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Pelagic *Sargassum* and some associated mobile fauna: new records for the archipelago of Madeira (subtropical eastern Atlantic)

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Abstract

Starting in the summer 2023 and peaking in late 2023, large amounts of *Sargassum* were observed floating off the coast of Madeira Islands, Portugal. The analysis of the samples revealed the presence of the three most common morphotypes of the two known species of pelagic *Sargassum*: *S. natans* I, *S. natans* VIII, and *S. fluitans* III. This is the first record for the subtropical eastern Atlantic Ocean for *S. natans* VIII and *S. fluitans* III. Both species were found entangled, and even though the main purpose of the study was to document the occurrence of pelagic *Sargassum* in the Madeira archipelago, some associated fauna were also recorded: the crab *Planes minutus* (Linnaeus, 1758), the amphi-Atlantic shrimps *Latreutes fucorum* (Fabricius, 1798) and *Hippolyte coerulescens* (Fabricius, 1775), and the nudibranch *Scyllaea pelagica* Linnaeus, 1758. The last two are new records for the Madeira archipelago.

Introduction

Sargassum is a brown seaweed genus that is widespread in temperate, subtropical, and tropical waters of the Atlantic, Pacific, and Indian Oceans. In the Atlantic, there are more than 60 benthic species of *Sargassum* and two common free-floating pelagic species, *Sargassum natans* (Linnaeus) Gaillon 1828 and *Sargassum fluitans* (Børgesen) Børgesen 1914 (Guiry and Guiry, 2024).

Sargassum species are highly differentiated into holdfast, cylindrical main axis, leaflike blades and gas-filled bladders (vesicles) or pneumatocysts (Graham *et al.*, 2022). The two free-floating (holopelagic) species, *S. natans* and *S. fluitans*, do not have a holdfast nor are attached to a substrate at any stage of their life cycle (Parr, 1939). As no receptacles have been observed, these two species are self-sustaining by fragmentation and vegetative reproduction (Collins and Hervey, 1917). Both species have distinct morphotypes, with three of them dominating the holopelagic *Sargassum* biomass (*S. natans* I, *S. natans* VIII, and *S. fluitans* III) and displaying different degrees of branching and foliation (Parr, 1939; Schell *et al.*, 2015; Godínez-Ortega *et al.*, 2021). There is a significant difference in growth rates among the holopelagic *Sargassum* morphotypes, with *S. fluitans* III on average doubling its biomass in 13 days, *S. natans* I in 22 days, and *S. natans* VIII in 31 days, under favourable conditions (Corbin and Oxenford, 2023). Recently, Siuda *et al.* (2024) proposed a revision of the names of the three most common holopelagic *Sargassum* morphotypes, due to their distinct morphological characteristics and sympatry within drifting aggregations: *Sargassum fluitans* var. *fluitans* (for *S. fluitans* III), *Sargassum natans* var. *natans* (for *S. natans* I), and *S. natans* var. *wingei* (for *S. natans* VIII).

Holopelagic *Sargassum* gathers in extensive rafts that serve as nursery, spawning, foraging, roosting, and protective habitat for a diversity of marine organisms, including invertebrates, sea turtles, marine birds, marine mammals, and for approximately 120 species of fish, including commercially important fisheries species (Dooley, 1972; Wells and Rooker, 2004; Doyle and Franks, 2015; Pries *et al.*, 2023). It is a unique and ecologically significant floating marine ecosystem, providing the necessary mechanism for motile epifauna and rafting animals dispersal to new locations (Haney, 1986; Martin *et al.*, 2021; Graham *et al.*, 2022; Pérez-Pech *et al.*, 2024). Attached to *Sargassum* stipes, branches, and blades there is a diversity of sessile filter-feeding fauna, which are predated by fish and invertebrate motile fauna, such as crabs, shrimps, and nudibranchs (Martin *et al.*, 2021). Ten invertebrates and two vertebrates are endemic to holopelagic *Sargassum*, with specialized coloration and morphology to camouflage within the habitat (Coston-Clements *et al.*, 1991).

For centuries, explorers and oceanographers have attempted to map the holopelagic *Sargassum* distribution in the Atlantic Ocean. They realized that there is a general pattern, called the North Atlantic subtropical gyre, a clockwise flow of the main ocean currents (the Gulf Stream to the west, the North Atlantic Current to the north, the Canary Current to the east, and the North Equatorial Current to the south), which has the Sargasso Sea at its core (Laffoley *et al.*, 2011; Lomas *et al.*, 2011). In 2011, a significant mass of *Sargassum* was discovered in the tropical Atlantic Ocean, south of the Sargasso Sea, and it has been increasing ever since, reaching mythic proportions and forming a new consolidated region known as the 'Great Atlantic *Sargassum* Belt', that extends from the Caribbean Sea and the Gulf of Mexico to tropical West Africa (Gower *et al.*, 2013; Wang *et al.*, 2019; Léger-Pigout *et al.*, 2024). Since then, unusually large quantities of pelagic *Sargassum* began to wash ashore during the spring and summer months, affecting the Caribbean islands, the coasts of Florida, Mexico, Brazil and Central America and the Atlantic coastline of tropical West Africa (Smetacek and Zingone, 2013; Bloom, 2015; Sissini *et al.*, 2017; Ody *et al.*, 2019; Chávez *et al.*, 2020; Yokoyama, 2022). Now holopelagic *Sargassum* is found well beyond the historic boundaries of the Sargasso Sea and places these regions at the heart of local and international concerns, because of the health, economic, and environmental risks it represents (Smetacek and Zingone, 2013; Chávez *et al.*, 2020; Schuhmann *et al.*, 2022; Hamel *et al.*, 2024).

There are 11 species of *Sargassum* recorded for the archipelago of Madeira, 10 of them benthic and one pelagic, *Sargassum natans* (Buch, 1825; Grunow, 1870; Piccone, 1884; Bianchi *et al.*, 1998; Parente *et al.*, 2000; Cruz-Reyes *et al.*, 2001; Neto *et al.*, 2001; Ferreira, 2011; Ferreira *et al.*, 2018). The main objective of this study is to document the co-occurrence of the two species of pelagic *Sargassum* in the Madeira archipelago. Following the survey, four species of invertebrates frequently found in this floating ecosystem were also identified.

Material and methods

Study area

The Madeira archipelago (32.00°–33.00°N; 17.50°–16.00°W) is located in the subtropical Northeast Atlantic. It is of volcanic origin and is formed by the islands of Madeira (737 km^2), Porto Santo (42 km^2), Desertas (13 km^2) and Selvagens (∼3 km^2), which are 700 km off the North African coast and almost 1000 km south of mainland Portugal (Haroun *et al.*, 2002; Mata *et al.*, 2013).

The Azores subtropical anticyclone mainly determines the weather conditions in this region, which is responsible for the predominance of northeast trade winds with an average speed of 20 km h^{-1} (Campuzano *et al.*, 2009). The surface ocean currents in the Madeira Archipelago are part of the general circulation of the North Atlantic current system. The eastern part of this circulation system is formed by the Azores Current, the Portugal Current, the Canary Current and the North Equatorial Current (Figure 1).

Field work

Pelagic Sargassum and some associated mobile epifauna were collected at a few different moments of opportunity. It should be

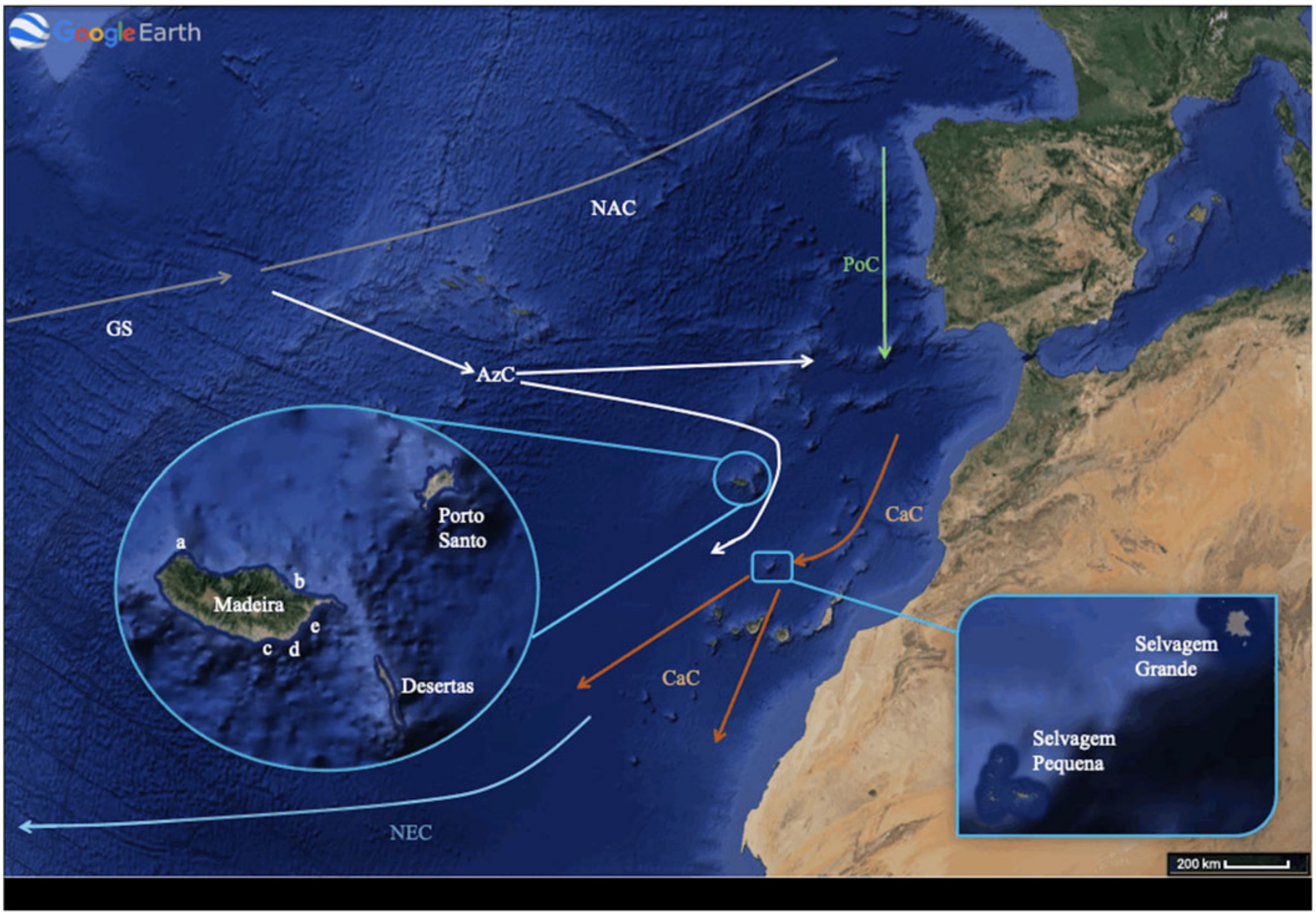

Figure 1. Geographical location of the Madeira archipelago, with the Madeira Island's sampling site location (a – Porto Moniz, b – Porto da Cruz, c – Funchal, d – Reis Magos, e – Machico) and the eastern boundary currents of the North Atlantic Subtropical Gyre (AzC, Azores Current; CaC, Canary Current; PoC, Portugal Current; NEC, North Equatorial Current; GS, Gulf Stream, NAC, North Atlantic Current).

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noted that the observation of large masses of these pelagic algae in the Madeira archipelago is an unpredictable event, and it was not possible to plan a sampling trip in advance. The algae mats approach the coast drifting with the current and, if they do not get stranded in a bay, they continue their journey until they drift away from the islands into the open sea. For this reason, the time available for sampling is very limited and it is necessary to always have the equipment ready for when the opportunity arises.

Sargassum specimens were collected from free-floating mats off Funchal, south coast of Madeira Island (32°35′42″N 16° 56′33″W, 07/07/2023), from masses washed ashore in Porto da Cruz, north coast of Madeira Island (32°46′04″N 16°49′17″W, 17/12/2023) and at Porto Santo Island (33°3′4.62″N 16° 20′38.41″W, 12/11/2023) (Figure 1). At the first two sites, the *Sargassum* samples were collected fresh by hand, placed in airtight bags and taken to the laboratory on the same day as collection. In Porto Santo, the samples were packed in airtight bags with seawater, kept cold in the refrigerator and transported to the laboratory the following day in a cold box. Following a thorough sorting/identification of the entire sample, using Parr (1939) and Godínez-Ortega *et al.* (2021), both species of pelagic *Sargassum* (*S. natans* I, *S. natans* VIII, and *S. fluitans* III) were found at these three sampling sites. Two specimens of each morphotype were selected, per sampling site, dry in herbarium sheets and incorporated into the Natural History Museum of Funchal herbarium (MADM), with also some fragments preserved in silica gel and others in 4% Formalin.

Throughout the pelagic *Sargassum* sampling, it was observed that there was a large amount of associated epifauna visible to the naked eye. Although collecting epifauna was not the initial aim of the study, the authors decided to take the opportunity to collect samples of the most visible and common organisms found in the pelagic *Sargassum* samples. They were carefully separated from the substrate, by rinsing each sample of pelagic *Sargassum* with fresh water into a container and collecting the specimens that were loose from the algae. They were then identified, placed in specimen jars according to their taxonomic classification (20 individuals of each species), preserved in 70% alcohol and incorporated into the collection of the Natural History Museum of Funchal (MMF) and of the Naturalis Biodiversity Center, Leiden, Netherlands (RMNH).

Floating and stranded *Sargassum* mats were also observed and photographed, at Porto Moniz (north coast of Madeira), Porto Santo, Desertas, and Selvagens islands (Figure 2).

Results

Macroalgal records

Sargassum fluitans (Børgesen) Børgesen 1914

Material examined: MADM4150, MADM4152, MADM4153, MADM4155

Sargassum natans (Linnaeus) Gaillon

Material examined: MADM4149, MADM4151, MADM4154, MADM4156

Remarks: *Sargassum fluitans* and *Sargassum natans* specimens were collected entangled, free-floating, or in large mats that washed ashore in Funchal, Porto da Cruz and Porto Santo. Unlike *S. natans*, *S. fluitans* has thorny stems, which is the main determining feature that distinguishes these two pelagic *Sargassum* species (Parr, 1939).

The specimens collected belong to the three morphotypes commonly found in *Sargassum* masses drifting in the Atlantic Ocean, *Sargassum fluitans* III, *Sargassum natans* I and VIII. *S. fluitans* III has small thorns along the stems, lacks apical spines on oblong bladders and has short, narrow blades; *S. natans* I has smooth stems (without thorns), narrow blades and apical spines on spherical bladders; *S. natans* VIII has thick and smooth stems (without thorns), spherical bladders rarely adorned with apical spine and has long, broad, and widely spaced blades (Parr, 1939; Schell *et al.*, 2015; Martin *et al.*, 2021) (Figure 3).

Sargassum natans was previously recorded in Madeira (Buch, 1825) and it is very likely that this observation might have been morphotype *S. natans* I. According to Parr (1939) in early

Figure 2. Accumulation of pelagic *Sargassum* in (A) Porto Moniz harbour (northwest coast of Madeira Island), (B) Porto Santo Island, (C) Deserta Grande (Desertas islands), (D) Selvagem Pequena, and (E) Selvagem Grande. Photo credits: Henrique Rodrigues, Ricardo Araújo, Isamberto Silva, and Manuel José de Jesus.

Figure 3. Three holopelagic *Sargassum* morphotypes recorded in the coastal waters of Madeira archipelago.a. *Sargassum natans* I, with smooth stems, narrow blades and spherical bladders with apical spines; b. *Sargassum natans* VIII, with thick and smooth stems, long, broad, and widely spaced blades and spherical bladders rarely adorned with apical spine; c. *Sargassum fluitans* III, with small thorns along the stem, short and narrow blades and oblong bladders without apical spines.

observations of *S. natans* the dominant morphotype in the Sargasso Sea was *S. natans* I, while *S. natans* VIII was extremely rare (and isolated to the Caribbean) until the recent proliferation of the GASB (Schell *et al.*, 2015; García-Sánchez *et al.*, 2020). To the best of our knowledge, for *S. natans* VIII and for *S. fluitans* III this is the first record for the subtropical eastern Atlantic Ocean.

Mobile Epifaunal Records (Figure 4)

Hippolyte coerulescens (Fabricius, 1775) (Figure 4A)

Material examined: MMF50302, MMF50303, MMF50304, MMF50305, MMF50306, MMF50307, MMF 50311, RMNH.CRUS.D.59355.

The specimens were found with *Sargassum* floating off Madeira Island. This amphi-Atlantic shrimp is usually associated

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Figure 4. (A) *Hippolyte coerulescens* (Fabricius, 1775), (B) *Latreutes fucorum* (Fabricius, 1798), (C) *Scyllaea pelagica* Linnaeus, 1758, and (D) *Planes minutus* (Linnaeus, 1758) Photo credits: Luís Berimbau.

with floating *Sargassum* (Coston-Clements *et al*., 1991). In the eastern Atlantic, *H. coerulescens* has previously been reported from the Azores (Lenz and Strunck, 1914), the Canary Islands (Ortmann, 1893), and the Cape Verde Islands (Ortmann, 1893) but not yet from Madeira archipelago.

Latreutes fucorum (Fabricius, 1798) (Figure 4B)

Material examined: RMNH.CRUS.D.59354

This amphi-Atlantic shrimp species was also common on floating *Sargassum* off Madeira Island. It is known to live not only with pelagic *Sargassum* but also on benthic algae (Sivertsen and Holthuis, 1956; Chace, 1972; Coston-Clements *et al*., 1991; Udekem D´Acoz, 1999) and has been recorded from Madeira previously (Wirtz, 2020).

Scyllaea pelagica Linnaeus, 1758 (Figure 4C)

Material examined: MMF50310, MMF50313, MMF50314

This amphi-Atlantic nudibranch species lives on floating algae (Pola *et al*., 2012). It was common on *Sargasssum* floating off Madeira Island. In the eastern Atlantic, *S. pelagica* has been recorded south of Madeira, e.g. at the Canary Islands (Ortea *et al*., 2014) but apparently not yet at Madeira Island or north of it.

Planes minutus (Linnaeus, 1758) (Figure 4D)

Material examined: MMF50312; RMNH.CRUS.D.59356

This amphi-Atlantic crab was by far the most common crustacean on *Sargassum* floating off Madeira and Porto Santo. It is known from Madeira archipelago, mainly associated with marine turtles and drifting debris (Manning and Holthuis, 1981; Dellinger *et al*., 1997; Araújo and Wirtz, 2015). *Planes minutus* has already been reported for Madeira and the Azores by Lenz and Strunck (1914) and for the Canary Islands by Heller (1863).

Some other species were observed associated with the pelagic *Sargassum*, like *Argonauta argo* Linnaeus, 1758 and *Schedophilus ovalis* (Cuvier, 1833), which were photographed but not collected (Figure 5).

Discussion

Since 2011, scientists worldwide are investigating the cause of the sudden increase in holopelagic *Sargassum* in the Atlantic Ocean, which was first noticed in the Madeira archipelago in 2023. Although the causes are not yet fully understood, there are several hypotheses that could explain this extreme event: an abnormal wind regime between 2009 and 2010 in the east-central Atlantic Ocean that led to the movement of *Sargassum* to the far eastern North Atlantic (Johns *et al*., 2020), an enrichment of nutrients from the Amazon, Pará, and Orinoco rivers (Djakouré *et al*., 2017; Aquino *et al*., 2022), an increase in dust from the Sahara desert (Johnson *et al*., 2012), a change in upwelling patterns off the north-east coast of Africa (Wang *et al*., 2019) and an increase in sea temperature (Johns *et al*., 2020). Nevertheless, investigating such a large-scale phenomenon must involve the study of physical and biological processes, like the physical transport of floating *Sargassum* and its growth in response to changing oceanic conditions (Berline *et al*., 2020; Corbin and Oxenford, 2023).

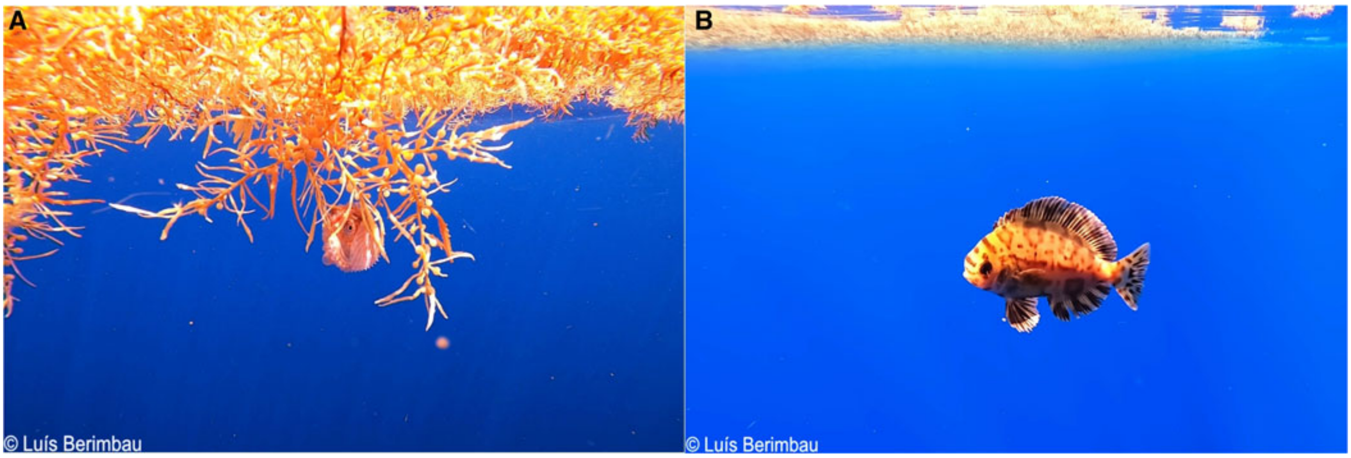

Figure 5. (A) *Argonauta argo* Linnaeus, 1758 and (B) *Schedophilus ovalis* (Cuvier, 1833). Photo credits: Luís Berimbau.

It is a fact that since 2011 there is a concomitant increase in holopelagic *Sargassum* beach landing events in the Caribbean Sea, the Caribbean coasts of Central America and Mexico, and on the Atlantic coastline of tropical West Africa (Gower *et al*., 2013; Franks *et al*., 2016; Wang *et al*., 2019). The large growth in biomass increases the chance that some of this *Sargassum* might enter the Gulf Stream and then drifts along the subtropical gyre to the waters of the Madeira archipelago, crossing the Atlantic Ocean. It must be emphasized that this is not an unprecedented event, whenever meteo-oceanographic conditions are favourable, small amounts of holopelagic *Sargassum* can occasionally be found in the area of Madeira (Menezes, 1926; Levring, 1974). What is unusual is the quantity that has been recorded since the end of 2023, in which large 'rafts' of *Sargassum* have washed up on the coast of the islands of Madeira, Desertas, Porto Santo, and Selvagens. There are also reports of large masses of holopelagic *Sargassum* washing up on the coasts of the Azores islands, having increased in volume since January 2024, following storms from the western Atlantic Ocean (Gabriel *et al*., 2024; J. Faria, personal communication to SJF).

Although we have not yet observed any negative impact on the coastal ecosystems of the Madeira archipelago, we do have access to the record of what has happened in the affected areas since 2011, were many environmental, health, and economic impacts have already been reported, such as the decrease in biodiversity, with the death of marine organisms as a result of the destruction of their habitats (McLawrence *et al*., 2017; van Tussenbroek *et al*., 2017; UNEP-CEP, 2021; López-González *et al*., 2023). Therefore, the recent influx of drifting holopelagic *Sargassum* approaching the coast of the Madeira archipelago needs a thorough monitoring effort, and, if necessary, some of the measures adopted in the coastal areas affected by this phenomenon should be implemented.

This could be a one-off situation, with a few occasional fragments of holopelagic *Sargassum* from the East Atlantic reaching the Madeira archipelago, or we could be facing a new reality. Whether it will become something common in the future, possibly seasonal, reflecting the changes taking place in the ocean, we will only know in the next few years. In the meantime, we should be vigilant and take the opportunity to study this phenomenon more thoroughly, tracking the frequency and intensity of these events and assessing any potential negative impacts on local biodiversity, possibly alongside researchers on the other eastern Atlantic islands that have been 'visited' by these floating algae.

Data. The data that support this study are in the Natural History Museum of Funchal (MMF) and in the Naturalis Biodiversity Center, Leiden (RMNH) collections and can be made available under request.

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