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First Atlantic record of the green alga *Parvocaulis exiguus* from St. Eustatius, Dutch Caribbean

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Abstract The Polyphysaceae is a well-studied family of green algae occurring in tropical and warm-temperate regions around the world. One of its species, *Parvocaulis exiguus* (Solms-Laubach) S. Berger et al. (Phycologia 42:506–561, 2003), has previously been reported from both the Indian and the Pacific Oceans. This report presents the first record of *Parvocaulis exiguus* from the Atlantic Ocean. It was collected at 18 m depth from rocky substrata surrounded by seagrass off the Dutch Windward Caribbean island St. Eustatius. Owing to its small size and close resemblance to co-occurring species, it is possible that this species has been previously overlooked in the Atlantic. Although Polyphysaceae have been intensively studied in the Caribbean and other Atlantic regions, this is not the case for subtidal algal vegetation on St. Eustatius. *Parvocaulis exiguus* could have been present for a longer time around St. Eustatius or it could have been introduced with shipping. Future investigations may show if *Parvocaulis exiguus* will be observed in additional locations in the Caribbean.

Keywords Marine macroalgae · Benthic · Rocky substrate · Subtidal · Polyphysaceae

Introduction

Green algae of the family Polyphysaceae (formerly Acetabulariaceae) are highly differentiated, uninucleate single cells that belong to the genera *Acetabularia* J.V. Lamouroux (including *Acicularia* d'Archiac), *Chalmasia* Solms-Laubach, *Halicoryne* Harvey, and *Parvocaulis* S. Berger, U. Fettweiss, S. Gleissberg, L.B. Liddle, U. Richter, H. Sawitzky & G.C. Zuccarello (according to the system in Berger et al. 2003; Zechman 2003 uses a slightly different system). The genus *Parvocaulis* contains six species, all of which have the same basic thallus construction consisting of a rhizoid system, a stalk, and whorls of branched hairs (during vegetative growth) or a cap (prior to reproduction) (Berger and Kaefer 1992; Berger et al. 2003). The rhizoid region at the base of the alga is formed by what was originally the zygote. It functions as a holdfast and contains the alga's only nucleus. The stalk forms whorls of branched hairs during vegetative growth. They fall off when new whorls are formed, leaving scars behind on the stalk. In the reproductive phase, the stalk produces a whorl of gametophores, which together form a cap. The cap consists of cap rays and special basal parts (coronal chambers) that form the corona superior. Cap rays can be free or joined by calcification and the coronal segments usually have branches (protuberances). The length of the main axis (which can be corrugated or not), diameter of the cap, number of cap rays, shape of cap rays, appearance or absence of corona inferior, and number of protuberances or hair scars per corona superior segment are species-specific characters (Berger and Kaefer 1992; Dumais and Harrison 2000). A key to the species was supplied by Berger and Kaefer (1992).

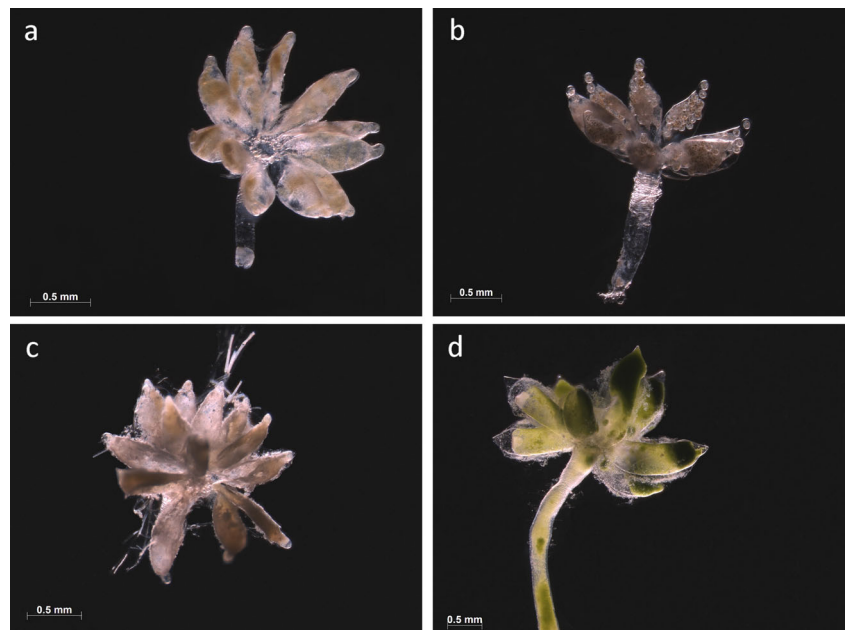
One of the six *Parvocaulis* species is *Parvocaulis exiguus* (Solms-Laubach) S. Berger et al. 2003, which has a complex synonymy. It was described by Solms-Laubach (1895) as *Acetabularia exigua* from Indonesia with a disk formed of

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Fig. 1 **a–c** Photographs of three specimens of *Parvocaulis exiguus* from St. Eustatius; **d** reference material (culture from the UTEX Culture Collection of Algae)



6–10 upwardly curved apiculate cucumiform rays. Later, Arnoldi (1912) described *Acetabularia pusilla* Howe forma *solmsii* from Indonesia with 8–9 rays and two hair scars on each corona superior segment. Egerod (1952) described *Acetabularia tsengiana* from Hawaii, with 6–14 free, pyriform, somewhat mamillate rays that form a crowded irregular cluster and never a flat disk on top of the rugose stalk. Berger and Kaefer (1992) considered *Acetabularia tsengiana* as well as *Acetabularia pusilla* Howe forma *solmsii* as synonyms of their *Polyphysa exigua* (Solms-Laubach) comb. nov.

Species belonging to the genus *Parvocaulis* are recorded from localities around the world in tropical or warm-temperate regions of the Atlantic Ocean, the Indian Ocean, and the Pacific Ocean. *Parvocaulis exiguus* has been recorded at several locations in the Indian Ocean and the Pacific Ocean, but no observations in the Atlantic Ocean have previously been documented (Berger and Kaefer 1992). We hereby report the first record of *Parvocaulis exiguus* in the Atlantic Ocean, from a coral reef off the island of St. Eustatius in the Caribbean.

Materials and methods

Three specimens of *Parvocaulis exiguus* (Fig. 1a–c) were collected at 18 m depth by means of scuba diving at Blue Bead Hole, a dive site at St. Eustatius (17°28'31.5" N, 62°59'33.6" W). All three specimens were found on a single rock in a sandy seagrass bed (*Halophila stipulacea* (Forsskål) Ascherson) with patches of coral and rubble. Because of their small size, they were preserved in 6 % formalin for morphological studies, which made them unsuitable for molecular analyses. The species were initially identified using Berger

and Kaefer (1992). Identity was confirmed by the use of reference material from cultures of the UTEX Culture Collection of Algae (strain LB 2706) (Fig. 1d). Photographs were made with the Zeiss AxioCam.

Results and discussion

In total, seven species of Polyphysaceae were found around St. Eustatius: *Acetabularia caliculus*, *Acetabularia crenulata*, *Acetabularia schenckii*, *Parvocaulis parvulus*, *Parvocaulis exiguus*, *Parvocaulis polyphysoides*, and *Parvocaulis pusillus*. *Acetabularia* species can be easily recognized by the presence of both a corona superior and a corona inferior, which are segments on the underside of the cap (Berger and Kaefer 1992). Of the existent *Parvocaulis* species, only two have cap rays that are distinctly tapered, viz., *Parvocaulis exiguus* and *Parvocaulis polyphysoides*. These two species can be rather easily distinguished from each other because the latter has 6–9 (1–13) protuberances per corona superior segment,

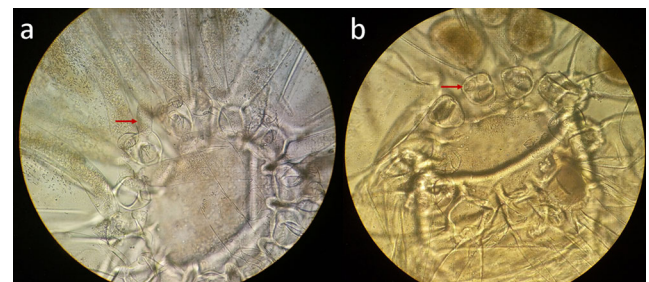


Fig. 2 Corona superior of the collected *Parvocaulis exiguus* specimens. **a** Specimen shown in Fig. 1a, showing the protuberances (red arrow). **b** Specimen shown in Fig. 1b, showing the hair scars (red arrow)

whereas *Parvocaulis exiguus* has only 2–3 of such protuberances (Fig. 2). Furthermore, the specimens from St. Eustatius displayed characters provided by Solms-Laubach (1895), Arnoldi (1912), Egerod (1952), Berger and Kaefer (1992), Berger et al. (2003), Kraft (2007), and Skelton and South (2007), as well as with reference material from the UTEX Culture Collection of Algae. The thalli of these Polyphysaceae are slightly calcified, they show a cap diameter of 2–3 mm, and have 6–14 cap rays (Fig. 1). We, therefore, concluded that the collected specimens were *Parvocaulis exiguus*, representing the first record of this species from the Atlantic. Our *Parvocaulis exiguus* specimens were found co-occurring with *Parvocaulis parvulus*, which was previously recorded from the Caribbean (Berger and Kaefer 1992; Littler and Littler 2000; Suárez 2005; Wynne 2011; Guiry and Guiry 2016).

All three of our collected specimens had rays (Fig. 1a–c). One of these showed cyst formation (Fig. 1b). A second specimen showed the irregular cluster growth form, with cap rays that are completely separated rather than in one plane (Fig. 1c) (Berger and Kaefer 1992, p. 175; Egerod 1952, Fig. 23,1 as *Acetabularia tsengiana*).

Regarding the first record of *Parvocaulis exiguus* from the Atlantic Ocean, two scenarios are possible as an explanation: either the species is indigenous to the Atlantic Ocean and has been overlooked previously, or the species has recently been introduced. Based on the amount of earlier extensive phycological field research in the Caribbean and other warm water areas of the Atlantic Ocean (Taylor 1960; Littler and Littler 2000; Haroun et al. 2002; Suárez 2005; Littler et al. 2010; Wynne 2011; Afonso-Carrillo 2014; Moura et al. 2014; Wynne et al. 2014), the assumption that it was overlooked may be unrealistic. However, *Parvocaulis exiguus* is a rather small alga (<4 mm in length) and, therefore, it is not unlikely that the species could have been overlooked, especially since it co-exists with closely related species that are quite similar in form. During the same fieldwork at St. Eustatius, a small (1-mm-long) coral-associated hydroid (*Zanclaea* sp.) was discovered, which was previously known from the Indo-Pacific, which implies that it has simply been overlooked before (Montano et al. 2016). In addition, the algal vegetation of St. Eustatius has not yet been studied very thoroughly. Vroman (1968) investigated the algal flora on several Caribbean islands. He found three Polyphysaceae species, but not on St. Eustatius. Since he only investigated the intertidal area, no assumptions can be made on the subtidal presence of *Parvocaulis exiguus*. During a recent investigation of habitat types around St. Eustatius, Debrot et al. (2014) did not find any Polyphysaceae species. However, their main goal was to map the habitat types around St. Eustatius, not to provide a complete species list. Thus, it is possible that *Parvocaulis exiguus* has been present at St. Eustatius for a longer time, but whether the species is indigenous to St. Eustatius or not is difficult to confirm.

Parvocaulis exiguus could have been introduced, because St. Eustatius has a large oil terminal and associated shipping (White et al. 2007). Hence, ballast water might have been a means for the introduction of this species. However, Polyphysaceae are not known to be invasive (Johnson 2007; Guiry and Guiry 2016), although future investigations may reveal that *Parvocaulis exiguus* is present in additional locations in the Caribbean. When sufficient material becomes available, phylogeographical analyses may reveal which population in the Indo-Pacific is most closely related.

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