The European Zoological Journal

ISSN: (Print) 2475-0263 (Online) Journal homepage: http://www.tandfonline.com/loi/tizo21

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To cite this article: F. Betti, M. Bo, S. Bava, M. Faimali & G. Bavestrello (2018) Shallow-water sea fans: the exceptional assemblage of *Leptogorgia sarmentosa* (Anthozoa: Gorgoniidae) in the Genoa harbour (Ligurian Sea), The European Zoological Journal, 85:1, 291-299, DOI: 10.1080/24750263.2018.1494219

To link to this article: https://doi.org/10.1080/24750263.2018.1494219

Published online: 27 Jul 2018.

The European Zoological Journal, 2018, 291–299
Vol. 85, No. 1, https://doi.org/10.1080/24750263.2018.1494219

Shallow-water sea fans: the exceptional assemblage of *Leptogorgia sarmentosa* (Anthozoa: Gorgoniidae) in the Genoa harbour (Ligurian Sea)

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(Received 6 March 2018; accepted 25 June 2018)

Abstract
An exceptional assemblage of the sea fan *Leptogorgia sarmentosa* (Anthozoa: Gorgoniidae) was observed inside the Genoa harbour, which represents one of the major Mediterranean ports. The studied assemblage is confined in a shaded portion of a floating dock thriving in extremely shallow water, with specimens even touching the sea surface. It represents the shallowest population of this species and of this genus known worldwide. A total of 188 specimens were observed and measured: the maximum density of 45 specimens m^{-2} was reached in the most shaded part of the dock, where the maximum height of colonies (30 cm) was also recorded. Light measurements showed that the illuminance along the dock was comparable to that observed outside the harbour at 20 m depth, where the nearest colonies of *L. sarmentosa* were recorded for this region. This suggests that high levels of incident light might be putatively interpreted as the limiting factor in the upper bathymetrical distribution of the species. Despite the extremely shallow distribution, however, the population cannot be defined as intertidal as the floating dock avoids exposing the gorgonians to air. The chance to grow far from the silted bottom, but still in a turbid, sciaphilous and nutrient-enriched environment, probably enhanced the settling and growth of the colonies and allowed the formation of a dense and healthy population.

Keywords: Leptogorgia sarmentosa*, shallow water, Genoa harbour, Ligurian Sea, Mediterranean Sea*

Introduction

Harbours are recognised as extreme marine ecosystems characterised by a wide array of environmental constraints such as high silting levels, low water circulation, sediment and water hypoxia, and high concentration of nutrients and pollutants, as well as a frequent occurrence of artificial substrates and ample variations of temperature and salinity not necessarily related to natural seasonal cycles (Ruggieri et al. 2011). The benthic communities thriving in this habitat are overall poor and dominated by pioneer species with short life cycles, occasional or visiting species, or highly tolerant organisms showing great adaptability to changing or extreme conditions.

Harbours are mostly known as crucial focal points to monitor the entrance and establishment of non-indigenous species (NIS), mainly because of vessel traffic, a known worldwide vector of marine organisms that are carried among basins through fouling on hulls or in ballast waters (Zenetos et al. 2012). Nevertheless, the harbour marine fauna is also constituted by many native species, selected by their natural capability to thrive in the difficult conditions characterising these sites. In particular, the low water renewal rate, the high sedimentation rate and the high concentrations of pollutants strongly select for soft-bottom benthic communities with low species richness (Guerra-Garcia & Garcia-Gomez 2004); hard-bottom assemblages are usually confined to the walls of jetties, docks and seawalls. Light penetration represents an important constraint factor for this type of community: Blockley (2007), for example, noticed that in the Sydney Harbour it was possible to distinguish two assemblages, depending on the presence or absence of wharves and their influence

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on illuminance: a sciaphilous community, mainly constituted by sessile invertebrates, and a photophilous one, dominated by macroalgae. In addition, thanks to the high sedimentation rate and organic input, harbours tend to select for mainly filter-feeding animals, such as cnidarians (Saiz-Salinas & Urdangarin 1994): hydroids such as *Eudendrium racemosum* (Cavolini, 1785) (Rossi 1964) and *Ectopleura crocea* (Agassiz, 1862) (Schuchert 2010) are known to be frequent inhabitants of Mediterranean harbours, probably also in relation to their preference for artificial substrates and their strong seasonality (Puce et al. 2009).

Among the large sessile fauna able to tolerate the harsh harbour conditions, gorgonians of the genus *Leptogorgia* Milne Edwards and Haime, 1857 (Alcyonacea: Gorgoniidae) are notable. In particular, *Leptogorgia virgulata* (Lamarck, 1815), common in the Gulf of Mexico, has been frequently reported associated with jetties and other man-made structures (Williamson et al. 2011). Also, the Mediterranean *Leptogorgia sarmentosa* (Esper, 1789) has been reported in the grey literature from such habitats (Marco Faimali, pers. comm.), even if this species is more commonly found in non-harbour conditions (Carpine 1963; Weinberg 1976; Gori et al. 2011a; Gatti et al. 2012). The morphological features of the harbour populations as well as their ecological characteristics have never been described or compared to their natural counterparts, and this might represent a crucial knowledge gap when monitoring the environmental status of the port benthic communities and their adaptability and response to natural or anthropic changes.

Here we describe a dense aggregation of *Leptogorgia* sea fans thriving just below the sea surface, observed along a floating dock during a biological survey conducted inside the inner part of the Genoa harbour.

Materials and methods

Study site

The Genoa harbour is located in the central portion of the Ligurian Sea (North-western Mediterranean Sea, Italy) and represents one of the major Mediterranean commercial and touristic ports: it covers an area of approximately 7 million m^2, spanning about 20 km of coastline. The water temperature inside the harbour seasonally ranges between 12 and 29°C, while the salinity ranges between 36 and 38 Practical Salinity Units (PSU) and turbidity usually shifts between 5 and 15 Formazin Turbidity Units (FTU) (Ruggieri et al. 2011). The studied dock lies in the inner, historical part of the harbour, and extends in the water following a direction of about 300° (WGS84 coordinates: base at 44°24’33.1”N, 008°55’38.7”E; extremity at 44°24’34.1”N, 008° 55’34.9”E) (Figure 1a). The dock is 75 m long and 2 m wide, and it is constituted by six wood modules (labelled from A to F seawards in Figure 1b), between 10 and 17 m long, sustained by a total number of 25 square concrete floats. For the purposes of this study, floats have been sequentially numbered from 1 to 25 from the land towards the sea. Each float is 2 m long and submerged to around 20 cm. The southern side of the dock is approximatively 2 m away from a wider concrete platform, and half of its length (the central portion, above floats 10 to 23) is covered by a large awning that shades the side of the dock facing the platform (Figure 1b).

In situ activities

During August 2017 the whole dock was inspected both from the surface and by snorkelling and scuba diving. In order to describe the population structure, all the specimens of *Leptogorgia* found on each float of the dock were counted and measured with the aid of a calliper. Three colonies were collected for further taxonomic investigations to unequivocally identify the species. Observations were carried out also on the other components of the benthic community.

Light measurements

On three occasions between August and October 2017, light measurements were taken by means of a Sunche HS1010 light meter in order to describe the zonation of the colonies in response to illuminance. In particular, in each survey conducted in full daylight at noon on sunny days, the maximum light intensity, recorded above the surface, and the light intensity below the surface, at 30 cm depth in the shadiest portion of the dock, close to float 15, were noted. Five other measurements were conducted along the Paraggi cliff, in the partial protection zone of the Portofino Marine Protected Area, 25 km far from the Genoa harbour, both on the surface (at noon on sunny days) and at 20 m depth in correspondence to the shallowest colonies of a small *L. sarmentosa* population, which represents the next closest known population of this species to the study site. Some specimens were collected from Paraggi for further analysis. The data obtained were also compared to data in the literature.

Microscopic observations

Portions 1 cm long of the collected samples were dissolved in sodium hypochlorite to isolate and observe sclerites, essential for the taxonomical identification of the species. The resulting sclerites were cleaned with

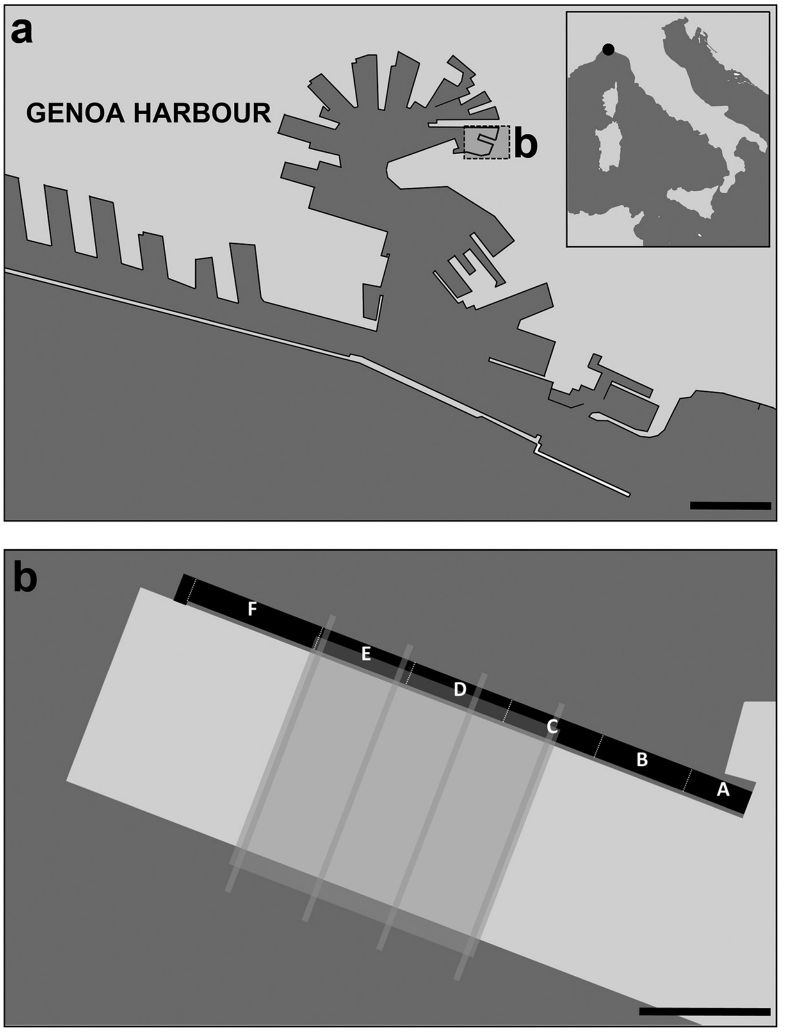

Figure 1. (a) Map of the study area and (b) floor plan indicating the floating dock (black), the concrete platform (light grey) and the awning (translucent dark grey). Scale bars: a = 500 m; b = 30 m.

distilled water and ethanol (70%), mounted on stubs covered with a carbon layer adhesive disk, sputter-coated with gold-palladium and observed with a Vega 3_TESCAN Scanning Electron Microscope (SEM) Tescan Vega 3 LM. The same treatment was applied on a specimen found in the nearby site of Paraggi (Ge).

Results

Taxonomic identification

The observed specimens were branched on multiple planes, with many slender, whip-like branches, slightly flattened at the tip; the colonies ranged in colour from bright red to orange and yellow, and the polyps were small (on average around 1 mm high), of the same colour as the colony or a little bit lighter. Light and SEM analysis of the sclerites of the collected samples confirmed that the gorgonians colonising the floating dock belonged to the species *Leptogorgia sarmentosa*, hence excluding the possibility of an invasive species. In particular, among the sclerite components, several types were recognised (following Bayer et al. 1983): long, tuberculate coenenchymal spindles (from 40 to 210 μm long); capstans (90 μm long); and anthocodial rods (70 μm long) (Figure 2a). A comparison with the sclerites obtained from the specimen collected in Paraggi confirmed the identification, despite showing a small amount of sclerite variability, typical of this species (Carpine & Grasshoff 1975) (Figure 2b).

Population structure

A total of 188 specimens were counted exclusively along the southern side of the dock, resulting in an average density along the side of 18.8 specimens m^{-2} (25 floats, each with a lateral submerged portion of 0.4 m^2; Figure 3a,b). No colonies were observed on the northern side of the dock, or on the adjacent concrete platform or the surrounding areas. The gorgonians were equally distributed along the whole height of the floats, from the surface (some branches effectively touching it) to 20 cm depth, on the edges of the floats (Figure 3c–e). On the submerged portion of the floats, the biological community included also algal turf, frondose rhodophyceans, sessile polychaetes such as *Sabella discifera* Grube, 1874 and the alien species *Branchiomma luctuosum* (Grube, 1870), and the alien bryozoan *Amathia verticillata* (delle Chiaje, 1822).

The gorgonian colonies were concentrated mainly in the central portion of the dock: the fourth module (sustained by floats 11 to 14) included the highest number of colonies, spanning between 14 and 18 specimens on each float (for a maximum density of 45 specimens m^{-2}). In contrast, the first nine floats, lacking the awning to provide shade, together hosted a total of 16 colonies (average density of 4.4 specimens m^{-2}); similarly, floats 24 and 25, exposed to direct sunlight, showed a further decrease in the

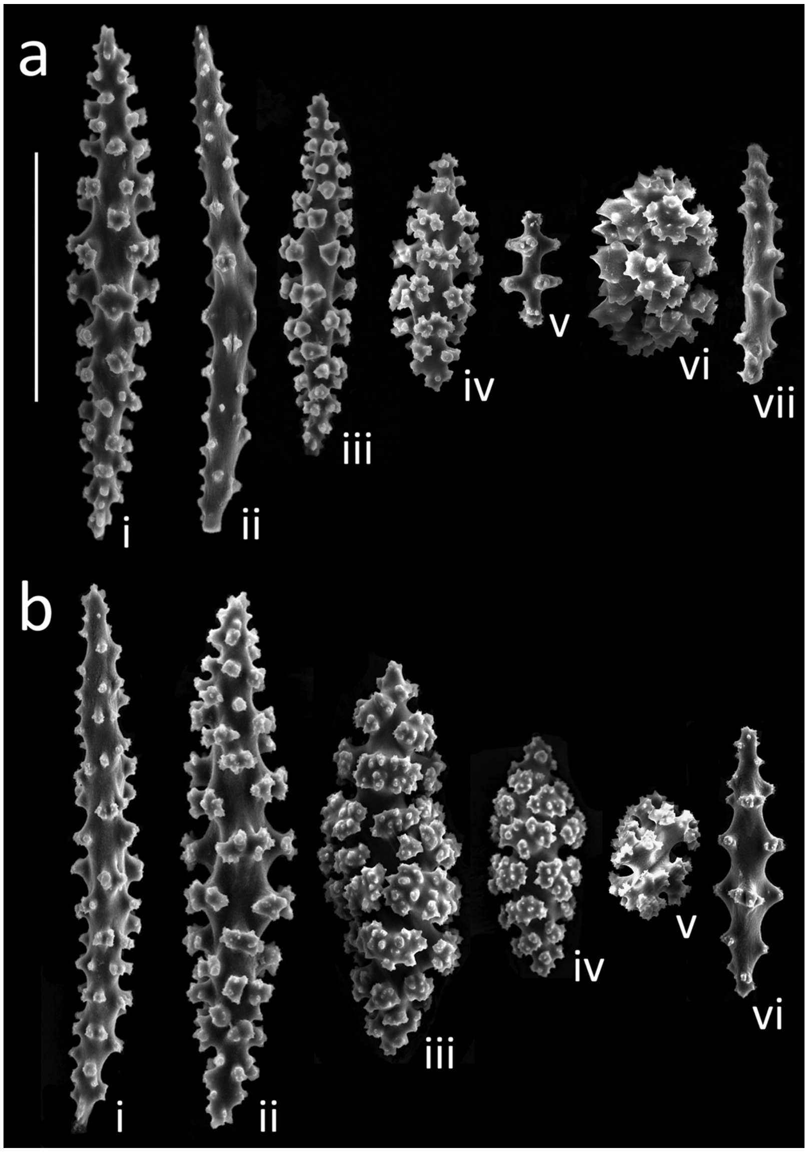

Figure 2. Sclerites of *Leptogorgia sarmentosa*. (a) Harbour colonies: coenenchymal spindles (i–v) and capstan (vi), and anthocodial rod (vii). (b) Paraggi colony: coenenchymal spindles (i–iv) and capstan (v), and anthocodial rod (vi). Scale bar: 100 μm.

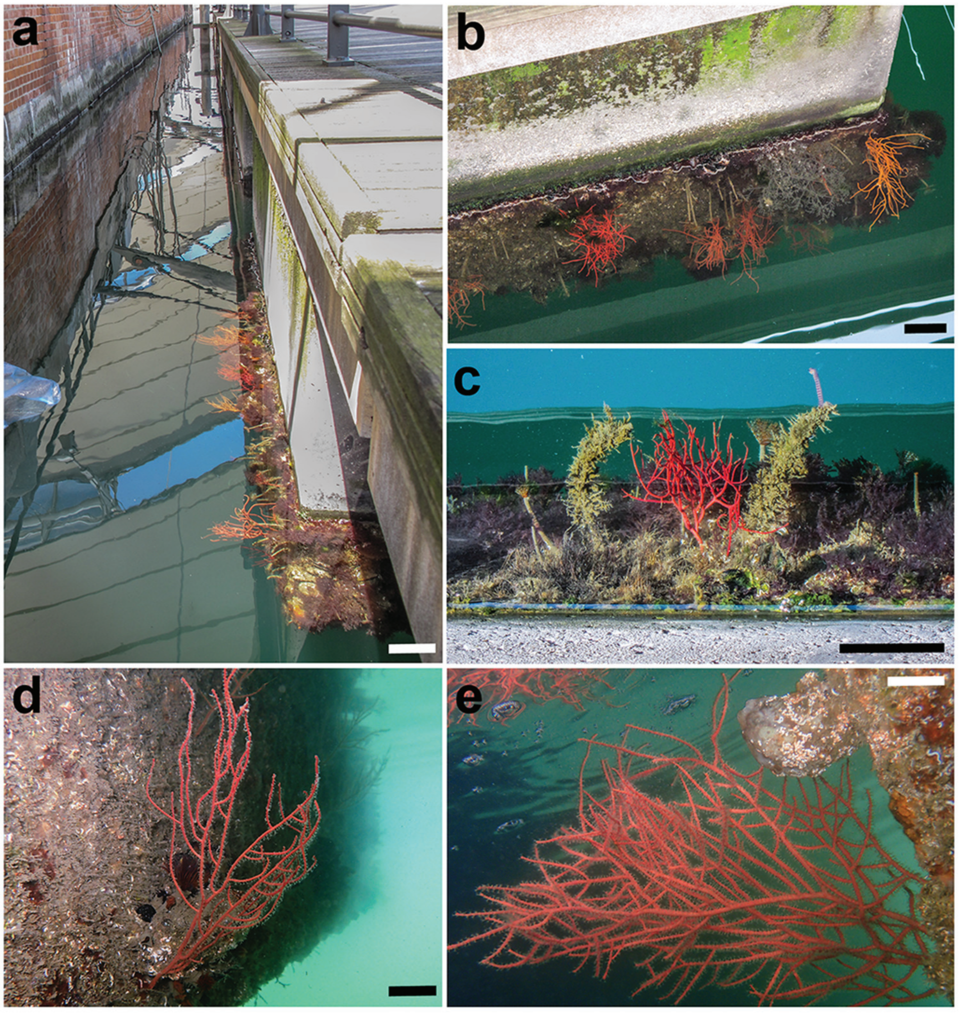

Figure 3. *Leptogorgia sarmentosa* along the floating dock. (a) The channel between the dock and the concrete platform, with *L. sarmentosa* colonies growing only on the dock's side. (b,c) Colonies thriving at the water surface. (d,e) Underwater pictures of two colonies. Scale bars: a–c = 10 cm; d, e: 2 cm. (Pictures a and b courtesy of Francesco Enrichetti; pictures d and e courtesy of 5th Coast Guard Diving Team of Genoa).

number of colonies (five and two, respectively, for an average density of 8.8 specimens m^{-2}) (Figure 4a). The size of the colonies follows a similar trend: the average height along the whole dock was 12.8 ± 1.1 cm, with the two largest colonies reaching a maximum length of 30 cm. The largest specimens were concentrated in the central, shaded portion of the dock, and the maximum average size of the colonies (20.3 ± 1.2 cm) was found on float 10. The average height of the colonies growing on exposed floats (1–9 and 24–25) was 7.0 ± 0.6 cm, while the average height of colonies on shaded floats was 15.8 ± 0.5 cm (Figure 4b).

The light measurements on the dock detected an average external light intensity of 83,100 ± 6000.8 lux, and an average illuminance at 30 cm depth of 1598.3 ± 39.2 lux, meaning that the *L. sarmentosa* colonies receive only 1.9% of the maximum solar light reaching the dock. The light measurements performed in Paraggi indicated a light intensity of 86,000 lux on the surface and 3100 lux at 20 m depth, corresponding to 3.6% of the surface light.

Discussion

The discovery of the present population is an exceptional finding in many ways, and may represent an important improvement in the knowledge of Mediterranean gorgonian ecology. The genus *Leptogorgia* includes more than 100 species of sea fans widespread in temperate and tropical seas from shallow to very deep waters (Bayer 2000).

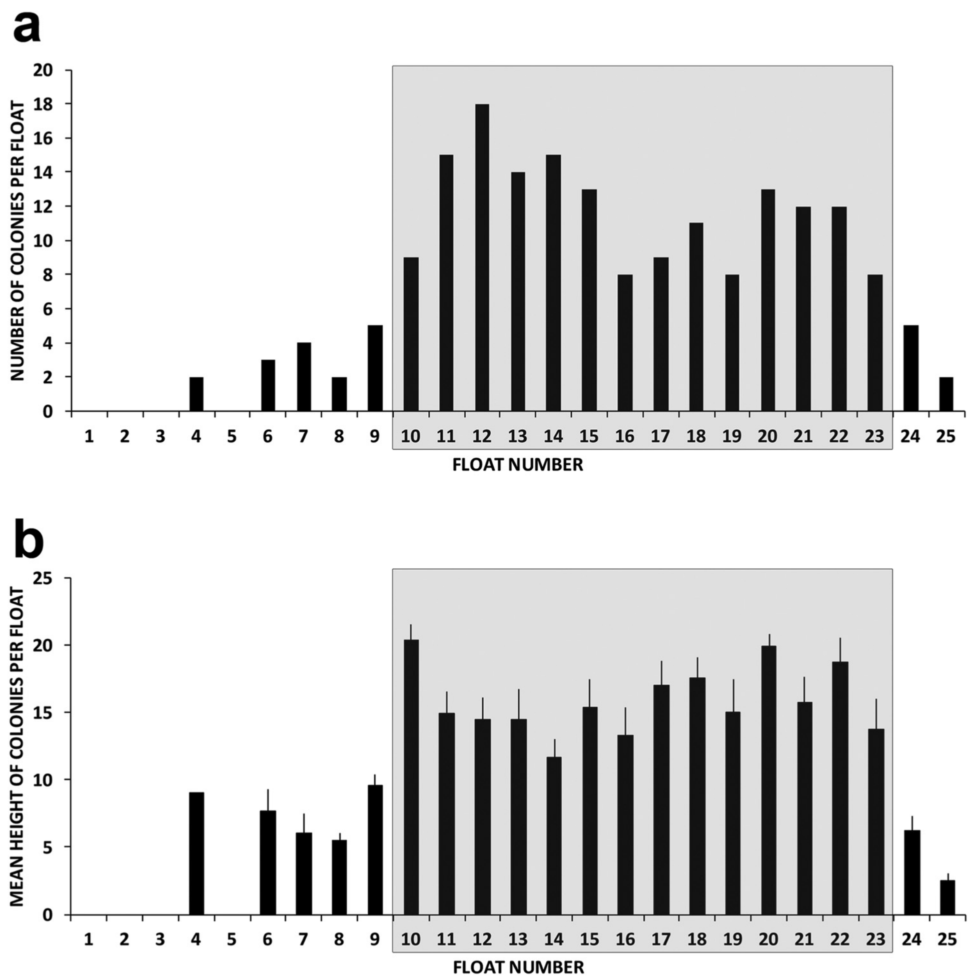

Figure 4. (a) Distribution of *Leptogorgia sarmentosa* colonies along the floating dock and (b) their average sizes (± standard error) per float. Numbers 1 to 25 indicate the concrete floats sustaining the dock, from the coast towards the sea; the grey squares indicate the floats covered by the awning, and therefore in sciaphilous conditions.

The species belonging to this genus are known for their extreme variability in terms of colony shape, colour and sclerital set (Carpine & Grasshoff 1975; Breedy & Guzman 2007). The specimens found along the floating dock showed both external and sclerital morphologies well fitting the features of the species *L. sarmentosa* (Carpine & Grasshoff 1975; Grasshoff 1992). The taxonomic identification was a significant aspect of this study since the harbour location and the extremely shallow distribution led us to hypothesise a possible invasive species, while the analysis confirmed that the population is actually constituted by a native Mediterranean species. Interestingly, the sclerital set of the harbour specimens matched those reported by Carpine and Grasshoff (1975) and Grasshoff (1992) in specimens collected inside the Marseille harbour (France), with special reference to the occurrence of very small spindles with few large warts (40 µm long) (Figure 2a–v). The gorgonian sclerite sets may vary slightly depending on the geographic location, depth range, specimen, size, analysed portion of the colony and predation pressure (Carpine & Grasshoff 1975; West et al. 1993; Breedy & Guzman 2007); it is therefore conceivable that a particular harbour's environmental condition may select for certain populations of this species. This is supported by the slightly different sclerite set observed in the Paraggi specimens, which is comparable to another set described by Carpine and Grasshoff (1975) for other Mediterranean specimens, and which lacks the small spindles typical of harbour specimens.

Leptogorgia sarmentosa is known to be an extremely resistant species, able to thrive in harsh environmental conditions, such as those typical of harbour habitats; for example, it is known to prefer high-nutrient waters (rich in small zooplankton on which it feeds; Rossi et al. 2004) and non-cohesive bottoms, and possesses the consequent ability to tolerate high silting levels and turbid waters (Pérès 1967; Weinberg 1978; Gili & Ros 1985; Relini et al. 1986; Grasshoff 1992; López-González 1993; Balduzzi et al. 1994; Bianchi 2007; Gori et al. 2011a,b). Even the colony shape possibly evolved to thrive in these conditions: the species is characterised by thin and long branches, not anastomosed, in order to reduce surface area prone to sediment accumulation (Cocito et al. 2002), and the branches can shrink in case of environmental stress, such as low food availability or high water temperature, as a fast response enhancing population maintenance (Weinbauer & Velimirov 1998; Rossi et al. 2011).

On the other hand, the bathymetric distribution of the studied population is unusual. Some species of the genus *Leptogorgia* are known for their ability to colonise very shallow waters: remarkable examples are *L. virgulata*, which can be found as shallow as 1–1.5 m depth and once or twice a year can remain temporarily exposed (Gotelli 1988; Mitchell et al. 1993), and *Leptogorgia cofrini* Breedy and Guzman (2005), which is abundant between 10 and 15 m depth between Costa Rica and Panama, but can be found as shallow as 1 m deep (Breedy & Guzman 2005). In the Ligurian Sea, the shallowest specimens of *L. sarmentosa* were recorded at 16 m depth in turbid waters (Mistri & Ceccherelli 1993), while the world record shallowest example of this species is at 7.5 m depth along the Algarve coast (although it appears to be more abundant at increasing depths) (Cúrdia et al. 2013). Within the Genoa harbour some colonies were found living on concrete blocks at 14 m depth (Marco Faimali, pers. comm.). Except for the occasional temporary exposure to air of *L. virgulata* in the Gulf of Mexico, the *L. sarmentosa* forest described here, thriving just below the water surface, represents the shallowest population of a species of the family Gorgoniidae known worldwide.

Leptogorgia sarmentosa usually does not form the dense forests typically constituted by other Mediterranean gorgonians (Mistri 1995; Rossi 2002), but monospecific gardens of this species are known from the eastern Ligurian Sea (Rossi 1965) and the Gulf of Lion (Weinberg 1979, 1980), characterised by turbid conditions (Table I). The mean and maximum density of specimens in the studied site indeed indicate an environment particularly suitable for their proliferation, as in a natural environment the species can reach a maximum density of 17 specimens m^{-2} (Weinberg 1979). As Weinberg (1978) stated, the two main factors affecting octocoral-dominated communities are irradiance and silting levels on the substratum. The fact that the gorgonians are found only along the southern side of the dock, close to the concrete platform, and that the higher densities and heights are recorded on the floats lying in the more shaded portion of the dock, indicates that the light in this site does not represent a limiting factor in the bathymetrical distribution of the species here, as it is under natural conditions. It is particularly noteworthy that the light intensity measured at 20 m depth in Paraggi, where the natural specimens of *L. sarmentosa* colonies grow, is comparable to the values recorded in the shaded portion of the dock. In support of these data there is a light profile made along a bathymetrical transect on the Portofino Promontory, close to Paraggi, reporting at 16 m depth the same amount of average light intensity as recorded in the harbour (Sarà et al. 1978). In this specific case, as the shaded environment allows the colonies to reach the water surface, it is important that the floating dock avoids exposing the gorgonians to the air during low tides. At the same time, considering that the semi-enclosed harbour basin enhances water stratification, it is evident that the gorgonians also have a good endurance to the freshwater input originated by precipitation. Regarding the second constraint, i.e. the presence of sediment on the sea bottom, even if the species is well adapted to high sedimentation rates, the chance to grow far from the silted bottom probably

Table I. The main *Leptogorgia sarmentosa* populations described in the Mediterranean Sea.

Reference	Region	Site	Habitat	Depth (m)	Max. density (specimens m^{-2})	Max. height (cm)
Mistri 1995	Ligurian Sea	La Spezia Gulf	Sediment covered bottom	19–22	9.8	100
Cocito et al. 2002	Ligurian Sea	La Spezia Gulf	Muddy bottom	17–24	-	-
Present paper	**Ligurian Sea**	**Genoa harbour**	**Concrete dock**	**0–0.2**	**45**	**30**
Balduzzi et al. 1994	Ligurian Sea	Gallinara Island	Detritic bottom	> 17	-	-
Weinberg 1976	Gulf of Lions	Banyuls-sur-Mer	Hard bottom	> 18	12	-
Weinberg 1979	Gulf of Lions	Banyuls-sur-Mer	Sediment covered bottom	> 10	17	-
Gori et al. 2011a	Gulf of Lions	Cape of Creus	Maerl, pebble, rocks	11–61	0.5–1.5	-
Rossi et al. 2004	Gulf of Lions	Medes Island	Small stones	20	1.5	-
Rossi et al. 2011	Gulf of Lions	Medes Island	Detritic-muddy bottom	25–50	1.2	-
Carpine & Grasshoff 1975	Mediterranean Sea		Various bottoms	15–300	-	-

enhanced the survival of the colonies and allowed the formation of a dense population. In this regard, it is known that the congeneric *L. virgulata*, although very tolerant to high sediment rates, shows a reduction in recruitment in the presence of sand, which ultimately inhibits the development of the assemblage (McGuinness 1987; White & Strychar 2011).

Also of note is the tolerance of this species to extremely high temperatures that, inside the harbour, can be as high as 29°C; in the last 20 years, different benthic species living in the Ligurian Sea have been subjected to mass mortality episodes, usually related to high temperature values: *L. sarmentosa* proved to be the only gorgonian not affected by these events (Sarà et al. 2003), and the present population confirms the high tolerance of this species to extreme and rapid changes in temperature. The Genoa harbour population might represent a good case study to understand the physiological features that allow this species' survival under rapid and extreme temperature changes. The ability to resist difficult conditions allows this species to colonise extreme environments, acting as an opportunistic species, which is probably the reason for its colonisation of the floating dock. This feature is also stressed by the rapid growth: the estimated growth rate of *L. sarmentosa* is 2.6 cm yr^{-1} (Mistri & Ceccherelli 1993; Mistri 1995), with maximum recorded heights of about 100 cm and average sizes of approximately 40 cm (Carpine & Grasshoff 1975; Weinberg 1978, 1979; Francour & Sartoretto 1992; Mistri & Ceccherelli 1993). The average size of the dock colonies suggests they are about 5 years old, while the largest specimens, up to 30 cm high, allow us to hypothesise a first settlement episode around 11 years ago. The high organic concentrations in the harbour may plausibly have increased the growth rates; in particular, larval dispersal might have originated more recently from the deeper population present at the site.

Acknowledgements

Images were acquired at the Scanning Electron Microscopy Laboratory installed at the Department of Earth, Environment and Life Sciences, University of Genoa; we acknowledge the technician Laura Negretti for sample coating. The authors would like to express their gratitude to Rear Admiral (ITCG) Giovanni Pettorino for the authorisation to operate in the Genoa harbour; many thanks also to L. Commander (ITCG) Felice Monetti, Lieutenant (ITCG) Angelo Doria and all operators of the 5th Coast Guard Diving Team of Genoa for their help in collecting samples and data in the waters of the harbour, and for the useful photos taken for the study. Finally, the authors would like to thank Oscar Bava, a young naturalist, who was the first to notice the assemblage here described.

Disclosure statement

No potential conflict of interest was reported by the authors.

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