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Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology

Official Journal of the Societa Botanica Italiana

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tplb20

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To cite this article: Thalassia Giaccone, Federica Ragazzola, Paolo Barone, Cristina Condemi & Anna Maria Mannino (2024) The flourishing of *Laminaria ochroleuca* in the strait of Messina (Sicily, Italy): resilience population between "Scylla and Charybdis", Plant Biosystems - An International Journal Dealing with all Aspects of Plant Biology, 158:3, 341-343, DOI: 10.1080/11263504.2024.2326826

To link to this article: https://doi.org/10.1080/11263504.2024.2326826

Published online: 12 Mar 2024.

PLANT BIOSYSTEMS - AN INTERNATIONAL JOURNAL DEALING WITH ALL ASPECTS OF PLANT BIOLOGY
2024, VOL. 158, NO. 3, 341–343
https://doi.org/10.1080/11263504.2024.2326826

The flourishing of *Laminaria ochroleuca* in the strait of Messina (Sicily, Italy): resilience population between "Scylla and Charybdis"

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ABSTRACT

The kelp forest and bed of *Laminaria ochroleuca* were found in October 2023 in Porticello (Scylla -Reggio Calabria, Italy) between 48 and 55 m depth. Samples were collected for future genetic and sedimentological analyses and identification of associated fauna and flora. The aim of the upcoming research campaigns is to update the current knowledge of *Laminaria* forests in the Messina Strait, estimating the action and consequences of climate change at the local level. The project will involve the community of technical divers in long term monitoring (3–5 years), in order to measure ecosystem services. The information will be used to draft a policy document for the proposal of protected areas of the most extensive forests.

ARTICLE HISTORY
Received 3 January 2024
Accepted 15 February 2024

KEYWORDS
Laminaria ochroleuca; forests; beds; Scylla; strait of Messina; Mediterranean sea

Introduction

Kelp forests are characterized by greater amounts of biomass and biodiversity than many other marine environments (Smale et al. 2013). They have a three-dimensional structure that provides a habitat for a wide range of marine organisms, many of which are commercially important (Mann 1973). They are brown algae belonging to the orders Laminariales and Tilopteridales and can be found in dense plant aggregations, extending up to tens of meters underwater, forming forests (stipitate individuals crammed on rocky substrates) and beds (prostrate individuals prostrate on mixed substrates). They are present in the Mediterranean Sea with the genera *Laminaria*, *Phyllaria* and *Saccorhiza*. Among the genera present in the Mediteranean Sea, of special notice is *Laminaria rodriguezii* Bornet 1888, an endemic species, one of the few examples of paleomediterranean elements of the Mediterranean algal flora (Giaccone 1969) present in all biogeographical sectors in the approximately littoral plane excluding the Black Sea, the Alboran Sea and the Egyptian and Libyan eastern Mediterranean coasts (Giaccone et al. 2009). *Laminaria ochroleuca* Bachelot Pylaie 1824 forests, on the other hand, are present in the Mediterranean Sea, in the Alboran Sea but also as a Lusitanian-Senegalese relict in the Strait of Messina (Giaccone 1972), and according to protocol SDM/3/6259 of July 30, 2003, represent priority habitat IV. 3. 1. 8 (Giaccone et al. 2009). The mapping and study of these priority habitats in the Strait of Messina is mainly due to Giaccone in the 1960s (Giaccone 1969), Drew, Mojo, and Buta in the 1970s (Drew 1974; Mojo and Buta 1971), Di Geronimo and Giacobbe in the 1980s (Di Geronimo and Giacobbe 1987), and Zampino and Di Martino in the year 2000 (Zampino and Di Martino 2000). In this work, we wanted to verify the status of the forests and bed of *L. ochroleuca* in the Scylla area (Calabrian side of the Strait of Messina) given that the last reliable record can be attributed to Giaccone in 1969. In October 2022 and in January 2023, a forest of *L. ochroleuca* on the Messina side of the Strait of Messina (38°15′31.24′ N,15°37′54.58′ E), extending from 40 to at least 60 m depth, was discovered (Giacobbe and Ratti 2023). The discovery of the forest and bed of *L. ochroleuca* in Porticello (Scylla), besides being an extraordinary discovery for the Calabrian side of the Strait of Messina, represents the confirmation of the permanence of this forest and bed for more than 50 years. The presence of other Laminariales, such as *Phyllariopsis purpurascens* (C. Agardh) E. C. Henry & G. R. South 1987, also described by Giaccone during hisphytographic survey carried out in Scylla in 1969, is to be verified in future monitoring.

Materials and methods

The forest and bed of *L. ochroleuca* were found in October 2023 at Porticello (Scylla) in a bathymetric range of 48 to 55 m but they appear to extend to greater depths (38°14′45"N – 15°40′39"E). Samples ($n = 4$) of *L. ochroleuca* including two with stipitate and two with prostrate habits (four different individuals) were collected by technical scuba divers. Apical fragments of the lamina of 4 different specimens, were placed in silica gel (granules 0.2–1 mm in diameter) for quick desiccation, for future DNA extractions. Care was taken to remove sediment, epiphytes and other contaminants from the

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Published online 12 Mar 2024

material prior to drying (Heesch et al. 2020). One specimen was dried to make an algarium. Species identification was made using the taxonomic keys found in Giaccone (1969). Additional samples ($n = 3$) of hard and ($n = 3$) of mobile substrate were also collected during the same dive for preliminary qualitative analyses (sedimentological, morphological and associated flora/fauna). Thorough photographic documentation was performed with Canon G7XMark II in Nauticam housing and Sea and Sea YS-D3 flash.

Results

Preliminary results describe the morphological characteristics of the forest and bed of *L.ochroleuca* from Porticello (Scylla) and provide some insights into the hydrodynamic characteristics of the site. Two morphological groups of *Laminaria* can be clearly distinguished: (1) stipitate (Figure 1a)—endowed with rigid stipites of about 1 m, which help them to keep upright in the water, anchored with powerful rhizoids on a rocky-organogenic substrate (encrusting calcareous algae facies) and with laminae as long as more than 2 m, and (2) prostrate (Figure 1b)—that cover with their laminae of about 1 m, the sandy-organogenic bottom (free calcareous algae facies), forming real beds of algae called "beds" in the literature. These are the non-floating species, which do not have rigid structures to keep themselves upright and have more slender jambs and rhizoids. The prostrate *Laminaria* bed begins at a depth of about 48 m, and continues on a sandy-organogenic bottom (free calcareous algal facies), to a depth of about 50–52 m. From depths greater than 52 m, the bed of *Laminaria* prostrate alternates with the forest of *Laminaria* stipitate, which instead develop on rocky and partly bioconstructed elements about 1 m high and about 3–4 m wide, distributed on the sandy-organogenic bottom.

Under the action of the Strait current, the stipes undergo only a slight inclination, while the fronds arrange themselves parallel to the current or droop umbrella-like over them. The fronds are uniformly olive-brown, lighter in the stipo-frondal region while the cylindrical jambs of the stipitate forms and the flat jambs of the prostrate forms as well as the rhizoids, are ochraceous yellow, giving the forest and bed a typical dark golden coloration. Documentation and sampling dives were carried out both during the periods of stasis and during the onset of the upwelling current, highlighting the orientation of the upwelling current from offshore to inshore. The intensity of currents, brightness, latitude, frequency, nutrient availability, and water clarity are some of the factors that influence the growth of *Laminaria*: in fact, another important factor is the organogenic substrate on which they grow. The relationship they establish with calcareous algae of the order Corallinales (non-geniculate) on which they strongly anchor rhizoids has not yet been described in the literature. Giaccone (1969) pointed out that *L. ochroleuca* establishes itself on mobile organogenic substrates such as nodules of *Lithophyllum racemus* (Lamarck) Foslie 1901 and *Spongites fruticulosus* Kützing 1841. However, this has not yet been recorded during our first survey because the sampled nodules of calcareous algae will be the subject of future analysis.

Discussion

Laminariales are very important organisms because with their laminae, stipes, and rhizoids they provide three different types of habitats for numerous benthic, planktonic, and nectonic species. As previously stated, the biodiversity hosted in these algae is proportionally greater than in terrestrial forests (Smale et al. 2013). They also represent ecosystems with high primary productivity and thus provide a significant ecosystem service as carbon sinks. Their ecosystem service also extends to food provisioning in terms of primary biomass for herbivorous fish and invertebrates and secondary biomass produced by the fragmentation of the distal part of kelp laminae into organic particles, for filter feeders and detritivores. Rising global temperatures and ocean acidification are altering the resilience of kelp forests (Steneck et al. 2002). Adverse and intense climatic events, such as changes in salinity or temperature, are equally dangerous to the survival of these kelp forests. Their strength, however, is their great resilience, allowing even complete regrowth in one to three years (Steneck et al. 2002). The first evidence of a drastic population decline arose in 1995, observed during a ROV investigation covering the whole Sicilian side of the Messina Strait (Giacobbe, unpublished POP'95 Report). Further SCUBA investigations by Zampino and Di Martino in 2001 confirmed the marked decline of the local *L. ochroleuca* population, suggesting its possible extinction. The absence of any reliable record of the species' presence over the next 20 years seemed to confirm this impression, which was contradicted in October 2022 by

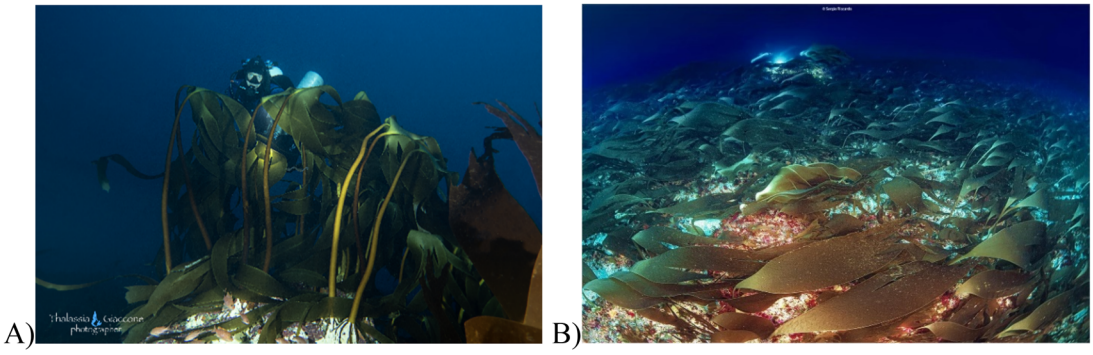

Figure 1. Stipitate (a, Forest) and prostrate individuals (b, bed) of *Laminaria ochroleuca* (photos by Thalassia Giaccone and Sergio Riccardo).

Giacobbe e Ratti (2023) in the Sicilian side and in October 2023 (Calabrian side) by our current finding is a sign of recovery, consistent with the northward shift of the species globally (Voerman et al. 2013). The health status of the observed specimens testifies to a clear reversal of the decades-long decline of this population in the Mediterranean Sea. The expansion or retraction of the species along the European coast appears to be modulated primarily by temperature and anthropogenic disturbance, but nutrient availability would be critical to maintaining optimal physiological performance. Range displacement of *L. ochroleuca* can have serious ecological impacts at regional and local scales (Franco et al. 2018). Laminariales stands in the Strait of Messina occur along the stretch where there is periodic mixing between the surface waters of the Tyrrhenian Sea (downstream current) and the deep waters of the Ionian Sea (upstream current). This mixing has the main effect of preventing thermal stratification and promoting the solution of metabolic gases. In addition, the continuous renewal of the "layer of water" in immediate contact with the living surface (boundary layer) of these algae, is the thinner the faster the current flows and results in a more intense exchange of metabolic gases and a continuous supply of new nutrients that allow considerable heterotrophic nutrition and exuberant development (Giaccone 1972). The Strait currents are also of the pulsating type, with periodic pulsations in synchrony with the tidal phases. At the Porticello site in Scylla, periods between the upstream and downstream current make possible the implantation of reproductive elements (spores and zygotes), while those with intense movement ensure their metabolism; where the current has an almost continuous flow, that is, south of P. ta S. Rainieri and north of Capo Peloro on the Messina side on the other hand, these stands fail to implant, despite the existence of a suitable substrate and the presence of Ionian water. Moreover, in these extreme areas, currents have a particular erosion force due to solid particles in suspension that damage the seedlings either through abrasion or by covering them with sediment (Giaccone 1972). The future project idea is to update the current knowledge of *L. ochroleuca* forests in the Strait of Messina, estimate the action and consequences of climate change at the local level, involve the community of technical divers in seasonal monitoring for the next three to five years, measure the ecosystem services provided by these plant aggregations, and draft a policy document for the proposal of protected areas at the most extensive forests.

Acknowledgments

We thank Sergio Riccardo for supplementary and detailed photographic documentation.

Disclosure statement

Authors declare they have no competing conflicts of interest in the study.

Funding

T.G, F.R. and A.M.M. acknowledge the support of the Project and funded under the National Recovery and Resilience Plan (NRRP), Mission 4 Component 2 Investment 1.4—Call for tender No. 3138 of 16 December 2021, rectified by Decree n.3175 of 18 December 2021 of Italian Ministry of University and Research funded by the European Union—NextGenerationEU. Project code CN_00000033, Concession Decree No. 1034 of 17 June 2022 adopted by the Italian Ministry of University and Research, CUP C63C22000520001 project title "National Biodiversity Future Center - NBFC".

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