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Taxonomic Investigations on Cladorhizidae (Carnivorous Sponges) of the East Scotia Ridge (Antarctica) with the Description of Three New Species

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Abstract: This study investigates taxonomic characteristics of carnivorous sponges from the Southern Ocean. The specimens were collected in 2010 from deep-sea hydrothermal vents of the East Scotia Ridge during the RRS James Cook Cruise JC42. All the investigated sponges are new to science. They belong to the genera *Abyssocladia* and *Cladorhiza* within the family Cladorhizidae. This study provides descriptions and remarks for the three new species *Abyssocladia truespacemeni*, *Abyssocladia hendrixii* and *Cladorhiza elsaae*. Comparative faunistic and ecological aspects of these sponge genera within the Southern Ocean sponge fauna are discussed. The genera *Abyssocladia* and *Cladorhiza* are recorded here for the first time from the ecosystem around hydrothermal vents in the Antarctic deep sea. The descriptions of new species contribute to and expand the current knowledge of the Cladorhizidae and consequently support future taxonomic identifications and descriptions of Antarctic deep-sea carnivorous sponges. The appearance of these newly discovered species underlines the hypothesis that Cladorhizidae is the second most species-rich family of Demospongiae in the Southern Ocean, and many new species of this deep-sea sponge family are still to be discovered.

Keywords: Porifera; Cladorhizidae (carnivorous sponges); *Cladorhiza*; *Abyssocladia*; Southern Ocean; Antarctica; East Scotia Ridge; deep sea; taxonomy; new species

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1. Introduction

The sponge family Cladorhizidae Dendy, 1922 [1] has been known for 146 years, whereby the first genus and species (*Cladorhiza abyssicola* Sars, 1872) were described by Sars in 1872 [2]. According to the World Porifera Database (as of 27 January 2024), there are 15 genera in the family Cladorhizidae (Poecilosclerida: Demospongiae): *Abyssocladia* Lévi, 1964 [3]; *Abyssosdiskos* Ekin, Erpenbeck, Goudie and Hooper, 2020 [4]; *Asbestopluma* Topsent, 1901 [5]; *Austrlocladia* Kelly and Vacelet, 2023 [6]; *Axoniderma* Ridley, 1886 [7]; *Bathytentacular* Ekins, Erpenbeck, Goudie and Hooper, 2020 [8]; *Cercicladia* Rios, Kelly and Vacelet, 2011 [9]; *Chondrocladia* Thomson, 1873 [10]; *Cladorhiza* Sars, 1872 [2]; *Euchelipluma* Topsent, 1909 [11]; *Koltunicladia* Hestetun, Vacelet, Boury-Esnault, Borchiellini, Kelly, Rios, Christobo and Rapp, 2016 [12]; *Lollipocladia* Vacelet [13], 2008; *Lycopodina* Lundbeck, 1905 [14]; *Nullarbora* Ekins, Erpenbeck, Goudie and Hooper, 2020 [8]; *Patriciacladia* Kelly and Vacelet, 2023 [6]. Members of the Cladorhizidae family are unique, characterized by their carnivorous mode of feeding and corresponding adaptations, such as a reduction in aquaferous systems and specialized spicules (types of chelae) [15]. Cladorhizidae, with few exceptions, are deep-sea sponges, and accordingly the number of species new to science still discovered within this family is high [16].

The morphology of carnivorous sponges is highly diverse and for some species poorly known because they are fragile and easily broken during sampling by, or removal from, the collecting gear, such as dredge or epibenthic sledge. The outer morphology includes feather-shaped, branched, pedunculate disc-shaped body forms, bearing radiating filaments and fan-shaped individuals [17,18].

The spicule skeleton of Cladorhizidae includes monaxonic megascleres, usually including mycalostyles, and a large variety of microscleres, generally chelae and derivates, to which sigmas, sigmancistras, micro-style and forceps may be added [19].

The East Scotia Ridge, where all sponges of this study were sampled, is located in the Southern Ocean and borders the Southern Atlantic. The Southern Ocean comprises about 34.8 million km^2 and is characterized by a very deep continental shelf with an average depth of 450 m and max. depths of 800–1000 m [20]. Conservative estimates suggest that a vast number of Antarctic benthic species are still undiscovered [21–23].

The main objective of this study is the taxonomic description of seven sponges collected in 2010 during the James Cook Cruise JC42, which was part of the CHESSO program [24], in which megafauna of Antarctica was sampled for later taxonomic investigations. In this study, we contribute to the taxonomic knowledge as basis for further zoogeographical biodiversity analyses of benthic fauna within the Southern Ocean. The sponges described in this study belong to the genera *Abyssocladia* and *Cladorhiza*, which are herein recorded for the first time within the ecosystem around hydrothermal vents in the Antarctic deep sea. The descriptions of new species contribute to and expand the current knowledge of the Cladorhizidae and consequently support future taxonomic identifications and descriptions of Antarctic deep-sea carnivorous sponges.

2. Materials and Methods

Seven sponge specimens were collected by the ROV *Isis* during dives at two sites of the East Scotia Ridge, JC42-E2 (56°05′19.2″ S, 30°19′07.7″ W, depth ~2600 m) and JC42-E9 (60°02′35.6″ S, 28°58′55.3″ W, depth ~2400 m) [24] (Figure 1). The specimens were fixed in either 96% ethanol or 4% formaldehyde in bottles or tubes. In some cases, they were preserved as part of the sediment remainder in the suction sampler vials and sorted later from the sediment under a stereomicroscope [25,26]. The specimens documented herein are deposited and cataloged in the Porifera collection of Senckenberg Research Institute and Nature Museum in Frankfurt am Main and can be found online in the electronic database SESAM.

For taxonomic investigations, dissociated spicules preparations as well as semi-thin histological preparations were prepared following the procedure recommended by Boury-Esnault and Rutzler [27] with some adjustments, as we use a block-heater to facilitate the preparation process and minimize the security risks, as siliceous sponges are treated with nitric acid to dissolve the soft body and isolate spicules [28]. Epoxy resin was used to produce stable thin-slice preparations, after that, the tissue samples were embedded in plastic molds with epoxy resin, dried and then dissected by hand-cutting or using a diamond blade cutting machine.

From each sponge, the spicule inventory was studied, identified and documented by using a light microscope (Leica DM750) and an SEM (REM CS24, CamScan). Species identification was made according to the standard Porifera morphological taxonomy procedures. Measurements are given as minimum–mean–maximum. The minimum number of measurements of each spicule type is n = 30. Total number of measurements is in brackets. Simultaneously with our morphological studies, molecular analysis was performed on subsamples from the same specimens of *Cladorhiza* n. sp., and a phylogenetic tree was published by Georgiva et al. [29]. We compared this with our morphological results to obtain an independent confirmation of the new species status and its phylogenetic affinities within the genus *Cladorhiza.*

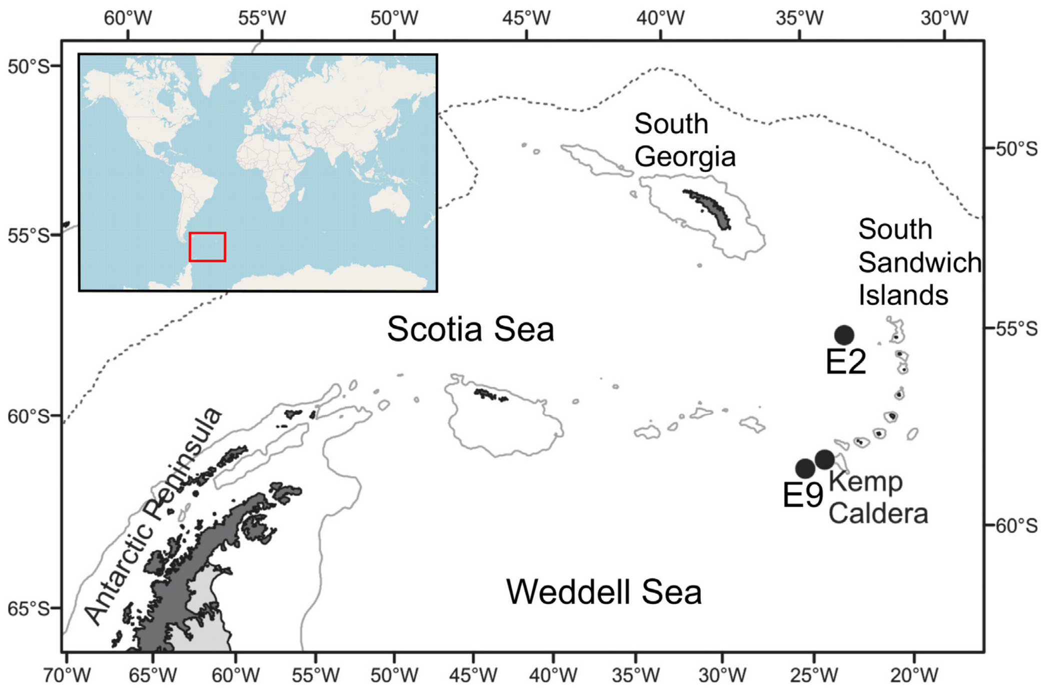

Figure 1. Location of the East Scotia Ridge hydrothermal vents in the Southern Ocean and the three sites Kemp Caldera, E2 and E9 (black dots) surveyed during the CHESSO Cruise JC 42 in 2010 [25]. E2 and E9 are the sites where the ROV *Isis* collected the studied sponges during the expedition [25]. The main map originated from Arango and Linse [24], whose study describes three new species of *Sericosura*, also collected on the RRS James Cook Cruise JC 42 [24]. The overview map in the upper corner, whose red frame broadly indicates the research area, was created using OpenStreetMap.

3. Results

The seven specimens collected were identified as three species of the family Cladorhizidae. One species belongs to the genera *Abyssocladia* Lévi, 1964 (three specimens) [3] and two species to *Cladorhiza* Sars, 1872 (four specimens, of which one was investigated but not included into the type series, as its species status still needs further morphological and molecular confirmation, beyond the scope of this paper) [2] (Tables 1 and S1). All three species are new to science.

Table 1. Identified species new to science and the corresponding number of specimens with the respective SMF numbers for the holotypes (Holo) and paratypes (Para).

Genus	Species	Specimens
Abyssocladia	*Abyssocladia truespacemeni* *Abyssocladia hendrixi*	1 (Holo: SMF-12213) 2 (Holo: SMF-12214; Para: SMF-12215)
Cladorhiza	*Cladorhiza elsaae*	4 (Holo: SMF-12210; Para: SMF-12211, -12212; Additional mat.: SMF-1344)

Systematics

Phylum: Porifera Grant, 1836 [30];
Class: Demospongiae Sollas, 1885 [31];
Subclass: Heteroscleromorpha Cárdenas, Perez and Boury-Esnault, 2012 [32];
Order: Poecilosclerida Topsent, 1928 [33];
Family: Cladorhizidae Dendy, 1922 [1];
Synonymy: Cladorhizeae Dendy, 1922: 58 [1]; Cladorhizidae de Laubenfels, 1936a [34]: 122 [35].

Diagnosis: Sponges are commonly small, symmetrical, mostly in deep water, with diagonal, radiating supporting processes and basal root adaptations. The axial skeleton is composed of monactinal and/or diactinal megascleres, from which radiating extra-axial tracts diverge to the ectosome. Microscleres include isochelae, anisochelae, sigmas, forceps, or microstyles and -subtylostyles. Considerable reduction to a complete loss of choanocyte layer and aquaferous system is known for some species, being associated with their adaptation to carnivory, preying on relatively large food items [36].
Genus: Abyssocladia Lévi,1964 [3].
Synonymy: *Abyssocladia Lévi*, 1964: 78 [3]. Non-*Phelloderma* Ridley and Dendy, 1886 [7,36]. Type species *Abyssocladia bruuni* Lévi, 1964 [3]: 78 (by monotype) [36].
Diagnosis: Cladorhizidae is most commonly pedunculate, carrying a disciform or flabelliform body with a radial architecture. In other cases, they are pinnate or branching. Microscleres are a combination of abyssochelae, cleistochelae, arcuate chelae and/or sigmancistras, but not placochelae [37].
Species: ***Abyssocladia truespacemeni***
Material examined

The material consists of a single specimen sampled from the area E9 in the East Scotia Ridge (Figure 1). Holotype SMF-12213 was sampled at station JC42-4-15, 2402 m. Longitude: −60.04303333°. Latitude: −29.98125°, 04.02.10.

Etymology

Named after the band True Spacemen, which is rooted in Frankfurt, the city where the taxonomic work for the description of the species was carried out.

Description

Shape and size

The sponge with a total length of 17.5 mm consists of a 12 mm long smooth, thin and flexible peduncle that bears a disc-shaped body (Figure 2a,b). The peduncle is most likely made of mycalostyles, it is highly flexible and most likely broken, as it is devoid of a fixation base. The body is circular and flattened with a diameter of 5.5 mm. There are eggs on the underside of the body, indicating that the sponge is adult (Figure 2b). Furthermore, the highly fragile body possesses several types of microscleres and radiating filaments. The short, blunt filaments are 2 mm in length. Due to the small size of the sponge and the fact that there was only one specimen, thin-section preparations for more detailed skeletal examination were not possible. An aperture or an aquiferous system is not found, which is typical for cladorhizid deep-sea sponges. The color in ethanol is white to light yellowish.

Spicules

Megascleres:

(1) Mycalostyles are monaxonal spicules with a short pointed and slightly ovoid end. In addition, they are straight or slightly curved and more or less fusiform (the larger ones are barely fusiform) (Figure 2c). Their length is 750.0–1328.3–1600.0 μm (30) with a diameter of 7.5–20.8–27.5 μm.

Microscleres: Two types of arcuate isochelae, oxeas and two types of sigmancistras.

(1) Arcuate, tridentate isochelae I have a lateral alae linked to the shaft (Figure 2e). The front alae is exposed and flattened at the end with a slight curvature, 21.3–33.1–42.0 × 11.3 –15.8–29.0 μm. The very similar ends of the chelae are 25.0–32.5–42.5 μm in diameter. Overall, the size of the chelae shows great variability between 60.0 and 87.8 and 113.8 μm, while the curved shaft is 5.0–7.7–10.0 μm in diameter (Table S2).

(2) Arcuate isochelae II have the same shape as (1) but are significantly smaller (Figure 2h). In addition, the front alae has a slight curvature outwards, not inwards. Arcuate isochelae II are 27.5–32.4–40.0 μm in length and 1.0–1.6–2.5 μm in shaft diameter (Table S2).

(3) Oxeas are fusiform and straight or slightly curved (Figure 2d). They show some morphological variation, where it is often possible to see that one end is more curved than the other. Both ends are pointed. Oxeas are 65.0–109.0–172.5 × 2.5–4.1–5.0 μm and are therefore relatively large for microscleres (Table S2).

(4) Sigmancistras I are slightly modified sigmas [27]. They are abundant, curved and have a slightly contorted shaft (Figure 2f). Their length is 17.0–19.8–22.0 µm and their diameter is 1.2–1.8–2.0 µm (Table S2).

(5) Sigmancistras II possesses a slightly enlarged shaft with two pointed, hooked ends (Figure 2g). They are bigger than Sigmancistras I. Their length is 27.0–29.2–32.0 µm, while the diameter is 1.7–2.0–3.0 µm (Table S2).

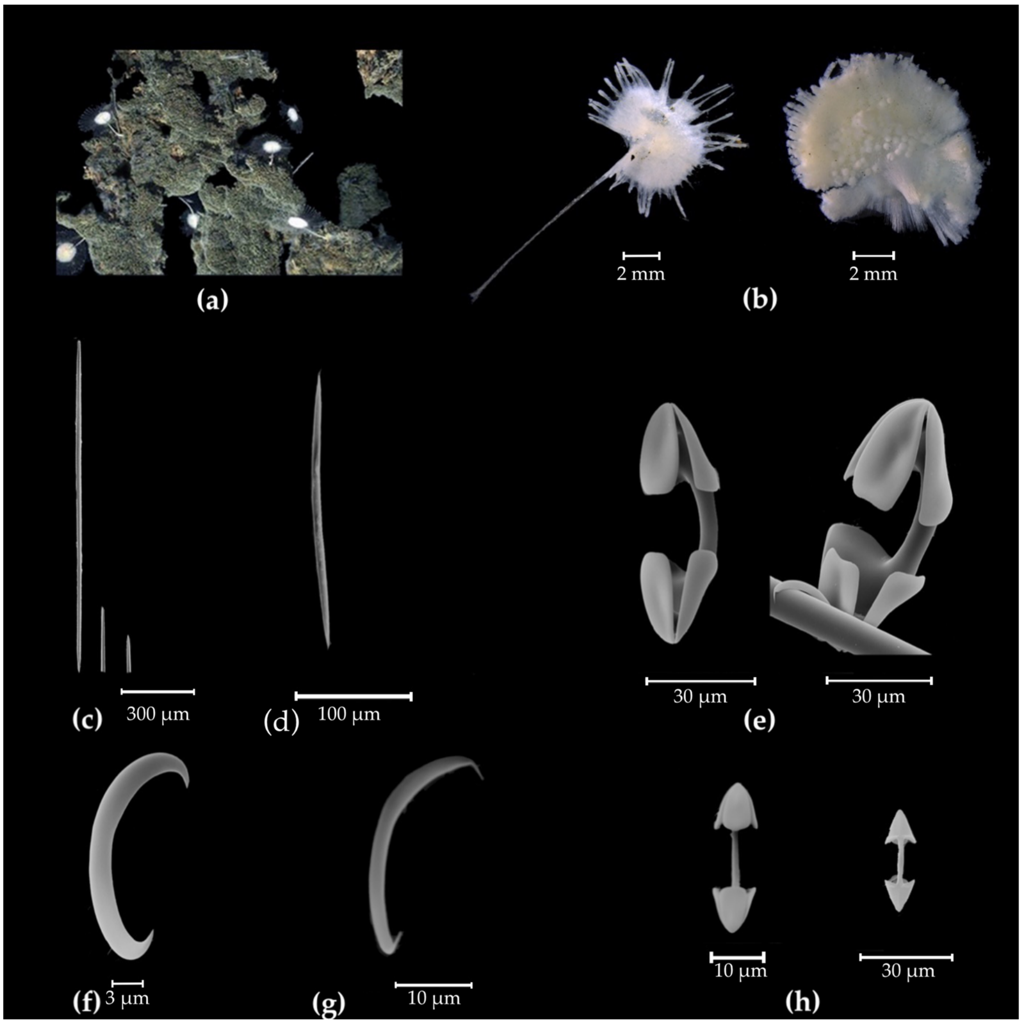

Figure 2. *Abyssocladia truespacemeni*. (**a**) In situ picture of specimen SMF-12213. (**b**) Holotype with a disciform body, the right picture shows eggs on the underside of the body. (**c**) Mycalostyle. (**d**) Oxea. (**e**) Isochela I. (**f**) Sigmancistra I. (**g**) Sigmancistra II. (**h**) Isochela II, front and back view.

Remarks

The possession of arcuate isochelae and sigmancistras as well as the pedunculate, disciform body attribute the present species to the genus *Abyssocladia*. The currently known species of *Abyssocladia* can generally be divided into two categories: on the one hand, sponges with pedunculate, disciform bodies, and on the other hand, sponges with feather-like forms [38]. *Abyssocladia truespacemeni* can be included in the first category. Unlike *A. oxeata*, the new species possesses smaller and bigger sigmancistras instead of sigmas that are 35 µm long [39]. *A. inflata* has sigmancistras, which are the same size as sigmancistras I of *Abyssocladia truespacemeni* (Table S2). Sigmancistras II and isochelae II, however, are absent in *A. inflata*. Furthermore, isochelae I of *Abyssocladia truespacemeni* are smaller and have a different shape than isochelae of *A. inflata* [39–41].

In addition to the spiculation, the new species can be distinguished from the other species by their distribution. So far, no *Abyssocladia* with pedunculate, disciform bodies from the Southern Ocean are known. The only other species of this from the Southern Ocean are *Abyssocladia leverhulmei* Godwin, Berman, Downey and Hendry, 2017 [42], and *Abyssocladia antarctica* Buskowiak and Janussen, 2021 [28], which are both dichotomously branching sponges which possess abyssochelae as microscleres. *Abyssocladia diegoramireszensis* Lopes, Bravo and Hajdu, 2011 [43] and *Abyssocladia umbellata* Lopes, Bravo and Hajdu, 2011 [43] are two species from South Chile with a branching, feather-like habitus. Thus, they also differ from *Abyssocladia truespacemeni* [42,43].

Species: ***Abyssocladia hendrixii***

Material examined

The material consists of two specimens sampled from the area E9 in the East Scotia Ridge. Holotype SMF-12214 was sampled at station JC42-4-7, 2402 m. Longitude: −60.04281667°. Latitude: −29.9822667°, 30.01.10. Paratype SMF-12215 was sampled at station JC42-4-15, 2402 m. Longitude: −60.04303333°. Latitude: −29.98125°, 04.02.10.

Etymology

Named after the famous guitarist, songwriter and singer Jimi Hendrix, whose music was a faithful companion throughout the time of the taxonomic work.

Description

Shape and Size

Abyssocladia hendrixii is a 14 mm small sponge, with a pedunculate, disciform body in the genus *Abyssocladia* (Figure 3a). The 9 × 2 mm thin peduncle bears a disciform body, which consists of dense spicular radiating fascicles. Both holotype and paratype are devoid of a fixation base. The fascicles, 4 mm in length, are firmly attached and radiate from the same center. Some of the fascicles are broken or possibly retracted in both specimens (Figure 3a). Because of the small size and the small number of specimens, semithin histological preparations for a detailed skeletal examination from different parts of the sponge body were not possible. The consistency of the specimens is very fragile after preservation. Nevertheless, according to the diagnosis for the genus and due to its high flexibility, it can be assumed that the peduncle consists of styles. An aperture or an aquiferous system is not visible. The color ranges from nearly transparent to white or light yellowish. The holotype possesses orange remnants on the fascicles that could have come from the substrate.

Spicules

Abyssocladia hendrixii is characterized by a particularly low variety of spicules.

Megascleres:

(1) Mycalostyles have a short, pointed and blunted end, which can be straight or slightly curved, and they are more or less uniform. (Figure 3c). Their length is 700.0–1334.5–1600.0 µm with a diameter of 12.5–23.0–30.0 µm, which shows great variability in size (Table S3).

Microscleres: Arcuate isochelae, two types of sigmancistras.

(1) Arcuate isochelae have a lateral alae linked to the shaft (Figure 3b). The front alae is exposed and ovoid, 26.3–31.9–38.0 µm long and 12.0–15.7–20.0 µm in diameter. The similar ends of the chelae are 25.0–32.3–37.5 µm in diameter. The isochelae are in total 62.5–81.4–91.25 µm long. The curved shaft has a diameter of 5.5–7.5–9.5 µm (Table S3).

(2) Sigmancistras I are curved and have a slightly contorted shaft with two pointed, hooked ends (Figure 3d). Their length is 19.0–21.4–24.0 µm, while their diameter is 1.9–1.3–2.7 µm (Table S3).

(3) Sigmancistras II has an enlarged shaft with two pointed, hooked ends (Figure 3e). Sometimes the pointed ends are not easy to recognize. With a length of 22.0–30.8–34.5 µm and a diameter of 2.0–2.7–4.0 µm, Sigmancistras II is bigger than (2) (Table S3).

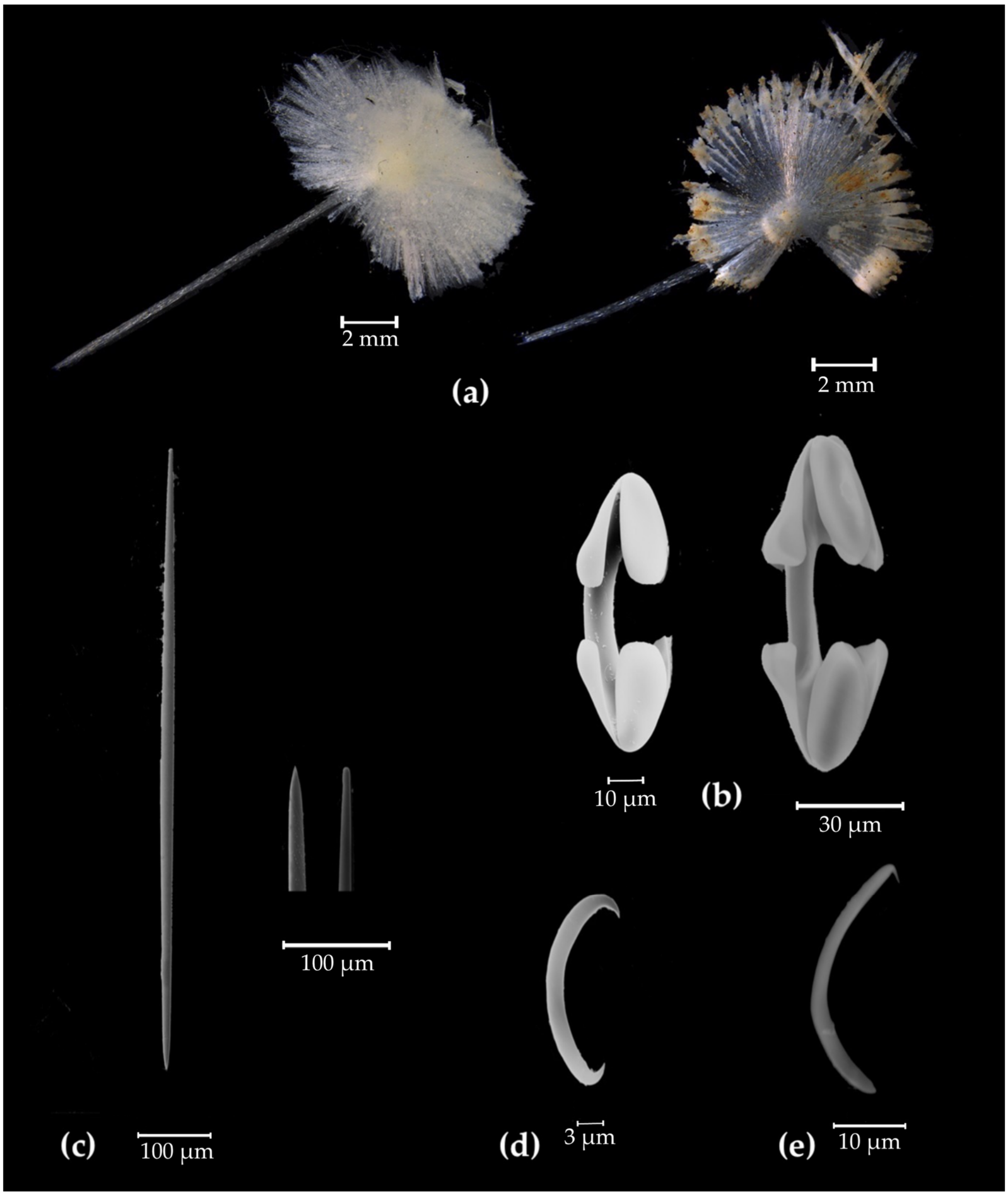

Figure 3. *Abyssocladia hendrixii*. (**a**) Left picture shows paratype SMF-12215, right picture shows holotype SMF-12214. (**b**) Arcuate isochelae. (**c**) Mycalostyle. (**d**) Sigmancistra I. (**e**) Sigmancistra II.

Remarks

Abyssocladia hendrixii and *Abyssocladia truespacemeni* are the only known species with a pedunculate, disciform body of the Southern Ocean. *Abyssocladia hendrixii* does not possess microxeas and a tiny type of isochelae. *Abyssocladia dominalba* has a very similar body shape to the new species. However, this species (atypical for *Abyssocladia*) has small anisochelae which are not present in the new species [40]. *Abyssocladia bruuni* is also similar to *Abyssocladia hendrixii*. But it does not possess Sigmancistras I [3]. Also, the body shape differs from the new species similar to *Abyssocladia truespacemeni* [3]. Nevertheless, both species seem to be closely related.

Genus: *Cladorhiza* Sars, 1872 [2].

Synonymy: *Cladorhiza* Sars, 1872 [2]: 65. [*Trochoderma*] Ridley and Dendy, 1886 [7]: 344 (preocc. By *Trochoderma* Théel, 1877, Echinodermata). *Axoniderma* Ridley and Dendy, 1887 [44]: 96 (replacement name for *Trochoderma* Ridley and Dendy). *Exaxinata* de Laubenfels, 1936a [34]: 122. Raoa de Laubenfels, 1936a: 123 [34,45].

Type species: *Cladorhiza abyssicola* Sars, 1872 [2] (by monotype) [45].

Diagnosis: Cladorhizidae with anchorate or unguiferate anisochelae [45].
Species: ***Cladorhiza elsaae***
Material examined

The material consists of a total of four specimens, all sampled from the same area E2 in the East Scotia Ridge, but during two dives. SMF-12210 (holotype), SMF-12211 (paratype 1) and SMF-12212 (paratype 2) were sampled at dive station JC42-3-15, 2642 m. Longitude: −56.08936667°. Latitude: −30.3172167°, 23.01.10. SMF-12212 (paratype 2) was sampled at dive station JC42-3-17, 2641 m. Longitude: −56.08963333°. Latitude: −30.31775°, 24.01.10. Additional material: SMF-1344 from dive station JC42-3-15 (same coordinates and depth as holotype); this specimen was not included in the type series.

Etymology

Named after the first author's sister, Elsa, who supported him during the study.

Description

Shape and size

The species has an arbuscular, erect habitus (Figure 4a). Examined specimens are up to 16 cm tall with a main stem carrying many slightly thinner side branches, which are 3–5 mm wide. The main stem is 5–9 mm wide and thicker towards the base. All branches are oriented quite irregularly and slightly upwards in one plane from the main stem (Figure 4a). The branches consist of a hard, central core covered in a looser surface layer and are often also branched. The surface layer carries filaments, which project in all directions. They are numerous on the branches and on the main stem, except for its lower and middle parts. Filaments are 2 to 4 mm long. The lower, bare part of the main stem ends in a plate-like basal structure that connects the species with the substrate. The root system which usually anchors cladorhizid sponges in the substrate is missing in all specimens. An aperture or aquiferous system is not found. The soft surface layer tends to disassociate from the hard, central core after storage in ethanol. The color in ethanol varies from white to beige or reddish.

Spicules

The skeleton of the solid stem core consists of tightly connected bundles of mycalostyle spicules. It is surrounded by a slight, soft outer layer containing scattered mycalostyles and microscleres, like anisochelae and sigmancistras, while their free ends are mostly pointed outwards. This allows the catching of small prey animals.

Megascleres:

(1) Mycalostyles I are the largest megascleres in *Cladorhiza elsaae.* They are monaxons with a pointed and a blunted end. In addition, they are straight or slightly curved and more or less fusiform (Figure 4e). Their length is 520.0–751.7–950.0 µm with a diameter of 10.0–19.5–30.5 µm (Table S4).

(2) Mycalostyles II are smaller than Mycalostyles I but with the same character. All mycalostyles with a diameter of less than 10 µm belong to this category. The length is 275.0–583.3–700.0 µm and the diameter is 1.2–5.2–9.0 µm (Table S4). Also, this category varies in size.

Microscleres: Anisochelae, sigmas, and sigmancistras of two categories.

(1) Anchorage anisochelae are numerous, with a curved shaft, five teeth with a sharp point in each end, and fimbriae in the upper end (Figure 4b). The shaft has a diameter of 2.3–3.2–4.0 µm. The large teeth of the upper end are 7.0–8.6–11.0 µm (30 measurements) in length, while the small teeth of the lower end, 3.0–4.2–5.0 µm in diameter, are 2.9–3.4–4.0 µm (30 measurements) in length. With a diameter of 9.0–10.7–14.0 µm, the upper end is about a third of the total length of the anisochela, which is 31.0–34.1–37.0 µm (Table S4).

(2) Sigmas are common, solid, not contorted, and have equal ends in the same plane (Figure 4c). The length is 140.0–148.7–160.0 µm and the diameter is 5.0–9.2–12.5 µm (Table S4).

(3) Sigmancistras I have ends in different planes. While the upper end is not as strongly bent as in the sigmas, the lower end is more bent. The lower end can be bent in different directions so that sometimes an S-shape occurs (Figure 4f). In addition, both ends are more

bent like a hook than in sigmas and are sharply pointed. The size of the sigmancistras I is 49.0–58.5–72.5 µm, while the diameter is 1.5–2.4–3.9 µm (Table S4).

(4) Sigmancistras II have the same characteristics as sigmancistras I. However, they are stockier in shape and have larger diameters (Figure 4g). Moreover, sigmancistras II are more common than sigmancistras I. Their length is 50.0–55.2–67.0 µm and the diameter is 2.9–3.5–4.2 µm (Table S4).

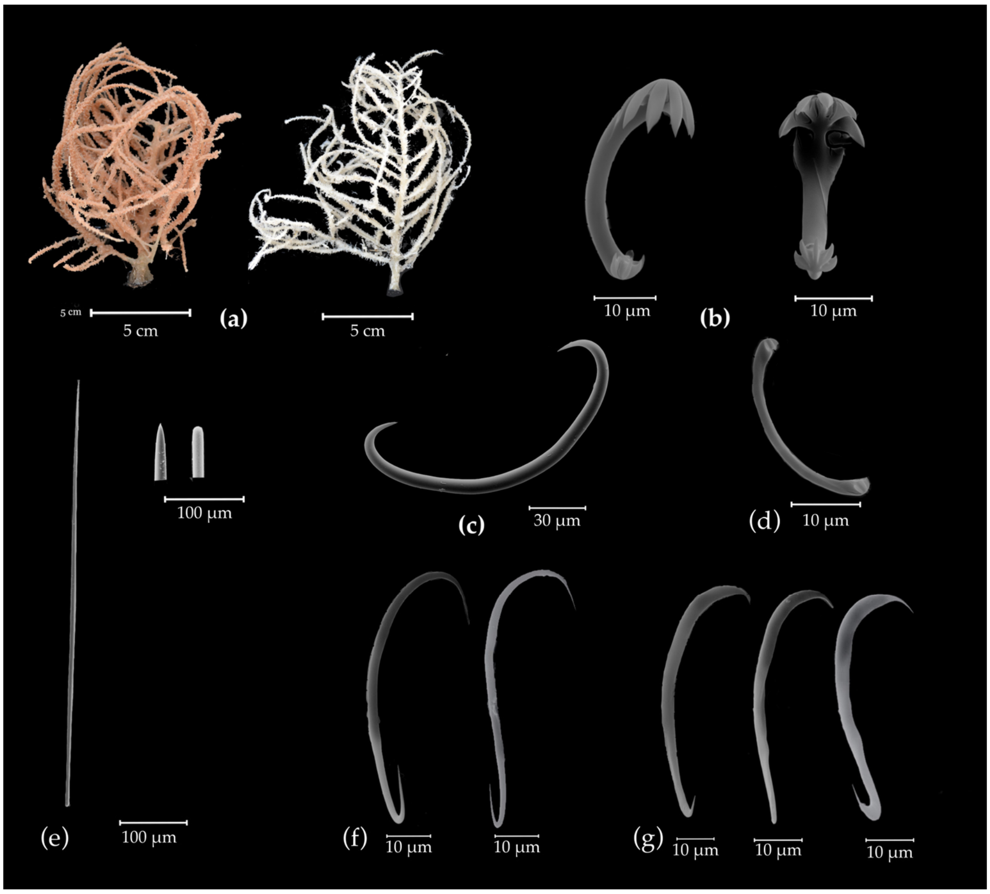

Figure 4. *Cladorhiza elsaae*. (**a**) The white holotype SMF-12210-a and the reddish paratype 1 SMF-12211. (**b**) Anchorate anisochelae front and side view. (**c**) Sigma. (**d**) Developing anisochela side view. (**e**) Mycalostyle and enlargement of ends. (**f**) Sigmancistras I. (**g**) Sigmancistras II.

Remarks

Cladorhiza elsaae usually shows less pronounced swellings at the ends. This leads to a more solid appearance of *Cladorhiza elsaae,* which is also reflected in the spiculation. All similar types of spicules are distinctly smaller in *C. abyssicola*. Consequently, *Cladorhiza elsaae* not only possesses bigger anisochelae and sigmas than *C. abyssicola* but also *C. gelida* [19]. *C. tenuisigma* also differs by its swellings at the ends of its branches and its much smaller sigmas (31.4–41.7–53.6 µm) [19]. *C. corticocancellata* possesses a lacunose, partly coalesced surface and small sigmas with sharply pointed ends, which are both absent in *Cladorhiza elsaae* [19]. While *C. iniquidentata* has anisochelae with seven teeth at the upper end, *Cladorhiza elsaae* has anisochelae with five teeth at its upper end. Although *C. oxalate* is the only other closely related species that shows the same color variability from white to reddish; it has a different type of megascleres (oxeas), which does not exist in *Cladorhiza elsaae* [19]. Sigmas are also the exclusion criterion for the very similar species *C. corallophila*. In this connection, sigmas have one bifurcate end [46]. *Cladorhiza elsaae* differs from both *C. gelida* and *C. methanophila* as well as the other closely related species by its two existing types of sigmancistras. Although the types exist in some of the species, both are never represented simultaneously [19,47]. In addition, this species is by far the southernmost occurring arbuscular species of *Cladorhiza* and differs strongly in its location from the known distribution of the other species.

4. Discussion

The taxonomic study of seven specimens resulted in the discovery of three Antarctic sponge species new to science. In all specimens, no aperture or aquiferous system, nor choanocyte chambers in histological sections, is visible, as is usual for cladorhizid sponges. Concerning the skeleton, sigmancistras are present in all specimens. Sigmancistras are slightly modified, hook-like sigmas that are probably used to catch small prey animals [27]. These attributes confirm that all examined sponges belong to the family Cladorhizidae. These results reinforce the prediction by Göcke and Janussen [48,49] that a large number of new species is still to be discovered in Antarctica. Furthermore, the results also confirm the studies by Janussen and Downey and by Goodwin et al. [42,50], which emphasize the taxonomic richness particularly of the family Cladorhizidae in the Southern Ocean. Carnivorous sponges are found in all deep-water regions of the Southern Ocean.

All stations, where the specimens studied herein were collected, are located at bathyal depths (>1000 m). Since all our new species are carnivorous sponges, these records increase the number of Cladorhizidae species now found in bathyal depths. In terms of sponges, the bathyal zone is assumed to be the most species-rich of all the Antarctic depth regions [42,48,49]. Our newly described species support this thesis.

The sponges of this study were found in the vicinity of hydrothermal vents at the East Scotia Ridge. In many cases, hydrothermal animal communities are tied to microbes that can use geochemical energy to make organic compounds. The symbiosis with microbes enables living in these extreme locations. In terms of the environment, the species of this study were likely to have similar symbionts. The different colors of *Cladorhiza elsaae* could also indicate different types of microsymbionts, as it is already known from other sponges [51]. To determine which symbionts occur in these sponges, new specimens and further investigations are needed. The importance of specific habitat requirements for hydrothermal vent fauna could be a reason for the high number of endemic species in these areas. Thus, *Cladorhiza elssae*, *Abyssocladia truespacemeni* and *Abyssocladia hendrixii* are also potentially endemic. Although demosponges were found to have a general level of species endemism at 38%, in the Southern Ocean, 68% of known Southern Ocean carnivorous species are potentially endemic. However, many cladorhizid sponges in Antarctic marine collections around the world are still unidentified [42], so we might also face pseudo-endemism due to the lack of new species descriptions and the general lack of taxonomic expertise for these sponges.

Also, it cannot be ruled out that the newly described species may also be found in other regions of the SO and/or in other oceans. In that case, they may be circumpolar (as 35% of all Antarctic sponges) or even longitudinally distributed. Deep-sea currents, like parts of the ACC or the North Atlantic Deep Water (NADW), coastal gyres, stable environmental conditions, lecithotrophic larvae or floating propagules are the most important factors for a wide longitudinal dispersal of deep-sea species through abyssal basins and plains [50,52]. In addition to this study's morphological analysis, Georgieva et al. (2020) [29] have already analyzed molecular data for the 28S, COI and ALG11 fragments of *Cladorhiza elsaae* (Figure 5). These molecular data confirm the result of our taxonomic analysis for the holotype SMF12210: *Cladorhiza elsaae* is a new species (Figure 5). The other specimens, SMF12210-a and PS119-46, which were also taken from the E2 site but still need to be morphologically analyzed, according to the molecular analysis, also belong to the new species *Cladorhiza elsaae*. According to the molecular investigations by Gergieva et al. [29], paratype 1 (SMF12211) is supposed to be another new *Cladorhiza* species. However, our taxonomic study cannot confirm this hypothesis, as the specimens do not differ morphologically (apart from the color variation, which may be due to different symbionts), in any significant way to justify two different species. Further molecular investigations must provide further clarity if specimen SMF12211 may be another new, cryptic species of *Clado*rhiza.

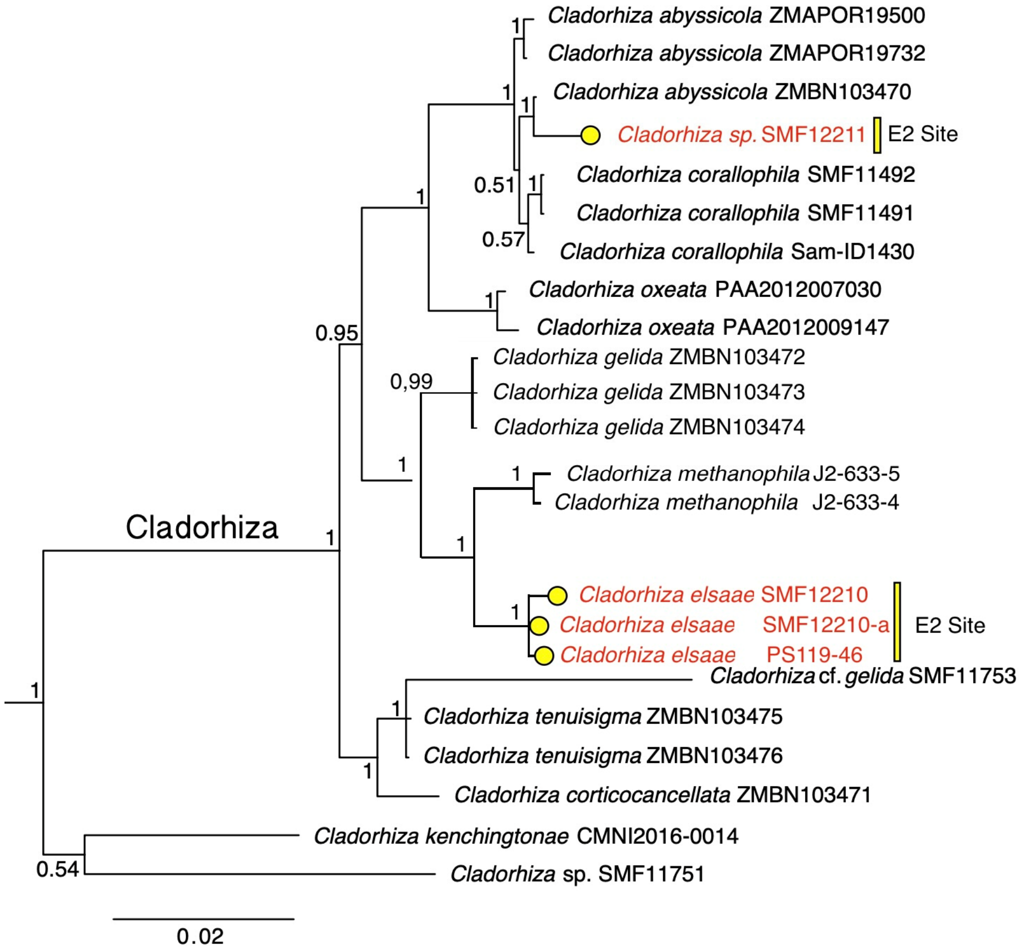

Figure 5. Bayesian phylogenetic analyses of *Cladorhiza* by Georgieva et al. [29] based on a concatenated dataset of COI, 28S and ALG11 [29] and modified with the new species *Cladorhiza elsaae*. The yellow marker and the red font indicate the samples taken from the E2 site. The specimens SMF 12210 (holotype) and SMF12211 (paratype) are particularly relevant and were investigated for this study.

The molecular studies underline the hypothesis that *Cladorhiza elsaae* is closely related to other arbuscular species (Figure 5). There seems to be a potential species complex within the genus *Cladorhiza*, in which the species are not only morphologically but also genetically very similar and possibly descended from a common ancestor. Longitudinal distribution and subsequent specialization in different environments could have led to this kind of species complex. This species complex includes species that are widely distributed from the Arctic to the Antarctica, although so far, most species are found in the boreal North Atlantic and Arctic waters [19]. For the two *Abyssocladia* species, no molecular data have been prepared. In total, 14 *Abyssocladia* species, including A. *truespacemeni*, have been found only once. This rarity could be based on both the combined effects of sparse sampling effort in the deep sea and the low densities at which carnivorous sponges occur [42]. As the new species described herein are very small in size, they also may easily be overlooked when sorting, e. g., of catches from the Epibenthic Sledge (EBS) where such tiny specimens can be expected and are actually found. Very possibly, further specimens, including new species of Cladorhizidae, are still to be discovered in the remaining materials from different deep-sea expeditions worldwide.

5. Conclusions

The results of this study reveal three new species, highlighting the taxonomic richness of the sponge family Cladorhizidae, the second most species-rich Demospongiae family in the Southern Ocean [42,50]. Although deep-sea expeditions of different research programs, such as ANDEEP and SYSTCO (Antarctic benthic deep-sea biodiversity, Pelagic–benthic system coupling), have led to breakthroughs in our understanding of Southern Ocean sponges, the results of our new study support the assumption of Göcke and Janussen [48] that a large number of carnivorous sponge species is still undiscovered in the Antarctic deep sea. This study emphasizes the continued need for future expeditions into under-sampled Antarctic regions, in order to bring more light into the species-rich world of the Cladorhizidae and other deep-sea sponge families [42,48,49]. Furthermore, in the process of sorting and the identification of catches by various sampling gears, particularly small unspectacular sponge species may remain undiscovered due to a lack of taxonomic expertise. In this context, the results presented herein may prove helpful for future identifications of Antarctic deep-sea carnivorous sponges.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/jmse12040612/s1, Table S1: Sampling data of RRS James Cook cruise JC42, including names of the species, sample ID, sample depths [m] and coordinates, used gears and fixation types; Table S2: *Abyssocladia truespacemeni* and sizes of its different types of spicules compared to other species of *Abyssocladia* with a similar shape. Minimum, mean and numbers of measured spicules are shown (in brackets). For some of the species used for comparison, only the size ranges of different spicules are given. If no values are given, the type of spicule is absent; Table S3: Spicule sizes of the holotype and the paratype of *Abyssocladia hendrixii*. Minimum, mean, and numbers of measured spicules are shown (in brackets). Comparison to spicule sizes of *A. dominalba* and *A. bruuni*; size ranges are given. If no values are given, the type of spicule is absent; Table S4: Spicule sizes of *Cladorhiza elsaae*. Minimum, mean, and numbers of measured spicules are shown (in brackets). For comparison, measured spicules of *Cladorhiza abyssicola* and *Cladorhiza gelida* are also shown.

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