foraminifera, for the Spratly Islands and the South China Sea (in Vietnamese, Biển Đông) in particular. This study aims to provide the first data on soft-walled foraminiferans and gromiids of the Truong Sa Archipelago. We also analyzed taxonomical diversity of the meiobenthic communities in bottom sediments and periphyton in aquatic habitats of the archipelago. Sampling was carried out during an expedition to the Spratly Islands in April 2022 at eight stations within a depth range of 6–20 m. Representatives of 20 high-level taxa (phylum, class, and order) were revealed in the composition of the meiobenthic communities of periphyton and bottom sediments in the study area. Among the protozoan hydrobionts, Ciliophora Doflein, 1901, Foraminifera d'Orbigny, 1826 (hard-shelled and soft-walled), and Gromiidea Cavalier-Smith, 2003 were recorded. In this work, particular attention is paid to Protozoa previously unknown for waters of the Vietnamese region: Foraminifera (monothalamous, soft-walled) and Cercozoa (Gromiidea). The former were found at two stations in periphyton; the latter were noted at seven stations in periphyton and at two stations in coral sand. We identified three species of soft-walled foraminifera, and two of those were tentatively assigned to the genera *Bowseria* Sinniger et al., 2008 and *Bathyallogromia* Gooday et al., 2004. Gromiids were represented by nine morphotypes; each morphotype is briefly described in the paper.

Keywords: *Gromia*, monothalamids, South China Sea, Truong Sa Archipelago, soft-walled foraminifera, meiobenthos

The Spratly Islands (Truong Sa Archipelago, Vietnam) have high biodiversity and are of great ecological importance [Latypov, 2012; Tkachenko et al., 2020]. For numerous marine species, coral reefs and atolls off the archipelago serve as 'marine oases' forming habitats for reproduction and migration. The marine area off the Spratly Islands is a critical fishing ground for Vietnam, providing the catch of many commercially valuable species [Nguyen et al., 2020]. Despite the ecological, economic, and political significance of the Spratly Islands, the studies on their marine biodiversity are still limited. In addition, increasing anthropogenic load on islands and surrounding ecosystems could result in extinction of marine species before they are even discovered. Therefore, it is crucial to carry out more research on marine bioresources of the Spratly Islands and assess their role globally.

Corals, fish, and molluscs are the most studied groups of marine hydrobionts off the Spratly Islands. Based on several surveys, Yu. Latypov [2012] listed for this water area 261 species belonging to 71 genera of the order Scleractinia Bourne, 1900. Recently, K. Tkachenko *et al.* [2020] revealed transformations of coral communities of the archipelago: changes toward the dominance of thermally-resistant

and stress-tolerant coral species. V. Nguyen [2005] identified 332 species of reef fish representing 131 genera of 44 families for four islands of the archipelago. Later, 331 reef fish species belonging to 38 families were recorded during JOMSRE III and JOMSRE IV expeditions [Stockwell, Nguyen, 2008]. V. Tran *et al.* [2023] reported 9 reef fish species from the Spratly Islands, which were noted in the Vietnam Sea for the first time. Representatives of Mollusca, Crustacea, Annelida, and Echinodermata (other groups important for reef ecosystems) were also registered: 443, 128, 93, and 75 species, respectively, were found [Do, Le, 2008]. Interestingly, new Mollusca species are constantly being discovered and described [Sirenko, 2024; Sirenko, Nguyen, 2021, 2022].

Foraminifera, a group of marine Protozoa, play an important role in marine ecosystems. Also, they are used for the assessment of the ecological health of coral reefs [A'ziz et al., 2021]. The information about foraminiferans from the Spratly Islands can be found in results of geological surveys. N. Ngọc and N. Cử [2002] listed 80 Foraminifera species belonging to 40 genera for Barque Canada Reef (Thuyen Chai Island). In other work, N. Ngoc [2018] identified 69 species of 42 genera of Holocene foraminiferans for Pearson Reef (Phan Vinh Island). However, there is still no material on soft-walled foraminifera, in particular for the Spratly Islands and the South China Sea (in Vietnamese, Biển Đông). This study aims to provide the first data on soft-walled foraminifera and gromiids off the archipelago.

MATERIAL AND METHODS

Sampling was carried out during an expedition to the Spratly Islands in April 2022. Periphyton was sampled at eight stations (TS1–TS8), while benthos was sampled at seven stations (except for TS5) (Fig. 1, Table 1). Periphytonic samples included dead corals and macroalgae, while the benthic ones were coral sediments. They were sampled at depths of 6–20 m by scuba diving. Periphyton fauna was studied on complex types of substrates (Table 1). At all the stations, bottom sediments inhabited by benthic fauna were white coral sand.

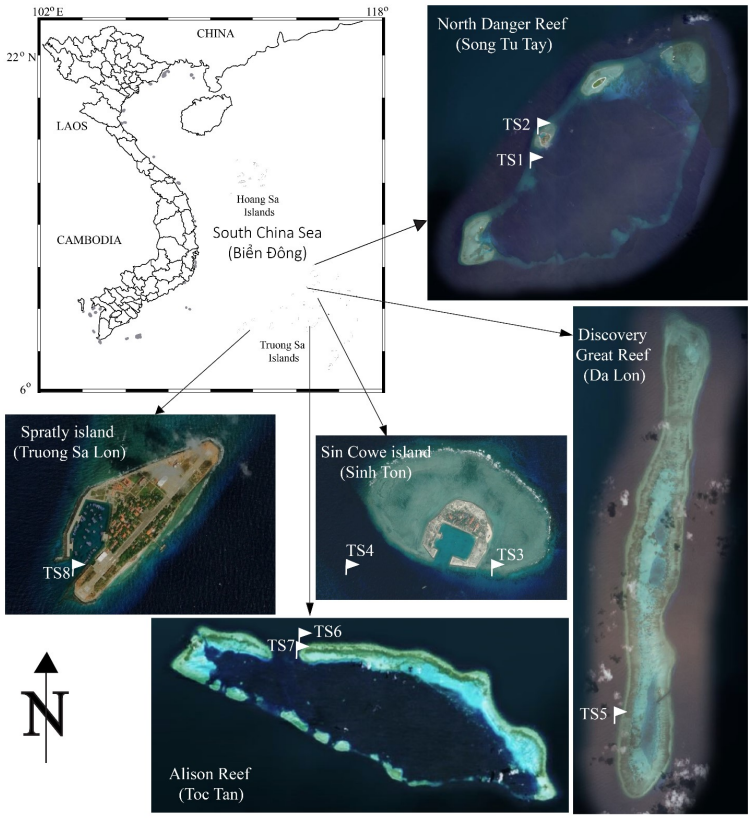

Fig. 1. Map of sampling stations TS1–TS8 marked with flags

Рис. 1. Карта станций отбора проб TS1–TS8, обозначенных флажками

Table 1. Stations of soft-walled foraminifera sampling on the Spratly Islands (Truong Sa Archipelago, Vietnam). Substrate type: R, rock; RB, rubble; SD, sand; HC, hard coral; SC, soft coral; SP, sponge; MA, macroalgae. Parameters: T, temperature, °C; EC, conductivity, mS·cm^{-1}; TDS, total dissolved solids, g·L^{-1}; S, salinity, ‰

Таблица 1. Станции отбора проб мягкораковинных фораминифер на островах Спратли (архипелаг Чыонг Ша, Вьетнам). Тип субстрата: R — скала; RB — щебень; SD — песок; HC — твёрдый коралл; SC — мягкий коралл; SP — губка; MA — макроводоросли. Параметры: T — температура, °C; EC — электропроводность, мС·см$^{-1}$; TDS — общее количество растворённых твёрдых веществ, г·л$^{-1}$; S — солёность, ‰

Station	Location	Coordinates	Depth, m	Substrate type	Physical parameters of surface water			
					T	EC	TDS	S
TS1	North Danger Reef (Song Tu Tay)	11°41′64.6″N, 114°32′55.4″E	14	R + RB + SD	+29.6	48.28	26.06	31.15
TS2	North Danger Reef (Song Tu Tay)	11°43′15.9″N, 114°32′78.4″E	7	R + RB + SD	+29.4	48.16	26.00	31.10
TS3	Sin Cowe Island (Sinh Ton)	9°88′12.5″N, 114°33′16.3″E	7	HC + SC + R + SD	+29.1	48.18	25.96	31
TS4	Sin Cowe Island (Sinh Ton)	9°88′10.1″N, 114°32′06.6″E	10	HC + SC + R + RB + SD	+29.6	49.61	26.69	32.1
TS5	Discovery Great Reef (Da Lon)	10°01′30.2″N, 113°84′18.0″E	20	HC + SC + R	+29.5	49.02	26.46	31.69
TS6	Alison Reef (Toc Tan)	8°83′34.5″N, 113°95′12.1″E	6	SC + R + RB + SD	+32.5	48.9	26.53	32.02
TS7	Alison Reef (Toc Tan)	8°82′79.2″N, 113°95′09.3″E	20	HC + SC + R + RB + SD + SP	+29.9	49.31	26.62	31.9
TS8	Spratly Island (Truong Sa Lon)	8°64′19.0″N, 111°91′60.9″E	7	R + RB + SD + MA	+31.4	48.85	26.15	31.36

The samples were fixed with Lugol's iodine, and later processed and analyzed in IBSS laboratory (Sevastopol). The samples were washed through two sieves: the upper one with a mesh size of 1 mm, and the lower one with a mesh size of 63 μm.

Detailed microscopic analysis of soft-walled foraminifera and gromiids was performed under MSP-2 (Russia), Olympus CX41 (Philippines), Nikon (Japan), and Mikmed-6 (Russia) microscopes (magnification of 400×) equipped with photo cameras connected to a computer.

RESULTS

During our studies of the meiobenthic communities of the northwestern Russian shelf of the Sea of Japan [Sergeeva, Anikeeva, 2023], we revealed protozoans, namely soft-walled foraminifera and gromiids. However, they had not been previously known for this region. Therefore, they were not considered as an integral part of the benthic communities, and their role in benthic ecosystems was not estimated. We suggest that it is important to draw the attention of researchers to taxonomic diversity of the benthic fauna and the distribution of these protozoans in the course of further studies of the meiobenthic communities in the waters of Vietnam (the Spratly Islands, Truong Sa Archipelago).

In the study area, the meiobenthic communities of periphyton and bottom sediments include representatives of 20 high-level taxa (phylum, class, and order). Among Protozoa hydrobionts, we recorded species of Ciliophora Doflein, 1901, Foraminifera d'Orbigny, 1826 (hard-shelled and soft-walled), and Cercozoa Cavalier-Smith, 1998 (Gromiidea). The other hydrobionts belonged to the multicellular fauna, and two representatives were not identified to a high level. The data on the occurrence of different taxa in biotopes of periphyton and bottom sediments (white coral sand) is provided in Table 2.

Table 2. Taxonomic composition of meiobenthos in biotopes of periphyton (Pe) and bottom sediments (Bo) in the study water area of the Truong Sa Archipelago (Pe / Bo)

Таблица 2. Таксономический состав мейобентоса в биотопах перифитона (Pe) и донных отложений (Bo) в исследованной акватории архипелага Чыонг Ша (Pe / Bo)

Taxon	Station number							
	TS1	TS2	TS3	TS4	TS5	TS6	TS7	TS8
	Pe / Bo	Pe / Bo	Pe / Bo	Pe / Bo	Pe / Bo	Pe / Bo	Pe / Bo	Pe / Bo
Ciliophora Doflein, 1901	– / +	– / +	– / +	– / +	– / –	– / –	– / +	– / +
Foraminifera d'Orbigny, 1826:								
hard-shelled	+ / +	+ / +	+ / +	+ / +	+ / –	+ / +	+ / +	+ / +
soft-walled	– / –	+ / –	– / –	– / –	– / –	– / –	+ / –	– / –
Gromiidea Cavalier-Smith, 2003	+ / +	+ / +	+ / –	+ / –	+ / –	– / –	+ / –	+ / –
Nematoda Rudolphi, 1808	+ / +	+ / +	+ / +	+ / +	+ / –	+ / +	+ / +	+ / +
Polychaeta Grube, 1850	+ / +	+ / +	+ / +	+ / +	+ / –	– / +	+ / +	+ / +
Turbellaria Ehrenberg, 1831	– / –	+ / –	– / –	– / –	– / –	– / –	– / –	– / –
Mollusca								
Gastropoda Cuvier, 1795	– / +	– / +	+ / +	– / +	– / –	+ / –	+ / –	+ / –
Bivalvia Linnaeus, 1758	– / +	– / +	– / +	– / –	– / –	– / –	– / –	– / +
Polyplacophora Gray, 1821	– / –	– / –	– / –	– / –	– / –	– / –	– / –	+ / –
Arthropoda								
Harpacticoida Sars G. O., 1903	+ / +	+ / +	– / +	+ / +	+ / –	+ / +	+ / +	+ / +
Amphipoda Latreille, 1816	– / –	– / –	– / +	– / –	– / –	+ / –	+ / –	+ / +
Tanaidacea Dana, 1849	– / –	– / –	– / –	– / –	– / –	+ / –	– / –	– / –
Isopoda Latreille, 1816	– / –	– / –	– / –	– / –	– / –	– / +	+ / –	+ / –
Ostracoda Latreille, 1802	+ / +	– / +	– / –	– / +	– / –	+ / +	+ / –	+ / +
Pantopoda Gerstäcker, 1863	– / –	– / +	– / –	– / –	– / –	– / –	– / –	– / –
Nauplia (Decapoda) Latreille, 1802	– / –	– / +	– / +	– / –	– / –	– / –	– / –	– / –
Chironomidae	– / –	– / –	+ / –	– / –	– / –	– / –	– / –	– / –
Arachnida Cuvier, 1812	+ / +	+ / +	+ / –	– / +	+ / –	+ / +	+ / +	+ / +
Chaetognatha	– / –	– / –	– / –	– / –	– / –	– / –	– / +	+ / +
Echinodermata Klein, 1778	– / –	– / +	– / +	– / +	– / –	– / +	+ / +	– / +
Unknown 1	– / –	– / +	+ / –	– / –	– / –	– / +	– / –	– / –
Unknown 2	– / –	– / –	– / +	– / –	– / –	– / –	– / –	– / –

In this paper, we focus on the groups of Protozoa: soft-walled foraminifera and gromiids, new for aquatic habitats within the archipelago. We identified three representatives of soft-walled foraminifera and nine species of gromiids inhabiting periphyton and coral sand. Morphometrically, gromiids did not exceed 400 μm, while soft-walled foraminifera ranged 600–1,150 μm. The spots of their occurrence are indicated in Table 2. Brief description of each representative of the studied groups is given below. The abbreviation used below, SCS, stands for the South China Sea. The designation used below, coefficient C, stands for length/width ratio.

Bowseria-like sp. SCS. The test is elongated, large (1,150 × 190 μm), with single simple aperture (Fig. 2B). The test wall is thin and transparent. The cytoplasm is dark, homogeneous, fine-grained (Fig. 2A). Coefficient C is about 6. The main morphological traits (the shape and size of the test, single terminal aperture, and the thin and transparent wall) allow assigning this specimen to the genus *Bowseria* [Sinniger et al., 2008] on this stage of our research. Distribution: Vietnam, sta. TS2, periphyton.

Bathyallogromia sp. SCS. This species is morphologically similar to *Bathyallogromia* sp. 2 found by us in the Black Sea at depths of 120 and 130 m [Sergeeva et al., 2010, see pl. 1, Fig. J]. The test is large (610 × 480 μm), more or less spherical (Fig. 2C), with a simple aperture (80 μm in diameter)

that does not project beyond the general outline of the test (Fig. 2D). The cytoplasm occupies the entire test and contains various small inclusions. A 'peduncular sheath' (this common term indicates the internal channel from the aperture to the inside of the cytoplasm) is clearly developed. A nucleus is not clearly visible. Coefficient C is about 1.27. Distribution: Vietnam, sta. TS7, periphyton.

Allogromiid sp. 1SCS. The test is large (900 × 700 μm), rounded, with wide simple aperture (Fig. 2E). The test wall is thin and transparent. The cytoplasm is dark, homogeneous (Fig. 2F). Coefficient C is about 1.3. Distribution: Vietnam, sta. TS2, periphyton.

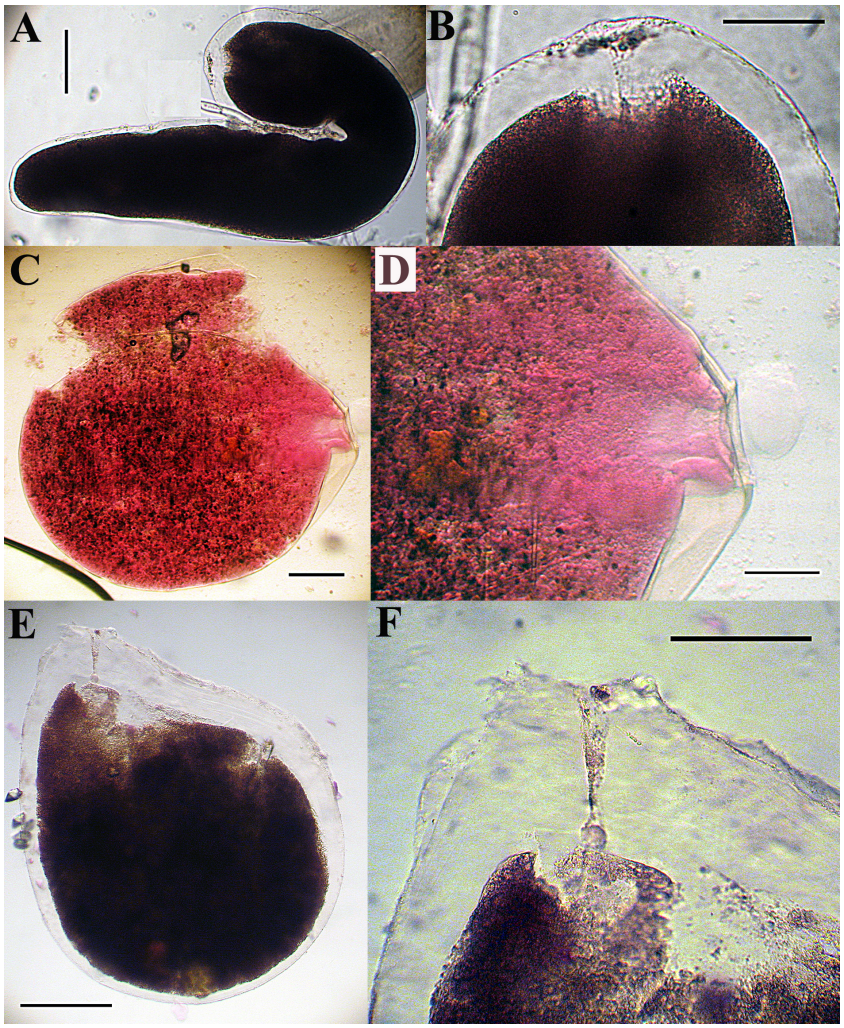

Fig. 2. Soft-walled foraminifera from the study area in the South China Sea. *Bowseria*-like sp. SCS: A, general view; B, aperture. *Bathyallogromia* sp. SCS: C, general view; D, aperture. Allogromiid sp. 1SCS: E, general view; F, aperture. Scale bars are 100 μm (A, C, F), 50 μm (B, D), and 200 μm (E)

Рис. 2. Мягкораковинные фораминиферы из исследуемого района Южно-Китайского моря. *Bowseria*-like sp. SCS: A — общий вид; B — апертура. *Bathyallogromia* sp. SCS: C — общий вид; D — апертура. Allogromiid sp. 1SCS: E — общий вид; F — апертура. Масштабная линейка — 100 мкм (A, C, F), 50 мкм (B, D) и 200 мкм (E)

Gromia sp. 1SCS. This specimen has average-sized (370 × 275 μm), oval test (Fig. 3A) with the thin wall (Fig. 3B) and heterogeneous brownish cytoplasm. Oral capsule is not visible. Coefficient C is about 1.3. Distribution: Vietnam, sta. TS8, periphyton.

Gromia sp. 2SCS. Almost spherical cell (200 × 190 μm) is filled with homogeneous dark cytoplasm (Fig. 3C). The test wall is thin and transparent (Fig. 3D). Oral capsule is not visible. Coefficient C is 1.05. Distribution: Vietnam, sta. TS8, periphyton.

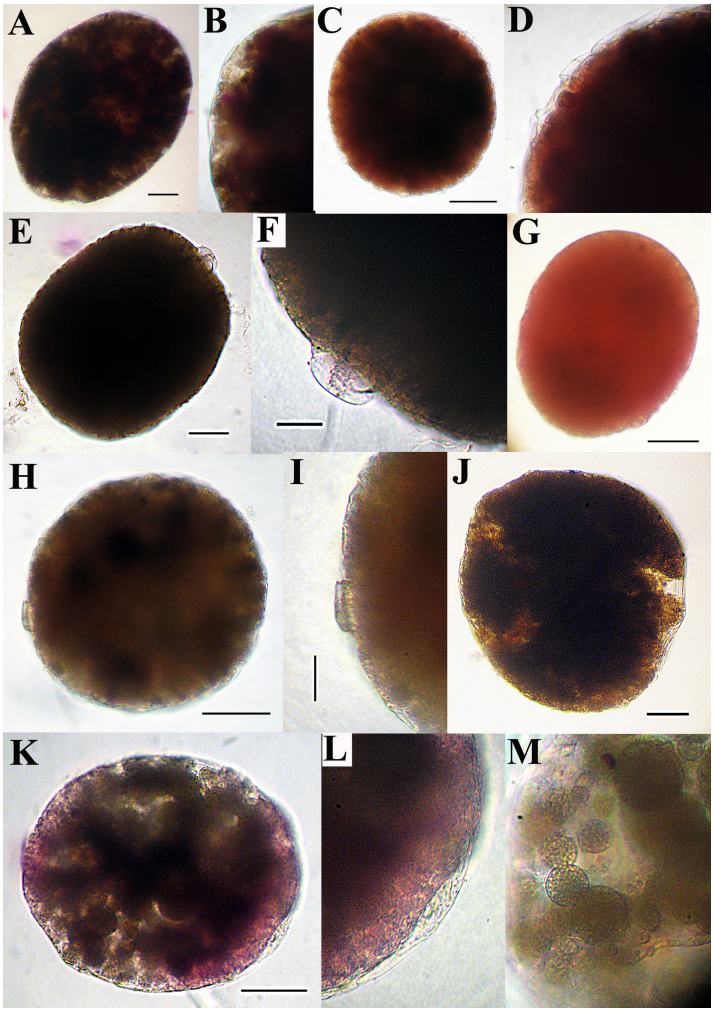

Fig. 3. Gromiids from the study area in the South China Sea. *Gromia* sp. 1SCS: A, general view; B, test wall. *Gromia* sp. 2SCS: C, general view; D, test wall. *Gromia* sp. 3SCS: E, general view; F, oral capsule. *Gromia* sp. 4SCS: G, general view. *Gromia* sp. 5SCS: H, general view; I, oral capsule. *Gromia* sp. 7SCS: J, general view. *Gromia* sp. 6SCS: K, general view; L, oral capsule; M, protoplasm content. Scale bars are 50 μm (A, C, E, G, H, J, K) and 20 μm (F, I)

Рис. 3. Громии из исследуемого района Южно-Китайского моря. *Gromia* sp. 1SCS: A — общий вид; B — стенка раковины. *Gromia* sp. 2SCS: C — общий вид; D — стенка раковины. *Gromia* sp. 3SCS: E — общий вид; F — ротовая капсула. *Gromia* sp. 4SCS: G — общий вид. *Gromia* sp. 5SCS: H — общий вид; I — ротовая капсула. *Gromia* sp. 7SCS: J — общий вид. *Gromia* sp. 6SCS: K — общий вид; L — ротовая капсула; M — содержимое протоплазмы. Масштабная линейка — 50 мкм (A, C, E, G, H, J, K) и 20 мкм (F, I)

Gromia sp. 3SCS. The rectangular-oval test is 280 × 230 μm in size (Fig. 3E). Oral capsule looks like a convex transparent structure and has a diameter of 30 μm (Fig. 3F). The cytoplasm is dark and dense. Coefficient C is 1.2. Distribution: Vietnam, sta. TS1, periphyton.

Gromia sp. 4SCS. This specimen is similar with *Gromia* sp. 1SCS (see Fig. 3A) in the shape of the test. Oral capsule is also not visible. However, *Gromia* sp. 4SCS (Fig. 3G) is smaller (210 × 180 μm) and has a light brown, almost orange cytoplasm. Coefficient C is about 1.1. Distribution: Vietnam, sta. TS1, periphyton.

Gromia sp. 5SCS. The test is spherical (180 × 180 μm) (Fig. 3H), with heterogeneous brown cytoplasm and small but clearly visible oral capsule (Fig. 3I) in the form of a short cap (23 μm in diameter). Coefficient C is equal to 1. Distribution: Vietnam, sta. TS1, periphyton.

Gromia sp. 6SCS. The test is almost spherical (210 × 190 μm). The cytoplasm is heterogeneous (Fig. 3K), with many little rounded inclusions (Fig. 3M). The test wall is thin, in one spot forming a small protrusion like an oral capsule (Fig. 3L). Coefficient C is about 1.1. Distribution: Vietnam, sta. TS1, periphyton.

Gromia sp. 7SCS. This species resembles *Gromia* sp. 2SCS (see Fig. 3C) in spherical form of the test and the absence of obvious oral capsule (Fig. 3J). However, *Gromia* sp. 7SCS is larger (310 × 290 μm) than the second species. Also, it has a lighter and less dense cytoplasm. Coefficient C is about 1.06. Distribution: Vietnam, sta. TS1, periphyton; sta. TS5, periphyton; and sta. TS2, bottom sediments.

Gromia sp. 8SCS. The test is spherical (Fig. 4A) and not large (280 × 240 μm). The oral capsule (34 μm in diameter) is slightly flattened and nipple-like in shape (Fig. 4B). The cytoplasm is dense and dark. Coefficient C is about 1.16. Distribution: Vietnam, sta. TS1, periphyton.

Gromia sp. 9SCS. The test is rounded, slightly elongated (260 × 210 μm). The cytoplasm is heterogeneous, taupe (Fig. 4C). The oral capsule is a small protrusion of the thin test wall with a diameter of 36 μm (Fig. 4D). Coefficient C is about 1.2. Distribution: Vietnam, sta. TS1, periphyton.

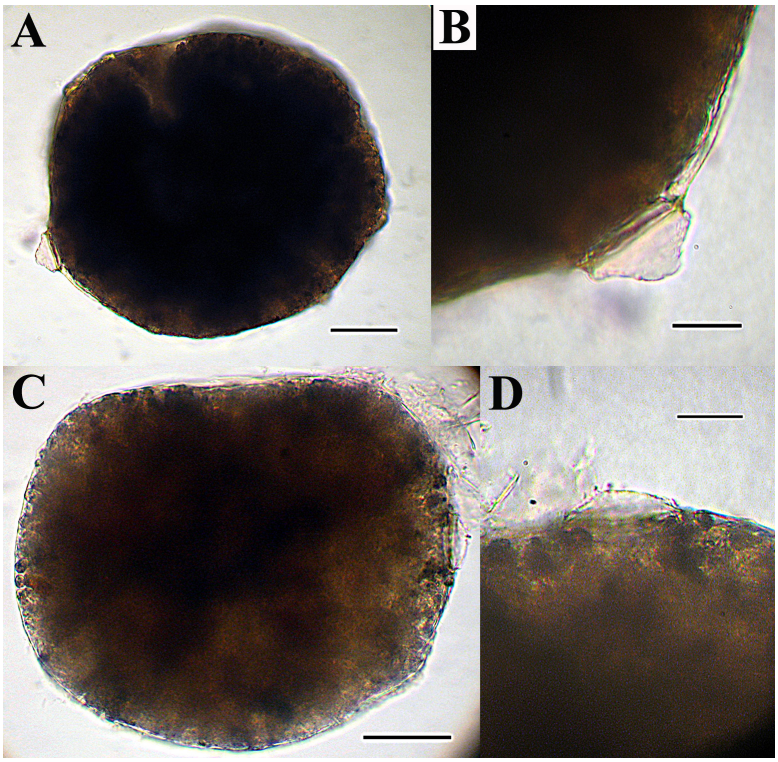

Fig. 4. Gromiids from the study area in the South China Sea (the continuation). *Gromia* sp. 8SCS: A, general view; B, oral capsule. *Gromia* sp. 9SCS: C, general view; D, oral capsule. Scale bars are 50 μm (A, C) and 20 μm (B, D)

Рис. 4. Громии из исследованного района в Южно-Китайском море (продолжение). *Gromia* sp. 8SCS: A — общий вид; B — ротовая капсула. *Gromia* sp. 9SCS: C — общий вид; D — ротовая капсула. Масштабная линейка — 50 мкм (A, C) и 20 мкм (B, D)

DISCUSSION

Soft-walled foraminifera and gromiids, an important component of marine meiobenthos, are almost unknown for the South China Sea, including the Spratly Islands (Truong Sa Archipelago, Vietnam). Thus, all soft-walled foraminifera and gromiids considered in the present study are the first records for this marine region.

These protozoans are involved in the organic matter cycle of bottom ecosystems [Sergeeva, Anikeeva, 2018, 2023], and inhabit various depths and biotopes of the South China Sea and adjacent water areas. They definitely require further detailed study. The list of monothalamous foraminifera and gromiids presented in this paper should be regarded as preliminary, as it will undoubtedly be supplemented during further research.

Conclusions. Despite the environmental importance of the Spratly Islands (Truong Sa Archipelago, Vietnam), the biodiversity of this marine region is poorly studied. Many groups of marine hydrobionts, such as soft-walled foraminifera and gromiids, remain unknown from this area. This survey provides the first data on soft-walled foraminifera and gromiids of the Spratly Islands. There, three representatives of soft-walled Foraminifera and nine *Gromia* species are recorded for the first time. None of them could be classified down to the species level which indicates the high specificity of their morphological traits. Therefore, further studies should be conducted to determine whether they represent new species for this marine region.

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ПЕРВЫЕ НАХОДКИ МЯГКОРАКОВИННЫХ МОНОТАЛАМУСНЫХ ФОРАМИНИФЕР И ГРОМИИД В МЕЙОБЕНТОСНЫХ СООБЩЕСТВАХ ЮЖНО-КИТАЙСКОГО МОРЯ

Н. Г. Сергеева[1], О. В. Аникеева[1], Х. К. Чан[2]

[1]ФГБУН ФИЦ «Институт биологии южных морей имени А. О. Ковалевского РАН», Севастополь, Российская Федерация
[2]Совместный российско-вьетнамский тропический научно-исследовательский и технологический центр, Ханой, Вьетнам
E-mail: *alegria@ibss-ras.ru*

Фораминиферы как группа морских простейших играют важную роль в морских экосистемах. Информация о фораминиферах с твёрдой раковиной с островов Спратли представлена в результатах геологических исследований. Сведения о мягкораковинных фораминиферах, в частности на островах Спратли и в Южно-Китайском море (Biển Đông по-вьетнамски), до сих пор отсутствуют. Целью настоящего исследования было предоставить первые данные о мягкораковинных фораминиферах и громиидах на архипелаге Чыонг Ша (Южно-Китайское море, Вьетнам), а также оценить таксономическое разнообразие сообществ мейобентоса в донных отложениях и перифитоне в водных местообитаниях архипелага. Образцы собраны во время экспедиции на острова Спратли в апреле 2022 г. на восьми станциях в диапазоне глубин 6–20 м. В составе сообществ мейобентоса перифитона и донных осадков в исследуемом районе отмечены представители 20 таксонов высокого ранга (тип, класс и отряд). Среди простейших зарегистрированы Ciliophora Doflein, 1901, Foraminifera d'Orbigny, 1826 (твёрдо- и мягкораковинные) и Gromiidea Cavalier-Smith, 2003. Особое внимание уделено простейшим, ранее неизвестным для вод вьетнамского региона, — Foraminifera (однокамерные, мягкораковинные) и Cercozoa (Gromiidea). Первые отмечены на двух станциях в перифитоне; вторые зарегистрированы на семи станциях в перифитоне и на двух станциях в коралловом песке. Выявлено три вида мягкораковинных фораминифер; два из них предварительно отнесены к родам *Bowseria* Sinniger et al., 2008 и *Bathyallogromia* Gooday et al., 2004. Громии представлены девятью морфотипами. Приведено краткое описание каждого представителя изученных групп.

Ключевые слова: *Gromia*, моноталамиды, Южно-Китайское море, архипелаг Чыонг Ша, мягкораковинные фораминиферы, мейобентос