



Short communication

Seagrass paleo-biogeography: Fossil records reveal the presence of *Halodule* cf. in the Canary Islands (eastern Atlantic)



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ABSTRACT

The recognition of marine vegetation in the fossil record brings useful information about past environmental conditions. The paleo-biogeography of seagrasses is largely unknown, since fossilized materials are rare. In this study, we report the existence of fossil deposits of a seagrass species, *Halodule* cf., at Gran Canaria Island (28° N, northeastern Atlantic). The identification was confirmed by the presence of fossilized plagiotrophic rhizomes and fruits/seeds in sedimentary deposits from the early Pliocene. This seagrass fossilized material is the first from the West African coasts. The presence of this seagrass in the Canary Islands is linked with warm-water conditions during the Pliocene.

1. Introduction

Habitats dominated by seagrasses provide essential functions and services to ocean ecosystems and human well-being (Hemminga and Duarte, 2000). In recent decades, seagrass meadows have shown acute regression trends, primarily in areas of intense human development, where a range of impacts erode seagrass vitality (Waycott et al., 2009; Tuya et al., 2014).

Seagrass are plants that evolved from terrestrial ancestors. Because of climatic changes, the distribution ranges of seagrass species have accordingly changed through geological scales (den Hartog, 1970; Den Hartog and Kuo, 2006). Because of the low likelihood of fossilization of seagrass material, the reliable identification of seagrasses in the fossil record is challenging (Reich et al., 2015; Forsey 2016). From the 13 extant seagrass genera, fossil deposits have been only found for seven (Velez-Juarbe 2014). It has been postulated, from the limited fossil record, that the historical distribution pattern of seagrasses has been quite different from the contemporary situation; for example, this is the case for *Cymodocea* and *Thalassodendron*-like species in North America (Lumbert et al., 1984; Den Hartog and Kuo, 2006). An indirect approach is to infer their past distribution from fossils of organisms inhabiting seagrasses meadows. Diverse seagrass consumers, such as sirenians (sea cows, manatees and dugongs), are much better represented in the fossil record than seagrasses and, as a result, have been used to track seagrasses past distributions (Mateu-Vicens et al., 2008; Velez-Juarbe, 2014; Brandano et al., 2016). Similarly, the occurrence of

seagrasses has been inferred through foraminiferal assemblages (Tomassetti et al., 2016) and invertebrates, such as encrusting acervulinids and soritid orbitolites (Tomas et al., 2016), and ostracods (Forsey, 2016).

In the Canarian archipelago, three seagrass species are currently found (Ruiz de la Rosa et al., 2015). *Cymodocea nodosa*, the most widespread seagrass (Tuya et al., 2014), is a warm-temperate species. *Zostera noltii*, a temperate species, is restricted to one location at Lanzarote Island, while the ephemeral *Halophila decipiens* has increased in extent in the last decades (Ruiz de la Rosa et al., 2015). In the nearby northwestern African coasts, several seagrass species are found; both *C. nodosa* and *Z. noltii* have their southern distribution range at the Banc d'Arguin in Mauritania (Cunha and Araujo, 2009). At the same time, the warm-water seagrass *Halodule wrightii*, an ampho-Atlantic species, has its northern range limit in the same region (Cunha and Araujo, 2009).

Marine sedimentary deposits from the late Miocene and early Pliocene have been found on the easternmost islands of the Canarian archipelago (Meco and Stearns, 1981). At Gran Canaria Island, the age of these deposits varies between 4.8 and 4.2 million years (Meco et al., 2015) and contain a range of organisms of warm-water affinities, such as marine gastropods of the genera *Persistrombus* and *Nerita*, and corals of the genus *Siderastraea* (Meco, 1977; Meco et al., 2007). During this age, the waters of the Canary Islands were warmer than nowadays, resembling those of the Caribbean and/or the Gulf of Guinea (Meco et al., 2015). In this study, we took advantage of these marine sedimentary deposits to, by the first time, report the presence of fossils a

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seagrass from the eastern Atlantic.

2. Materials and methods

2.1. Geological and stratigraphic setting

The geological, paleontological and stratigraphic setting of the study site (Barranco Seco, Gran Canaria Island, 28° 05' 25.40" N, 15° 25' 40.25" E) are detailed in Betancort et al. (2016). Sedimentary deposits consists of grey to white sands, medium to fine in grain size, with bioturbation structures (Appendices A and B). The chronostratigraphic location of the fossiliferous sedimentary layers corresponds to the early Pliocene (4.80 ± 0.03 Ma), according to ⁴⁰Ar/³⁹Ar radiometric dating of lava flows and submarine pillow lavas (Meco et al., 2015).

2.2. Fossils collection and processing

Fossilized seagrass fragments were found within a layer of fine to medium grey sands, at about 95 m above the current sea level. These fragments were distributed in a ca. 1 m² surface layer (10 cm width) with no connections among them. Fragments were firstly cleaned with a brush; a set of these fragments were then cross-sectioned. Vegetative fragments were immersed in black polyester resin and cut in thin slices with a high-speed cutting machine. The slices were polished by hand, then glued to black acrylic slides, and photographed under a reflected light, using a compound stereoscope coupled to a digital camera. The same procedure was carried out to obtain a cross section of a fruit/seed. Additional photographs were taken using a digital camera connected to a stereoscopic magnifying glass. Photographs of vegetative and anatomical structures of current seagrass species were provided by the BCM herbarium (www.geoportal.ulpgc.es/herbariobcm) and John Kuo (University of Western Australia).

3. Results and discussion

In this study, we found fossilized seagrass plagiotrophic rhizomes (Fig. 1), ranging in total length between 2 and 15 mm (2.44 ± 0.88 mm, mean ± SD) and between 0.8 and 3 mm (1.77 ± 0.241, mean ± SD) in width (diameter) (Fig. 1). Nodes are visible from the rhizomes surface (Fig. 1 and); the scars of vertical nodes are particularly identifiable in some fragments (Fig. 2). The shape and width (diameter) of these plagiotrophic rhizomes are similar to those of other species of the Cymodoceaceae family, for example the genera *Halodule* (Creed, 1997; Den Hartog and Kuo, 2006) (Fig. 2, Appendix C). Cross-sections of these fragments revealed the presence of air lacunae (Fig. 1). *Halodule* species typically have a uniform cortical tissue (Den Hartog and Kuo, 2006), similar to our cross-sections (Appendix D). The spherical shape of fruits/seeds (Appendix E) resemble those of current species of *Halodule*, which are typically spherical to egg-shaped (Orth et al., 2006; Kowalski and DeYoe, 2016), e.g. those of *Halodule pinifolia* (Appendix F). The mean size of our fruits/seeds (6.1 mm, n = 3) are larger than those of *Halodule wrightii* from Laguna Madre (between 2.6 and 4.8 mm, Kowalski and DeYoe, 2016). The accumulation of sediment particles on the fruits/seeds surface through fossilization, including re-mineralization to generate opal glass structures, overestimate the size. A cross section view of a fossilized fruit/seed still provided evidence of two layers (Appendix G), despite remineralization through fossilization, corresponding to a thick 'seed coat' and an internal area of large nutrients accumulation (Appendix H).

Evidence of the potential presence of this seagrass in the Canaries is also provided by the paleo-climate of the region during the Pliocene (4.8 and 4.2 million years old). A considerable number of species with warm-water affinities have been found, including several genera of marine snails, e.g. *Persistrombus* and *Nerita*, and corals, e.g. *Siderastraea* spp. (Meco, 1977; Meco et al., 2007). In turn, the waters of the Canary



Fig. 1. Cross and longitudinal sections of fossilized plagiotrophic rhizomes of *Halodule* cf. from the Pliocene at Barranco Seco, Gran Canaria Island. Scale: 1 cm. n: nodes; a: air lacunae.

Islands were warmer and resembled conditions actually found at the Caribbean and/or the Gulf of Guinea (Meco et al., 2015), providing ideal conditions for the development of *Halodule*, a warm-water seagrass genus (Den Hartog and Kuo, 2006). In addition, fossils of a range of invertebrates inhabiting shallow-water sandy bottoms have been recorded from the study site, including irregular sea urchins, e.g. *Brissus* sp. and *Clypeaster aegyptiacus* (Meco et al., 2015), crustaceans of the genus *Callianasa* (Betancort et al., 2014) and burrows of the ichnofossil *Ophiomorpha*. Fossils of fish species typically inhabiting seagrass meadows on shallow waters have been also found, e.g. *Archosargus* sp. and *Diodon* sp. (Betancort et al., 2016). Foraminiferal assemblages have been used to track the presence of seagrasses in paleontological studies (Tomassetti et al., 2016). Several benthic foraminiferal taxa have been described from our study site, including the genera *Ammobaculites*,



Fig. 2. Fossilized plagiotropic rhizome of *Halodule* cf. (up) and *Halodule uninervis* (down). Scale: 2 mm.

Dorothia, *Dentalina*, *Elphidium* and *Rotalia*, which are characteristic of a shallow water environment (Anguita-Virella and Ramírez del Pozo, 1974). Fossils of seagrass-associated biota are relevant to track the presence of seagrasses (Mateu-Vicens et al., 2008; Brandano et al., 2016).

At present time, the seagrass *Halodule wrightii* inhabits on tropical waters of the eastern Atlantic. According to Green and Short (2003), this seagrass is present in Nigeria, Benin, Ghana, Sierra Leone, Guinea, Guinea Bissau and São Tomé and Príncipe (Alexandre et al., 2017), as well as in Cape Verde Islands (Cunha and Araujo, 2009). Currently, beside *H. wrightii* there are another five described species within the genus *Halodule* (Den Hartog and Kuo, 2006) and even new species to be potentially described from the Western African coasts (Alexandre et al., 2017).

Taxonomy of seagrasses is majorly based on leaf morphology and leaf sheath; as the fossilized material do not contain such structures, we do not have complete evidence to unambiguously tag our material as

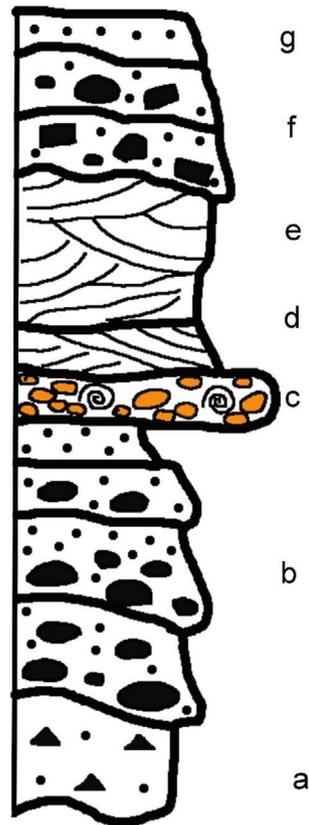
Halodule. We then have included the epithet cf. (confer) to label our material; this means there is a set of coherent arguments to believe this material belongs to the genus *Halodule*, but it can be confounded with other seagrass species due to a lack of complete probes.

In summary, this study reports fossil seagrass (*Halodule* cf.) deposits from the early Pliocene at Gran Canaria Island (28° N), i.e. northwards of the Tropic of Cancer. Our discovery is particularly notable, as to the best of our knowledge, this seagrass fossilized material is the first from the West African coasts (Velez-Juarbe, 2014).

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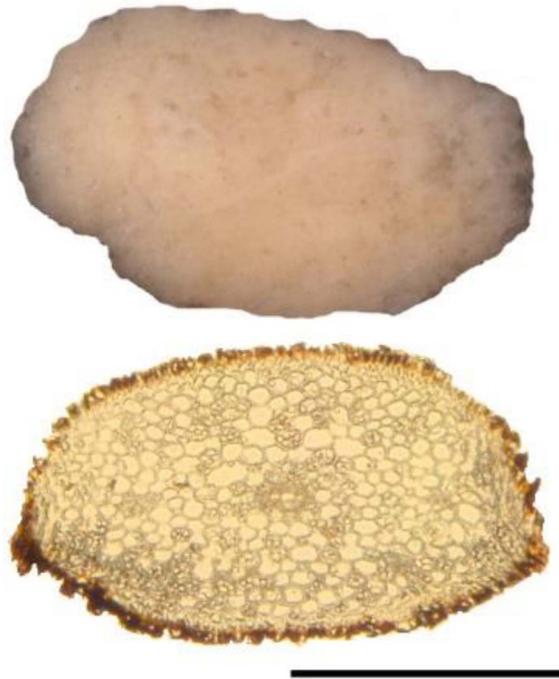
Appendix A. Schematic stratigraphic sections of the study site (Barranco Seco, Gran Canaria Island, modified from Betancor et al., 2017): (a) Miocene phonolitic ignimbrite, (b) Miocene alluvial fan, (c) early Pliocene marine deposit (reddish conglomerate), (d) foreshore grey fine sand, (e) dune white sand, (f) Pliocene alluvial fan, and (g) colluvium



Appendix B. Outcrop at Barranco Seco site where seagrass fossil material was found: (a) Fossiliferous conglomerate, (b) grey fine sand arenas with bioturbation structures, and (c) colluvium



Appendix C. Cross sections of a fossilized plagiotropic rhizome (up) of *Halodule cf.* and *Halodule uninervis* (down). Scale: 2 mm



Appendix D. Vegetative fragments of *Halodule uninervis* (top) and *Halodule beaudetlei* (down)



Appendix E. Fossilized seed of *Halodule* cf. from the Pliocene at Barranco Seco, Gran Canaria Island



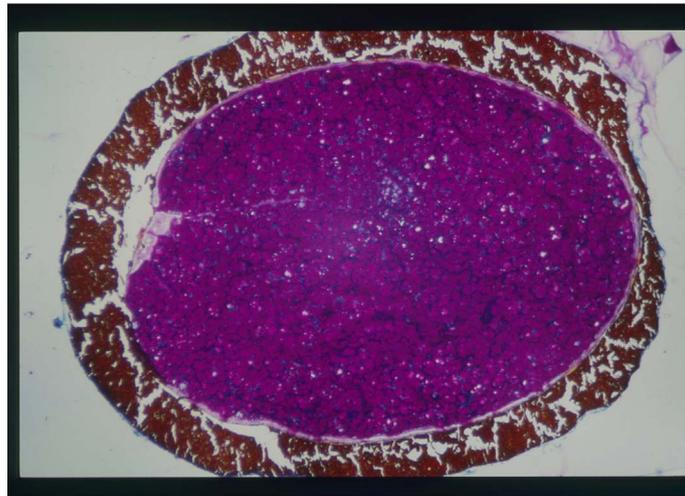
Appendix F. Vegetative fragment of *Halodule pinifolia* containing a seed. Photo courtesy of Dr. John Kuo (University of Western Australia). Scale: 2 mm



Appendix G. Cross section of a fossilized fruit/seed of *Halodule* cf. Scale: 2.5 mm



Appendix H. Cross section of a seed from *Halodule uninervis*, showing a thick ‘seed coast’ and starch rich nutrients stored in the seed. Photo courtesy of Dr. John Kuo (University of Western Australia)



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