



The rare, giant gorgonian *Ellisella paraplexauroides*: demographics and conservation concerns

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ABSTRACT: A striking occurrence of the gorgonian coral *Ellisella paraplexauroides* off the Chafarinas Islands (western Mediterranean) requires serious conservation attention owing to considerable damage initiated by small fishing operations. Although this gorgonian is among the largest Atlantic-Mediterranean invertebrates, its biology remains virtually unknown. The studied population, established within an area of regulated fishing, was in unusually shallow waters (12–32 m). Density averaged 0.5 colonies m⁻² (max 5 m⁻²); colony volume averaged 48 ml (max 511 ml), height averaged 76 cm (max 167 cm), and number of branches averaged 16 (max 72). Allometric growth revealed increasing branching and thickening once colonies reached approximately 60 cm in height. Size distribution suggested moderate to low recruitment. Three geographic zones of fishing pressure (A–C) were semi-quantitatively identified, based on the activity of a small-scale fishing fleet: 'A' had the highest level of fishing pressure (frequent gillnetting, trolling lines, and occasional trawling); 'B' had the lowest level (occasional gillnetting and fishing lines), and 'C' an intermediate level. Most fishing gear was tangled in the gorgonians in zones A and C. Mortality and colony damage were significantly higher in zones with intensive and poorly regulated fishing activity and appeared unrelated to predation or disease. In high-pressure zone A, about half (44.6%) of the colonies were dead, while about 82% of the surviving colonies showed significant damage, with a large number of epibionts disrupting colony functioning. The Chafarinas population of *E. paraplexauroides* is likely a unique Mediterranean relic from a Mauritanian-Senegalese Pleistocene interglacial expansion but is now being seriously impacted by illegal fishing.

KEY WORDS: Gorgonian mortality · Population structure · Small-scale fishing · Fishing impacts · Gorgonian predation · Epibiosis · Chafarinas Islands · Corals

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INTRODUCTION

The gorgonian *Ellisella paraplexauroides* (Stiasny 1936a) is one of the largest colonial invertebrates in the Mediterranean and the only member of the genus *Ellisella* (Anthozoa, Alcyonacea, Ellisellidae) recorded in European waters (Grasshoff 1992). In the North Atlantic, the species occurs along the west coast of Africa (from Angola to Morocco), off the Canary Is-

lands, and at some sites in southwestern Spain (reviewed by Angiolillo et al. 2012). In contrast, *E. paraplexauroides* is rare and discontinuously distributed in the Mediterranean, thus far found only in isolated colonies on the Seco de los Olivos offshore bank (Almería, Spain), around Alboran Island, along the Ceuta and Melilla coasts, at some locations off Algeria and Tunisia, and in the Strait of Sicily (Arroyo et al. 2008, Angiolillo et al. 2012). Samples are occasionally

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found in the catch of fishing trawls, and sightings have been reported during remotely operated vehicle (ROV) explorations (Oceana 2006, Angiolillo et al. 2012). The optimal depth range is believed to be 50 to 150 m (Arroyo et al. 2008, Angiolillo et al. 2012), although the species has been recorded at an extreme range of depths—from as deep as 690 m in the Canary Islands (Brito & Ocaña 2004) to as shallow as 15 to 35 m in the vicinity of the Strait of Gibraltar and around the Chafarinas Islands (Arroyo et al. 2008). Although *E. paraplexauroides* is a large and charismatic invertebrate, very little is known about its basic ecology, biology, and population organization.

Our exploration of the deep continental shelf (70 to 200 m) of Alboran Island via ROV in September 2011 and scuba dives on the shallow shelf (0 to 35 m) of the Chafarinas Islands in September and October 2009 to 2011 revealed only a few scattered colonies of *Ellisella paraplexauroides* on the Alboran deep shelf, but a relatively dense population on the Chafarinas shallow shelf. This unusually shallow population resides primarily in a regulated fishing area on the archipelago shelf and provides an unparalleled opportunity to investigate the basic and thus far unknown demographic parameters of this species. To this end, we examined colony abundance, density, volume, biomass, size distributions, and 'health' condition. Colony health became particularly relevant, owing to the abundance of damaged and dead colonies observed during the period of study.

Some major threats to gorgonian populations are predation, disease, and fishing gear entanglement. Gastropods, crustaceans, and polychaetes are well-known predators of gorgonian polyps (e.g. Ott & Lewis 1972). Although predation rarely leads to colony death, a massive attack by caprellids has been shown to cause significant local mortality (e.g. Scinto et al. 2008). In the past decade, gorgonian populations have also reportedly suffered severe diseases triggered by a complex combination of pathogenic microbes and abnormally high seawater temperatures (Garzón-Ferreira & Zea 1992, Nagelkerken et al. 1997, Cerrano et al. 2000, Perez et al. 2000, Rosenberg & Ben-Haim 2002, Hall-Spencer et al. 2007, Coma et al. 2009). As just mentioned, the third major threat derives from assorted fishing practices, as is evident from increasing reports of damage in this regard. For instance, coastal sport fishing (fishing rods), artisanal small-scale fleets (operating long-lining, trawling lines, gillnetting, trap deployment, etc.), and boat anchorage have been shown to damage from 25 to 40% of the gorgonians in areas where those activities are common (e.g. Bavestrello et al.

1997, Chiappone et al. 2005, Heifetz et al. 2009, Shester & Micheli 2011). Therefore, we have also assessed the role of predation, disease, and small-scale fishing as sources of colony damage. As this study makes clear, the gorgonian populations off the Chafarinas Islands are being affected by illegal small-scale fishing within an area of regulated fishing.

MATERIALS AND METHODS

Study region

The Chafarinas Islands lie in the southern part of the Alboran Sea in the western Mediterranean (Fig. 1). This region has a complex hydrography, characterized by a large influx of North-Atlantic surface water, which in the Alboran Sea branches into several cyclonic and anticyclonic gyres (Tintoré et al. 1988, Vargas-Yáñez et al. 2002).

The archipelago of the Chafarinas Islands consists of 3 islets: Congreso, Isabel II, and El Rey, hereafter referred to as islands or zones A, B, and C, respectively (Fig. 1). These islands are 3.2 km from the coast of Morocco, the closest land site. Islands A and C emit minimal pollution and sewage as they have been uninhabited for over 60 years. Since 1948, a small, but permanent, population—currently consisting of only about 40 members of the Spanish Army and 4 members of the Spanish Natural Parks (OAPN)—has been present on island B. The archipelago's terrestrial ecosystems have been protected under conservation legislation since 1982, whereas the marine habitats received little attention until July 2006, when the islands gained the legal status of a Site of Community Importance (SCI). As a result, fishing and extractive activities have come under regulation within a band of water extending 0.5 km from the archipelago coastline. Nevertheless, both before and after the declaration of SCI status, Spanish authorities have done little to discourage the illegal trawling and gill-net fishing that local fishermen conduct daily within the SCI regulated zone. In 2 of the selected study zones, that is, on the western side of island A and the eastern side of island C (Fig. 1), poaching is particularly prevalent because illegal fishers can go undetected. Since the Spanish authorities staff the watchtowers only on island B, poaching seldom occurs in the third study zone on the northern side of island B (Fig. 1), which is located directly below the main watchtower.

Because bottom trawling, gillnetting, and/or trolling are known to have a considerable impact on

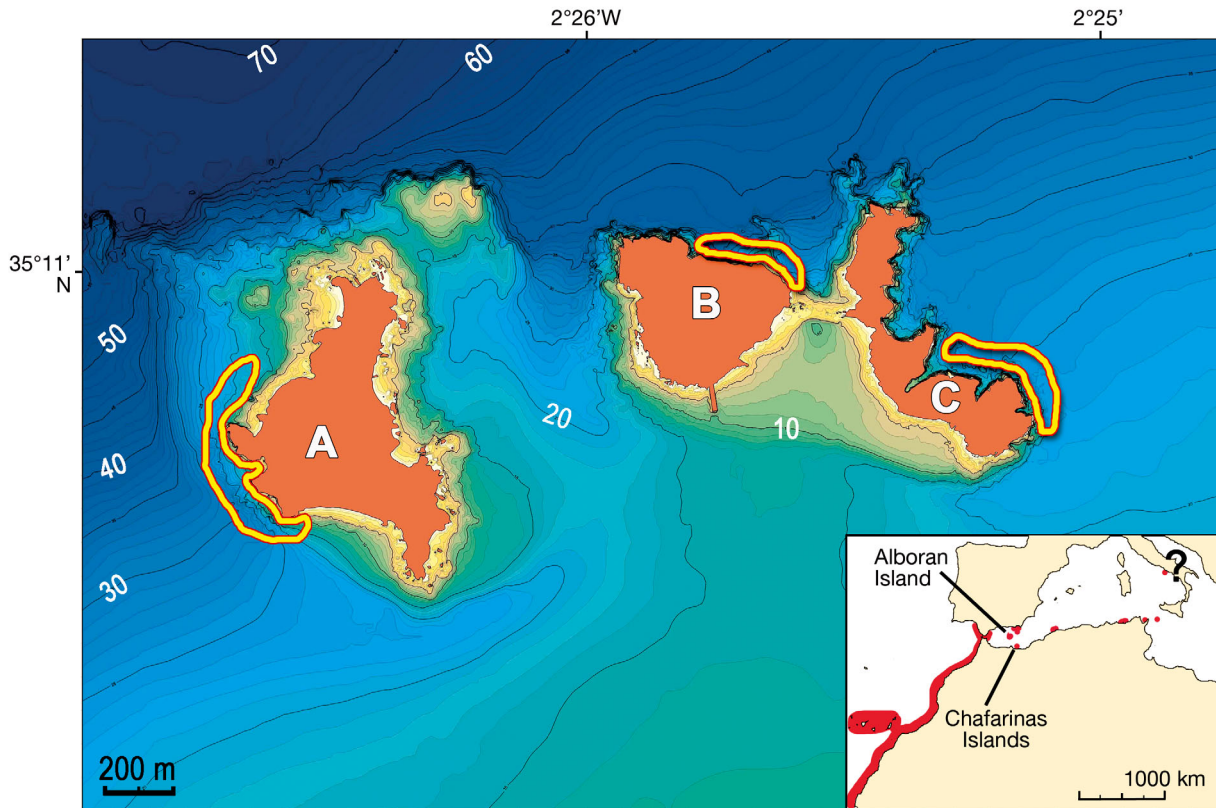


Fig. 1. Biogeographical distribution of *Ellisella paraplexauroides*. The inset shows the general species distribution (in red) relative to the Alboran and the Chafarinas Islands; the occurrence of the species in coastal waters around Naples is doubtful (?). The larger map shows the specific location of the 3 study zones (outlined in yellow) around the Chafarinas Islands (A = Congreso island, B = Isabel II island, C = El Rey island); white numbers = bottom isobaths

large 3-dimensional organisms such as *Ellisella paraplexauroides*, it seemed useful to compare the results of fishing pressure in these 3 zones. During our scuba dives, we documented evidence of fishing lines and gillnet gear on the bottom of all 3 zones, which coincides with available OAPN information. Fishing gear was more abundant in zone A than in zones B and C. In zone A, we photographed cases of illegal trawling occurring less than 150 m from the island shore and in depths of about 10 to 15 m. In recent years, OAPN staff have documented similar illegal trawling both in zone A and in zone C. Still cameras have captured evidence of gill net deployment in these 2 zones as well, although the authorities have seized such nets in only a single case in the past 4 years. It was difficult to quantify the exact between-zone differences in fishing pressure as many of the gear deployments occur during the night and monitoring these activities was risky and beyond the logistical capabilities of the research team. Even so, all information collected to date makes it clear that fishing pressure in zone A is

higher than in zone C, which in turn is higher than in zone B.

The various environmental parameters (e.g. seawater temperature, salinity, plankton abundance, siltation, overall hydrodynamic exposure) in the 3 study zones exhibit no major differences that could substantially affect gorgonian occurrence (Fig. 1). Indeed, colonies of *Ellisella paraplexauroides* and several other gorgonians are common in all 3 zones. Bottom structure is also similar in the 3 study zones: from 0 to 20–25 m, vertical rocky walls and overhangs alternate with a less steep hard-bottom profile (Fig. 1); below 20 to 25 m, the bottom consists of a sandy seabed with a scattering of large boulders.

Sampling design

Our team made 3 fortnightly trips to the Chafarinas Islands, the first of which occurred in October 2009 and focused on inspecting the population, identifying potential sources of damage, and establishing an ap-

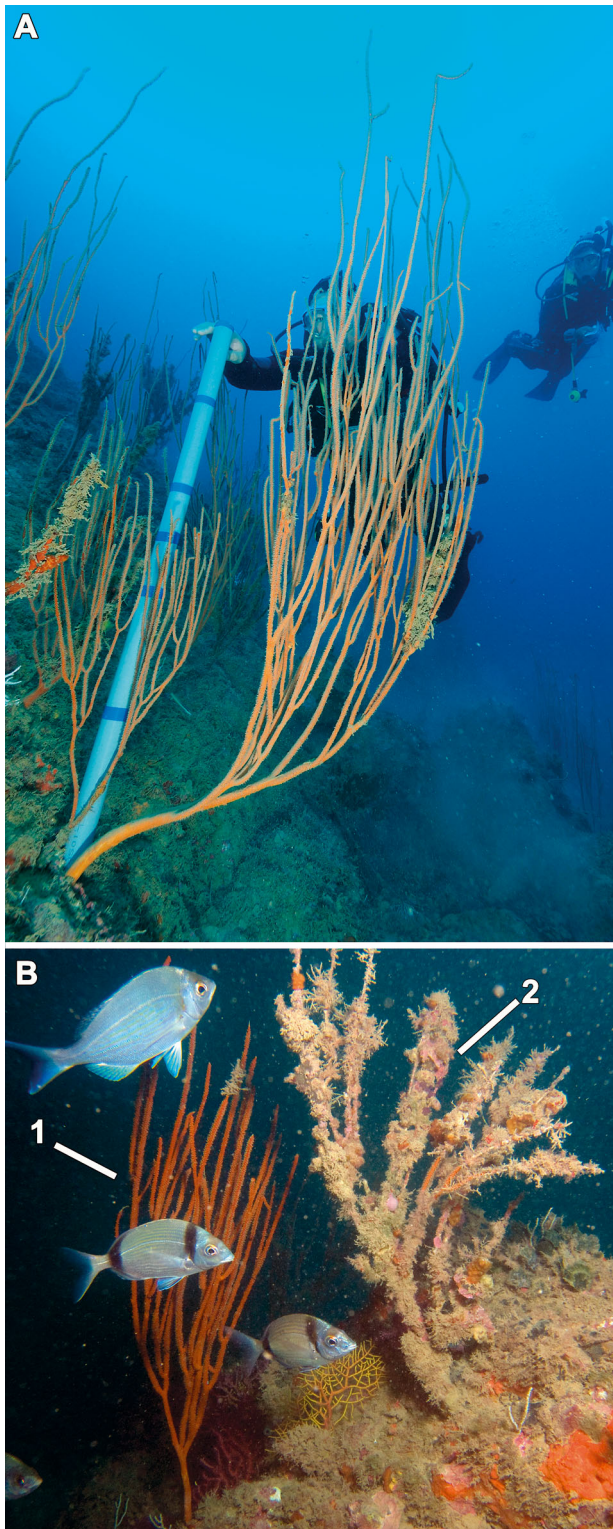


Fig. 2. *Ellisella paraplexauroides*. In situ views of the gorgonian at 15–32 m depth. (A) Healthy colonies at 25 m in zone B, being photographically scaled with the help of a marked 1m pole for further morphometric analyses. (B) Comparative view of a healthy colony (1) adjacent to a dead colony (2) entirely fouled by epibionts

proach to survey design. The 2 subsequent trips (in October 2010 and September 2011) were devoted to the survey and data collection. Colony abundance, size, damage, and mortality counts were obtained using 1×1 m quadrats during scuba dives. The quadrat size was 4 times larger than that usually applied in work on midsized gorgonians, such as *Paramuricea clavata* (e.g. Linares et al. 2008). It was also the largest practicable size with which to achieve high survey replication as well as meet dive safety standards. The quadrats were randomly distributed at depths of 12 to 32 m, and the number of living and dead gorgonians recorded in each. We also obtained wide-angle, scaled digital images of each gorgonian (Fig. 2). Photographs were processed using Image J Software to quantify volume, biomass, total height, number of terminal branches (tips), and epibiont load (see details in subsequent sections). Living gorgonians were divided into 2 categories: healthy (with no noticeable physical damage or epibiotic load; Fig. 2A) and damaged (showing obvious physical injuries, fishing line tangles, and/or serious epibiotic load; Fig. 2B). We took high numbers of replicates in the quadrats of all 3 zones ($n_A = 250$; $n_B = 252$; $n_C = 258$) to ensure that representative values could be obtained for each of the quantifiable variables.

Density of colonies

Average (\pm SD) number of living colonies m^{-2} were estimated for each study zone (A, B, C) and then pooled for the entire archipelago. Because the most suitable conditions for *Ellisella paraplexauroides* growth are assumed to be in the 50–150 depth range whereas we were investigating an unusually shallow population (<35 m depth), we had to consider the possibility that the Chafarinas population might consist of highly stressed colonies growing at the upper limit of their environmental tolerance. To test this plausible hypothesis, we examined the density of colonies for variation with depth over the range of sampled depths (12 to 32 m) using regression analysis.

Biomass, size and morphological complexity

Morphometric software applied to the scaled digital images (Fig. 2A) provided estimates of total volume, maximum height, and number of terminal branches (tips) for each colony. The tip data served to indicate actual branching level or morphological complexity.

To estimate volume, we decomposed the 2-dimensional images of the gorgonian colonies into a collection of geometric figures (cone, truncated cone, and cylinder). Length, diameter, and area were measured for each geometric figure and volume calculated from these data. Because *Ellisella paraplexauroides* is a large coral and images of colonies can best be obtained with a wide-angle lens and low aperture setting, all branches that appear in an image are not in the same plane as in the coral's natural state. Nor are all branches perfectly orthogonal to the plane of the image because of camera-setting restrictions. These small deviations from the true state of the coral *in situ* need to be considered when reconstructing volume from images. To determine the magnitude of any such error, we took images of 8 sections of the gorgonian colonies, then sampled pieces of the photographed colony and determined their volume (ml) by water displacement. The more accurate volume-displacement values were then compared with those estimated from the image analysis. A paired *t*-test indicated that the photographic method ($df = 7$, $t = 6.313$, $p < 0.001$) tended to slightly overestimate volume compared with the displacement method ($20.1 \pm 4.9\%$). Volume data from photographic images were then corrected by multiplying by a factor of 0.79. Collected samples of known volume were then dried at 60°C to constant dry weight (DW) and were used to infer the relationship between volume (ml) and DW (g) via regression analysis. This procedure allowed an inferred biomass (as DW g) to be estimated from volume and thus avoided any further destructive morphometric approach to the gorgonian colonies.

In our morphometric assessment, we also calculated the frequency distribution for volume, biomass, height, and number-of-tips classes in each zone and in the overall combined population, and investigated whether the results fit known distribution models. To assess frequency distributions, we rearranged volume data into 20-ml classes, height into 10-cm classes, and number of tips into 5-branch classes. This produced a similar number of classes for all the study variables. Finally, regression analysis was used to evaluate allometry between volume, height, and branching.

Epibiosis, damage and mortality

During the initial inspection dives in 2009, a surprisingly high number of colonies (hereafter referred to as fouled colonies) were observed serving as sub-

strate for a large variety of epibionts (Fig. 2B). This led us to consider whether this epibiotic load might be substantial because the gorgonian population was living in shallow water at the upper bathymetric limit of its environmental tolerance. That is to say, the Chafarinas population could consist of highly stressed colonies that would be unable to protect their surface against epibiont settlement. We tested this hypothesis in 2 ways. First, the incidence of epibiosis m^{-2} was quantified as the number of gorgonians affected by epibiosis in a quadrat relative (%) to the total of living colonies in that particular quadrat. Empty quadrats and quadrats with only dead colonies were excluded from the analyses. Under the hypothesis that epibiosis might be related largely to a colony's occurrence at the upper bathymetric limit, one could expect the incidence of epibiosis to decrease with increasing depth.

Initial inspection dives also revealed that many of the gorgonians had fishing lines and pieces of net material tangled in their branches; they had broken branches, scars from surface abrasion, and some polyps removed—all of which suggested contact with fishing gear. Therefore, it appeared that the large epibiotic loads could be related not only to a potential shallow-water effect but also to recurring damage that fishing gear inflicts on colony skeletons, the coenosarc, and polyps. In this case, epibiosis incidence per m^2 and epibiotic load per colony should be greater in zone A (where the highest fishing pressure occurs from trawling, netting, and trolling lines) than in zone C (an area where netting and trolling are more prevalent), which in turn should be higher than in zone B (where no trawling occurs, netting is occasional, and trolling is a common practice).

Visual inspection during scuba dives also revealed a relatively high number of dead and dying gorgonians in some zones, as indicated by remnants of colony stems and colonies with >90% of their surface covered by epibionts. The incidence of mortality m^{-2} was quantified by calculating the proportion (%) of dead colonies in a quadrat in relation to the total number of colonies occurring in that particular quadrat. This measure was applied only in quadrats containing only dead or living colonies, or a combination of both ($n = 615$). To explore whether disease and predation were significant causes of mortality in this gorgonian population, counts were made of the number of colonies showing evidence of disease and the number bearing potential predators. However, counts turned out to be insignificant in both cases, so no further analyses of this kind were carried out.

Statistical analyses

To ascertain whether between-zone difference in fishing pressure had an effect on the average density, volume, biomass, height, number of tips, epibiosis incidence (%), epibiosis load, and incidence of mortality (%), the non-parametric Kruskal-Wallis test was applied on untransformed, non-normally distributed data. *A posteriori* pairwise comparisons to identify which zones were responsible for the significant differences were made using the non-parametric Dunn's method. Sample sizes for analyses of volume, biomass, height, and number of tips were $n_A = 62$, $n_B = 188$, and $n_C = 195$. Sample sizes for epibiosis incidence (%) were $n_A = 38$, $n_B = 112$, and $n_C = 112$, and for mortality incidence (%), $n_A = 51$, $n_B = 120$, and $n_C = 135$.

Allometry between volume, height, and branching was investigated using regression analysis to examine the pairwise relationships between these parameters for each zone ($n_A = 62$, $n_B = 188$, $n_C = 195$), as well as for all zones combined ($n = 445$).

Bathymetric patterns in density of colonies, volume, biomass, height, tip number, epibiotic load, incidence of epibiosis (%) and incidence of mortality (%) within each zone and collectively for the total number of sampled quadrats were investigated through regression model fitting. For the analyses of volume, biomass, height, number of tips, and epibiotic load data sets, the sample sizes were $n_A = 62$, $n_B = 188$, and $n_C = 195$. For incidence of epibiosis, sample sizes were $n_A = 38$, $n_B = 112$, and $n_C = 112$, and for incidence of mortality, they were $n_A = 51$, $n_B = 120$, and $n_C = 135$.

RESULTS

Density of colonies

A total of 445 living organisms were recorded in the 760 sampling quadrats, averaging a density of 0.59 ± 0.99 colonies m^{-2} , with a maximum of 5 gorgonians m^{-2} . Average density in zone A (0.25 ± 0.67 colonies m^{-2}) was significantly lower than that in zones B and C (0.75 ± 1.03 and 0.76 ± 1.12 , respectively), which were not statistically different from each other (Fig. 3A). In the bathymetric range covered in this study (12–32 m), the density of living colonies did not correlate with depth either when all samples were pooled (Fig. 3B) or when each zone was analyzed separately (data not shown).

It is also noteworthy that at the $1 m^2$ scale used for sampling, the colonies were not uniformly distrib-

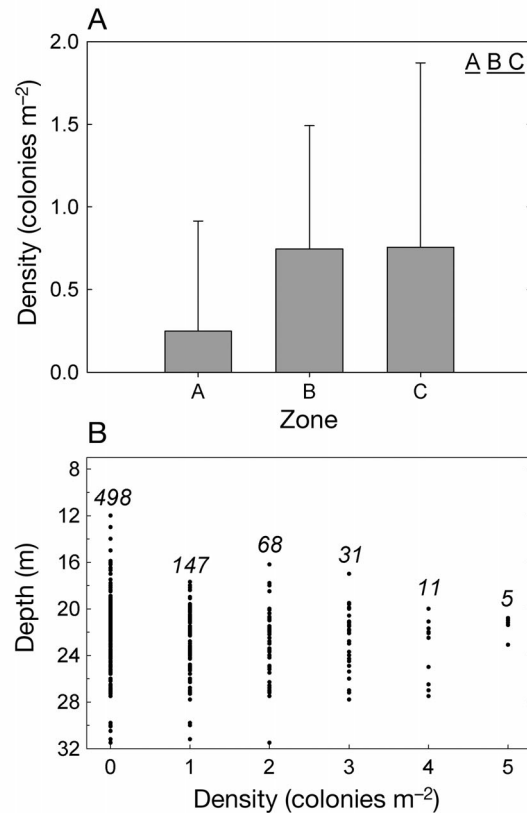


Fig. 3. *Ellisella paraplexauroides*. (A) Summary of statistically significant differences in density average (\pm SD) as a function of study zone (A, B, C) following a Kruskal-Wallis test ($H = 58.66$, $df = 2$, $p < 0.001$) and *a posteriori* pairwise Dunn's tests. Letters in the upper right corner indicate study zones ordered by increasing value in colony density, with zones that are not significantly different from each other sharing underline. (B) Colony density in each $1 \times 1 m$ quadrat plotted versus the depth at which each quadrat was located. There is no substantial association ($r^2 = 0.006$, $p = 0.03$, $n = 760$) between both variables. Numbers in italics indicate number of sampled quadrats

uted within the overall population (Fig. 3B). Rather, a large number of quadrats were empty, and most that were occupied contained only 1 or 2 colonies. This pattern is largely a reflection of the patchiness of hard substrate suitable for gorgonian settlement, intermingled with unfavorable soft substrate. Five quadrats had a maximum occurrence of 5 living colonies.

Biomass, size and morphological complexity

Colony volume within the population averaged 48.25 ± 54.60 ml, with the largest colony (511.39 ml) being about 10 times that of the average volume. Colony biomass (as DW g) was directly related to

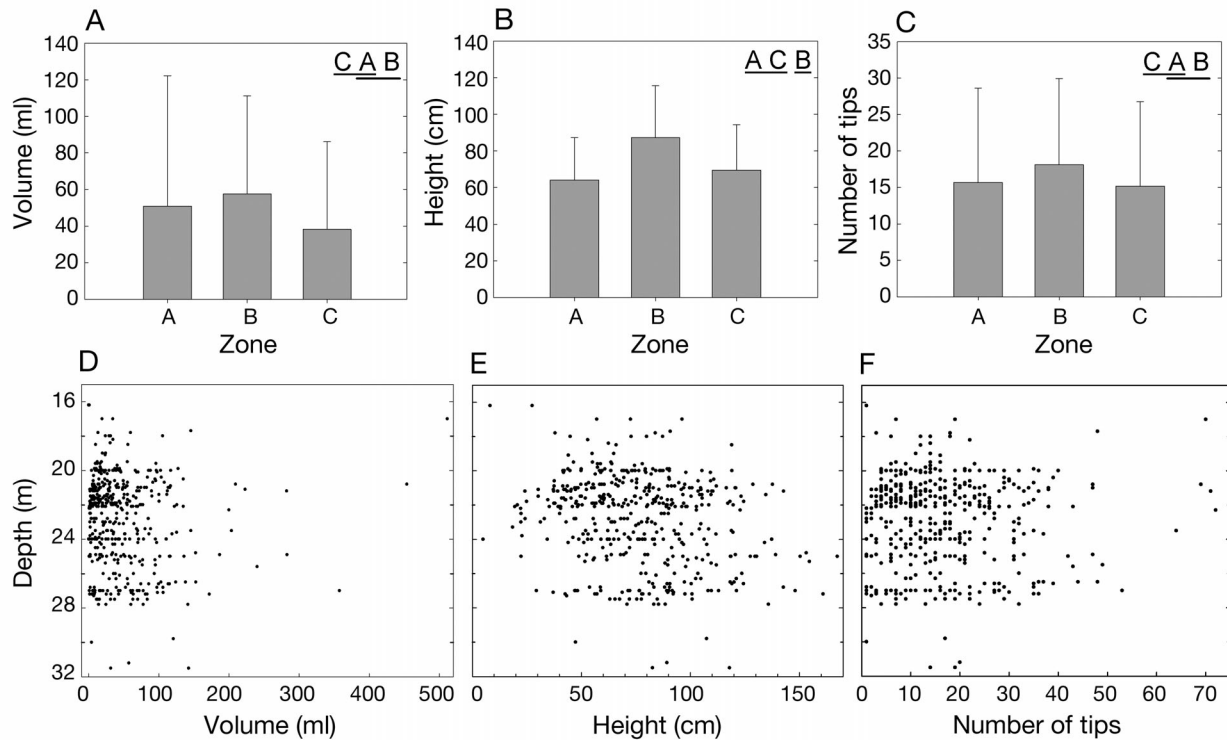


Fig. 4. *Ellisella paraplexauroides*. Summary of statistically significant differences in average (\pm SD) (A) volume, (B) height, and (C) number of tips, as a function of study zone, following in all cases a significant Kruskal-Wallis test ($df = 2$, $0.001 < p < 0.01$) and a *posteriori* pairwise Dunn's tests. Letters in the upper right corner indicate study zones ordered by increasing value in average volume, height, or number of tips, with zones that are not significantly different from each other sharing underline. Also shown are data on (D) volume, (E) max height, and (F) number of tips of each sampled colony ($n = 445$) plotted versus the depth at which colonies occurred. There is no statistically significant bathymetric pattern for these variables

volume (ml), as shown by a linear equation ($DW = -0.763 + 1.574 \times \text{volume}$; $n = 8$, $r^2 = 0.947$, $p < 0.001$). Because of this direct relationship between both biomass and volume variables, their distribution patterns across zones and by depth levels are always identical. Consequently, analytical results are only shown for the measured variable, i.e. volume. Height averaged 76.32 ± 27.74 cm, with the tallest colony being 167 cm. Number of terminal branches (tips) averaged 16.50 ± 11.94 , with the most branched colony displaying 72 tips (Table S1 in the Supplement at www.int-res.com/articles/suppl/m479p127_supp.pdf).

Between-zone differences in volume (Fig. 4A), biomass (Table S1 in the Supplement), and number of tips (Fig. 4C) showed similar patterns. Gorgonians in zone B were significantly larger in volume (57.69 ± 53.44 ml) and more branched (18.12 ± 11.84 tips) than those in zone C (38.32 ± 47.79 ml; 15.18 ± 11.58 tips). Gorgonians in zone A were characterized by intermediate values of volume and number of tips, with Dunn's test not recognizing these A values as significantly different from those in B or C (Fig. 4A,C). Colony height showed a slightly different pattern,

with average height in zone B being significantly larger (87.32 ± 28.29 cm) than that in zones C and A (69.60 ± 24.73 and 64.13 ± 23.14 cm, respectively). Zones A and C were not statistically different from each other (Fig. 4B).

Volume, height, and number of tips did not correlate with depth, neither when the analyses were run separately for each zone (data not shown) nor when all samples were pooled (Fig. 4D–F).

When the morphometric variables (volume, height, and number of tips) were analyzed in terms of frequency distribution (f), each fitted a different distribution model (Fig. 5). Only the results at the population level (i.e. the 3 study zones pooled) are presented here, as distribution trends did not change when zones were analyzed separately. Volume (and biomass) significantly conformed with an exponential decay distribution (Fig. 5A). The most frequent volume class consisted of colonies smaller than 20 ml. In contrast, colony height better fitted a relatively symmetric Gaussian distribution (Fig. 5B). The most frequent colony height ranged from 80 to 90 cm, but classes from 40 to 80 cm were also well represented. From the frequency distribution of volume and

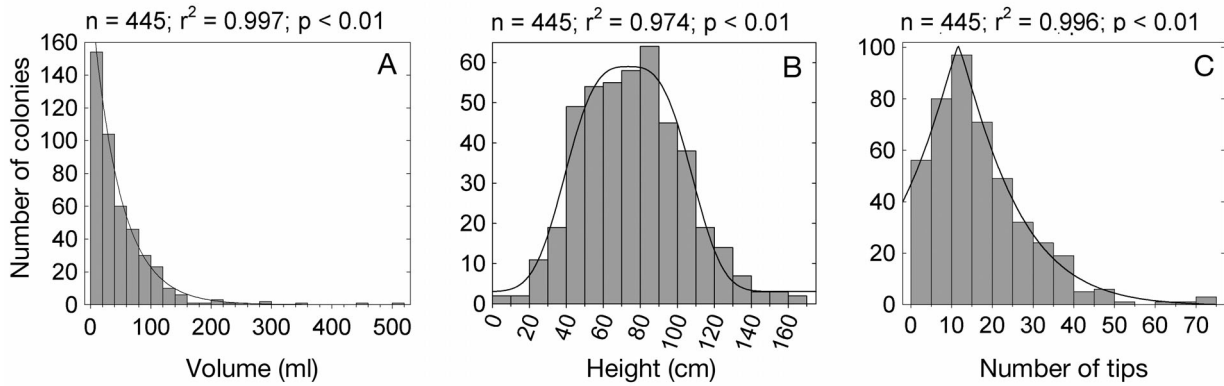


Fig. 5. *Ellisella paraplexauroides*. Frequency distributions (f) of colony (A) volume, (B) maximum height, and (C) number of tips. Volume distribution significantly fits an exponential decay function ($f = 191.15 \times e^{-0.02 \times \text{volume}}$). Height distribution fits a symmetrical Gaussian function ($f = 3.06 + 55.91 \times e^{-0.5 \times \left[\frac{\text{height} - 73.55}{31.46} \right]^2}$). Number of tips better fits a modified Gaussian function ($f = -0.46 + 101.10 \times e^{-0.5 \times \left[\frac{\text{no tips} - 11.64}{8.06} \right]^2}$). Statistics for fitting significance are given above each graph

height data, it can be deduced that only a moderate number of young, small colonies are recruiting into the population (see 'Discussion'). The number of tips conformed to an asymmetrical Gaussian distribution (Fig. 5C), with the most frequent class consisting of colonies characterized by 10 to 15 terminal branches.

Morphometric analyses revealed that height increased with both volume and number of tips, following an exponential rise to a maximum (Fig. 6). This pattern largely coincides with that of a hyperbolic function, which showed only a slightly inferior level of fit. The mathematical relationship suggests that initially young colonies grow faster in height than in

total volume and number of branches; it appears that once the colony reaches a threshold height (between 60 and 100 cm), that aspect of growth slows down, and the production of new branches, and branch thickening, accelerates.

Epibiosis and damage

A total of 302 (67.8%) of the 445 colonies examined showed some epibiotic load. In addition, most (77.4%) of the fouled colonies exhibited some signs of physical damage (e.g. broken branches, surface erosion and

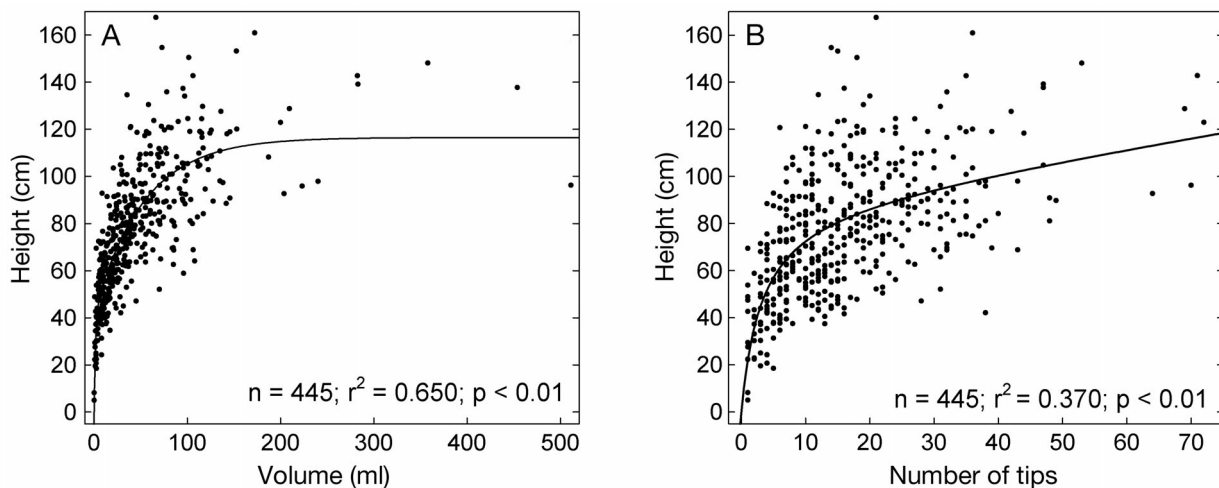


Fig. 6. *Ellisella paraplexauroides*. Allometry of colonies. (A) Relationship between colony volume and maximum height, significantly fitting an asymptotic exponential regression (height = $41.83 \times (1 - e^{-0.65 \times \text{volume}}) + 74.66 \times (1 - e^{-0.02 \times \text{volume}})$). (B) Relationship between number of tips and maximum height, also fitting an asymptotic exponential regression function (height = $56.49 \times (1 - e^{-0.44 \times \text{no tips}}) + 65.07 \times (1 - e^{-0.03 \times \text{no tips}})$). Statistics for fitting significance are given at the bottom of each graph

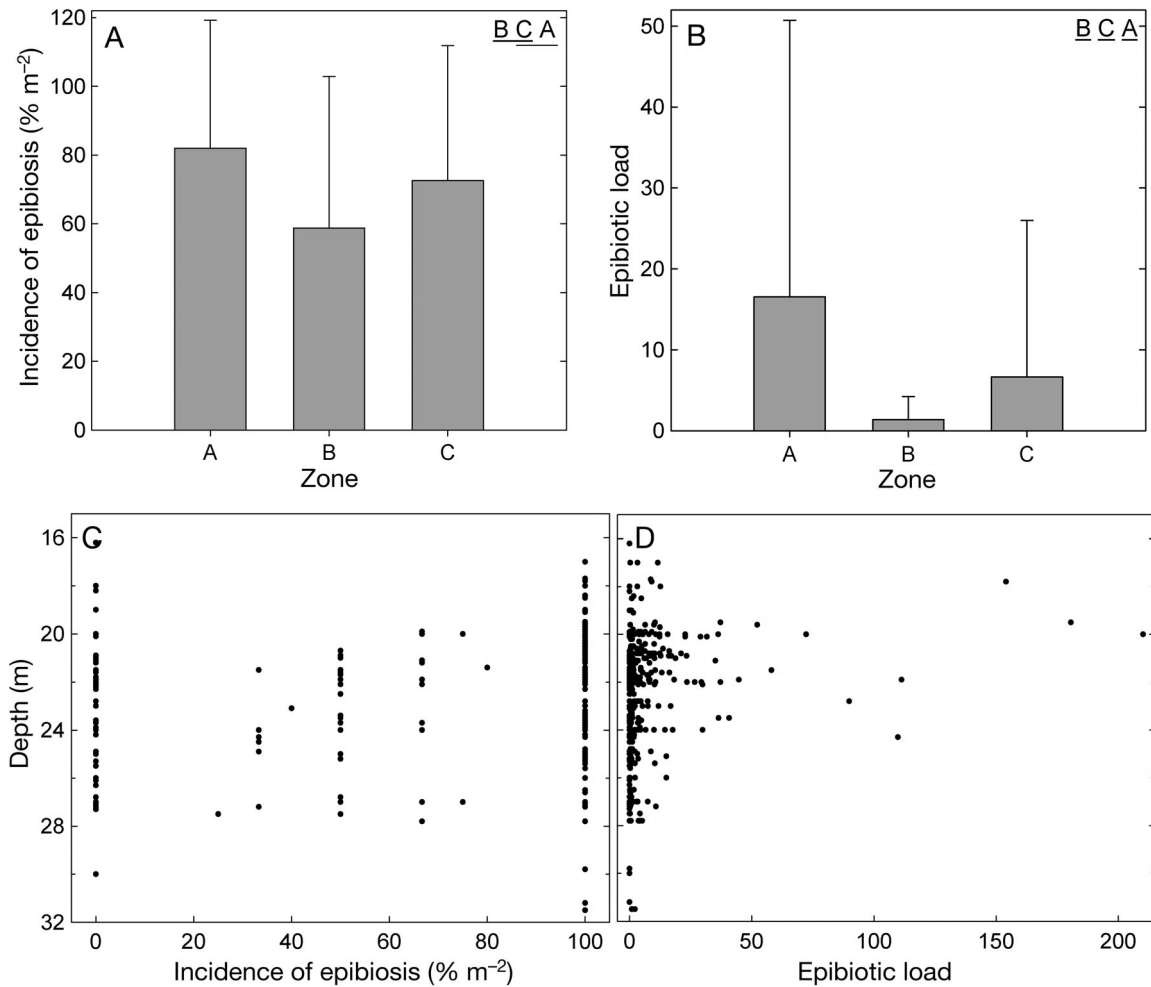


Fig. 7. Epibiosis on *Ellisella paraplexauroides*. (A) Summary of between-zone differences in incidence of epibiosis (i.e. % of fouled colonies m⁻²) and (B) epibiotic load per colony (epibiont volume relative to gorgonian volume), as indicated by significant Kruskal-Wallis tests (df = 2, p < 0.005) followed by pairwise *a posteriori* tests. Letters in the upper right corner indicate study zones ordered by increasing value in incidence of epibiosis or epibiotic load, with zones that are not significantly different from each other sharing underline. Data on incidence of (C) epibiosis and (D) epibiotic load plotted versus the depth at which each quadrat (for C) or colony (for D) was located. No statistically significant bathymetric pattern was recognizable for these epibiosis parameters

healing scars). The incidence of epibiosis in the population (i.e. % of fouled colonies m⁻²) averaged $68.05 \pm 41.86\%$. Epibiotic load per colony (i.e. total volume of epibionts relative to the gorgonian volume) averaged 5.80 ± 18.77 , which means that the volume of epibionts was on average 5 times that of the gorgonians. Epibiotic load on *Ellisella paraplexauroides* typically consists of macroalgae, sponges, other cnidarians, bryozoans, and tunicates, as well as a large variety of other organisms in lower abundance (Fig. 2B).

When the incidence of epibiosis was analyzed as a function of zone (Fig. 7A), the percentage of fouled colonies in quadrats of zone A (which had the highest fishing pressure) was significantly higher than in

zone B (which had lowest fishing pressure). Zone C (with intermediate levels of fishing pressure) showed intermediate values, which Dunn's tests failed to recognize as significantly different from those in A or B (Fig. 7A). The analysis of the epibiotic load revealed a similar pattern, but in a more powerful way. Colonies of zone A displayed an epibiotic load significantly higher than those in zone C, which in turn showed a larger load than those in zone B (Fig. 7B).

Interestingly, unlike zone, depth showed no significant effect on either epibiosis incidence or epibiont load per colony. High and low values of epibiosis occurred at all depths within the investigated bathymetric range (Fig. 7C,D).

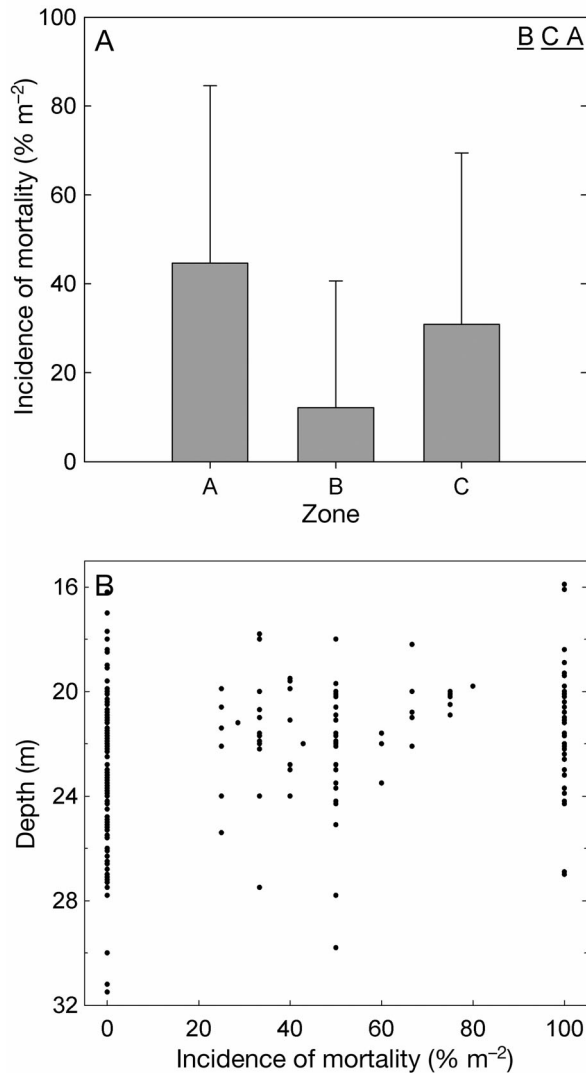


Fig. 8. *Ellisella paraplexauroides*. (A) Between-zone differences in incidence of mortality m^{-2} (% of dead colonies m^{-2}), as indicated by a significant Kruskal-Wallis test ($H = 36.82$, $df = 2$, $p < 0.001$) followed by pairwise *a posteriori* tests. Letters in the upper right corner indicate study zones ordered by increasing value in mortality incidence, with zones that are not significantly different from each other sharing underline. (B) Incidence of mortality plotted versus depth, showing no statistically recognizable relationship between both variables

Mortality

A total of 170 dead colonies occurred in the 760 sampled quadrats, averaging 0.22 ± 0.63 dead colonies m^{-2} . Because the density of dead gorgonians can only be properly assessed if compared to the density of living colonies, we also examined the proportion (%) of dead colonies in a quadrat relative to the total (dead + alive) number of colonies occurring in that same quadrat (i.e. incidence of mortality). Calculated

in this way, the incidence of mortality averaged $25.83 \pm 37.08\%$ at the population level. However, this parameter was not uniformly distributed across zones. The Kruskal-Wallis tests and *a posteriori* comparisons revealed that incidence of mortality in zone B ($12.15 \pm 28.48\%$) was significantly lower than in zones A and C (44.66 ± 39.90 and $30.87 \pm 38.55\%$, respectively), which were not statistically different from each other (Fig. 8A). In other words, in zones A and C, where fishing pressure was high to medium, a dead colony occurred for about every 1 or 2 living colonies. In contrast, in zone B a dead colony occurred for every 9 living ones. Note that mortality incidence did not correlate with depth at the population level (Fig. 8B) or at the zone level. These results strongly suggest that most mortality in the Chafarinas population resulted from unregulated fishing (trawling, gillnetting, and trolling; Fig. 9) rather than from the unusually shallow depths inhabited by the colonies.

During the 3 year study, we found no epidemic disease affecting the gorgonian populations of the Chafarinas Islands; i.e. neither affecting *Ellisella paraplexauroides* nor other common species (e.g. *Eunicella* spp., *Leptogorgia* spp., *Paramuricea clavata*). Predation did not appear to be a significant mortality factor either. Although we noticed large individuals (30 to about 60 cm) of the bearded fireworm *Hermodice carunculata* (Pallas, 1766) feeding on *E. paraplexauroides* (Fig. 10A,B), polychaete predation was restricted to the polyps at branch tips (Fig. 10C), thus causing only small terminal injuries that underwent rapid recovery with no significant adverse effect on the colony (Fig. 10D,E).

DISCUSSION

Abundance and distribution

Ellisella paraplexauroides is an Atlantic-Mediterranean gorgonian rarely found in the Mediterranean (Templado et al. 2006, Arroyo et al. 2008). For this reason, the occurrence of a relatively profuse population off the Chafarinas Islands (averaging a colony every $2 m^2$) is somewhat puzzling. Because the basic ecological information on this species is still poor, it is difficult to arrive at demographic comparisons with other species. The most common Atlantic-Mediterranean gorgonian species are smaller in height and colony diameter, and therefore their spatial distribution may obey different constraints regarding competition for food and space, reproductive output, etc.

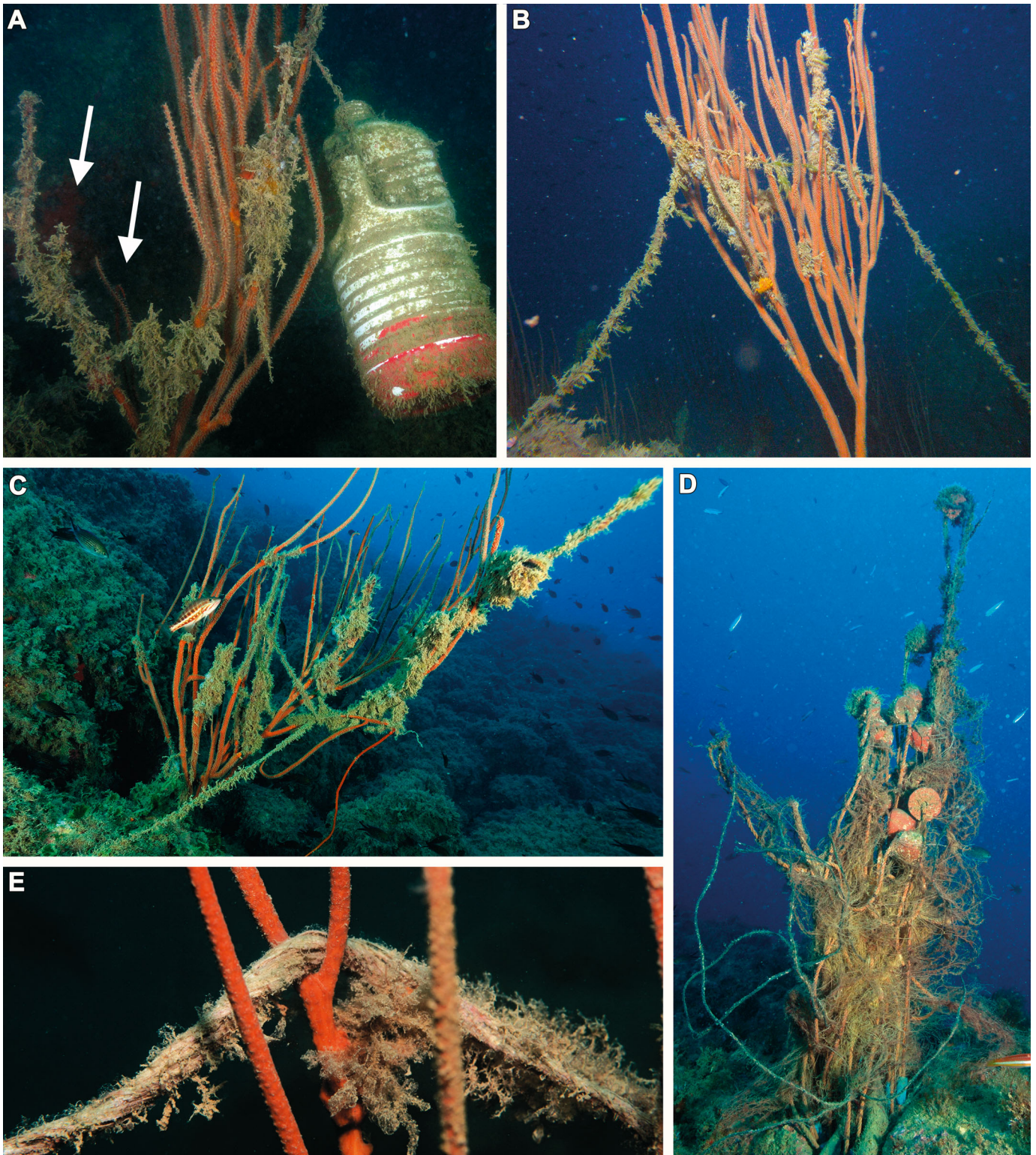


Fig. 9. *Ellisella paraplexauroides*. Damage of colonies by fishing gear. (A) Example of damaged colony, with a plastic bottle (used by local fishermen as a buoy for marking deployed guillnets) tangled in the branches, several missing branches (white arrows), and a significant load of epibionts. (B,C) Additional examples of colonies with tangles of lines used for gillnetting and trolling, and displaying substantial epibiont loads. (D) Colony killed after massive tangle of a gillnet. (E) Detail of a fish line eroding the colony coenosarc and favoring epibiont settling

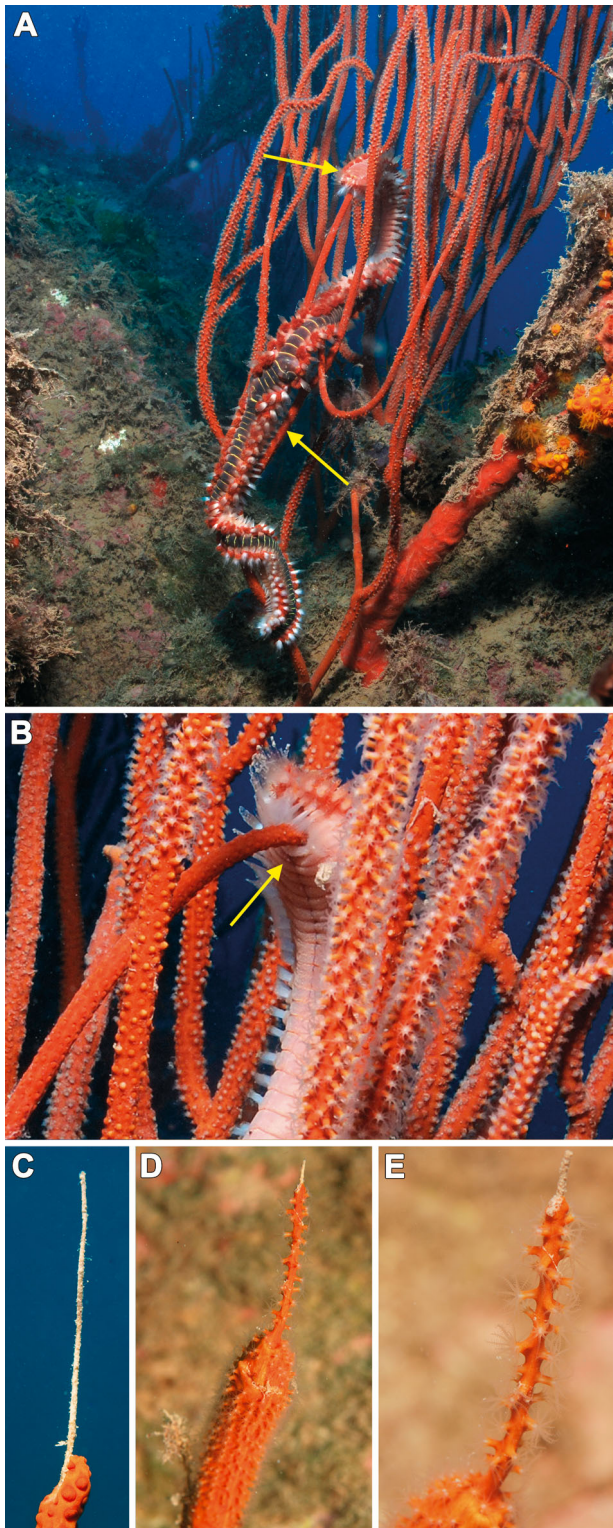


Fig. 10. *Ellisella paraplexauroides* and *Hermodice carunculata*. Predation of the gorgonian by large individuals of the polychaete. (A) General view of a polychaete (yellow arrows) climbing a gorgonian colony. (B) Detail of the worm's proboscis (yellow arrow) while ingesting the tip of a gorgonian branch. (C) A branch tip after predation by the polychaete. (D,E) Details of previously depredated tips that have (D) regenerated the coenosarc and (E) produced new polyps

Smaller species, such *Eunicella* spp., often reach much higher colony densities (Table 1). Populations of midsized gorgonians, such as *Paramuricea clavata* (Risso, 1826) and *Leptogorgia sarmentosa* (Esper, 1791) show more modest density values, but these are still high in comparison with *E. paraplexauroides* (Table 1). Better comparative data might be obtained from gorgonian corals of large size (i.e. >50 cm in mean height; Table 1), such as the epibathyal, Atlantic-Mediterranean *Callogorgia verticillata* (Pallas, 1776) and the bathyal, boreal Atlantic *Paragorgia arborea* (Linnaeus, 1758), which both have densities one to 3 orders of magnitude lower than those recorded for *E. paraplexauroides* (Table 1). In other words, *E. paraplexauroides* in the study area occurs at far higher densities than other large species.

Another striking feature of the *Ellisella paraplexauroides* population of the Chafarinas Islands is that many of the undamaged colonies are up to 167 cm high and exhibit notable branching complexity (up to 72 tips). Such colony 'splendor' on the shallow Chafarinas bottoms belies the belief that this species finds its most suitable or preferred habitat in the deepest areas of the continental shelf (50 to 150 m; Arroyo et al. 2008). In the absence of a consistent correlation between any morphometric or abundance parameter and depth, it cannot be assumed that the Chafarinas population consists mainly of highly stressed colonies living at the upper limit of their bathymetric tolerance range. Our ROV inspection of the Alboran Island deep shelf (70 to 200 m; Fig. S1 in the Supplement at www.int-res.com/articles/suppl/m479p127_supp.pdf) revealed rocky outcrops and boulder bottoms covered by dense populations of the large, unbranched gorgonian *Viminella flagellum* (Johnson, 1863), with only scattered colonies of *E. paraplexauroides* (Fig. S1A,B in the Supplement). All in all, one cannot discount the possibility that *E. paraplexauroides* is eurybathic rather than a deep-water species. Its fragmentary distribution in Mediterranean shallow habitats may have a paleozoogeographic explanation. Since this gorgonian appears to be more abundant in the Mauritanian and Macaronesian regions of the Atlantic, it may have entered the western Mediterranean as part of the documented interglacial faunal invasions during the Pleistocene, when the distribution area of numerous Senegalian and Mauritanian marine species may have expanded into the western Mediterranean. While some of those species became established and proliferated in the Mediterranean, others regressed during subsequent glacial periods, with some now persisting as mere vestigial relics (e.g. Zeuner 1959,

Table 1. Comparative summary of average and maximum density (data pooled from assorted studies) for small-medium (mean height <50 cm) and large (mean height >50 cm) gorgonians common in the Mediterranean and/or the North Atlantic. Mean and maximum sizes for each species come from the specific populations reported in the studies cited in the Source column. 1 = Linares et al. (2008); 2 = Gori et al. (2011); 3 = Weinberg (1976); 4 = Weinberg (1979); 5 = Rossi et al. (2011); 6 = Coma et al. (1994); 7 = Coma et al. (1995); 8 = Linares et al. (2005); 9 = Sánchez et al. (2009); 10 = Mortensen & Buhl-Mortensen (2004)

Species	Mean/max size (cm)	Depth (m)	Study area	Density (colonies m ⁻²)	Max density (colonies m ⁻²)	Source
<i>Eunicella singularis</i>	16/67	0–50	W Mediterranean	33	38.31	1–4
<i>Leptogorgia sarmentosa</i>	26/34–94	0–70	W Mediterranean	1.2	10.17	2–5
<i>Paramuricea clavata</i>	24/98	0–70	W Mediterranean	20	44.34	1–4, 6–8
<i>Callogorgia verticillata</i>	76/122	546–570	Cantabrian Sea	0.008	0.22	9
<i>Paragorgia arborea</i>	57/180	183–498	Boreal Atlantic	0.006	0.006	10
<i>Ellisella paraplexauroides</i>	76/167	12–32	Chafarinas Islands	0.59	5	This study

Fairbridge 1961, Maldonado & Uriz 1995). That would explain the rarity of *E. paraplexauroides* across the western Mediterranean and its extremely fragmented distribution (Fig. 1). In view of its sparse occurrence in the Mediterranean and vulnerability to demographic collapse, *E. paraplexauroides* may be a good candidate for a conservation plan.

Size distribution and allometry

Maximum colony height reported for this species falls in the range of 1 to 2 m (Stiasny 1936a,b, Hofrichter 2005, Templado et al. 2006, Angiolillo et al. 2012), which coincides with the maximum height of 1.67 m recorded in the quadrats of the current study. Unlike other gorgonians, *Ellisella paraplexauroides* does not display branch development preferentially constrained into a single plane. Most of the colonies we examined had 5 to 15 terminal branches, although some had as many as 72 (Fig. 5C). This branching pattern accords with that widely reported in the literature for this species (e.g. Stiasny 1936a, Angiolillo et al. 2012), except in colonies off the Canary Islands, which typically display no more than 5 branches (Brito & Ocaña 2004). We found no noticeable morphological differences between the sclerites in the colonies of the Chafarinas population (data not shown) and those reported for colonies from Mauritania (Stiasny 1936a,b), the Canary Islands (Brito & Ocaña 2004), and the Strait of Sicily (Angiolillo et al. 2012). In view of the branching peculiarities and unusually deep distribution of colonies off the Canary Islands, molecular tools would help to confirm that the Mauritanian, Macaronesian and Mediterranean colonies are actually conspecific rather than cryptic species.

The distribution of volume classes indicates that small (and presumably young) and midsized colonies

are abundant (Fig. 5A), which suggests success in recruitment in previous years (or decades, depending on the still unknown growth rate). However, very few colonies are less than 20 cm in height (Fig. 5B), which suggests that recruitment has not been that successful in recent years. Note, too, that the distribution of volume classes and height classes may not correspond because early growth in young colonies occurs mainly in height (reaching up to 60 cm) rather than in branches or volume (or biomass). In other words, the 154 colonies in the small-volume classes are indeed distributed in about the first 6 height classes. The regression analyses exploring the relationship between colony height and volume, and between colony height and number of tips (Fig. 6) also corroborated the idea that young colonies grow more rapidly in height and that they only increase rates of branch production and thickening once a threshold height (60 to 100 cm) has been reached. Consequently, as more accurately indicated by height distribution data, actual recruitment can be considered low to moderate in this population. How these morphometric parameters relate to age and sexual maturity remains to be investigated.

Damage, mortality and conservation

During our 3 year study, we saw no sign of disease in the *Ellisella paraplexauroides* population of the Chafarinas Islands. However, branch tips were being preyed upon by huge (0.5 m long on average) individuals of the polychaete *Hermodice carunculata* (Fig. 10A–C), although colonies appeared to recover easily, regenerating their coenosarc and polyps without difficulty (Fig. 10D,E). Likewise, marine pollution by the local human population cannot account for the substantial dam-

age sustained by the gorgonian population, as most mortality was observed at the 2 uninhabited islands. Any irreversible damage noticed in the Chafarinas gorgonian population appears to derive from continuous unregulated fishing within the SCI area, primarily from gillnetting and trolling but also from occasional trawling. Daily unregulated use of nets and fishing lines has an adverse effect not only on the coenosarc and polyps, but also on the tridimensional architecture of the colonies (Figs. 9 & S1C in the Supplement). In many cases, tangled fishing gear and broken branches drastically disrupt the pattern of water circulation through the colony branches. Colonies disturbed in these various ways are then easily settled by larvae and propagules from a diverse array of benthic organisms. As further evidence that injury by fishing gear facilitates epibiosis in the Chafarinas population, ROV studies of the deep-water colonies (70 to 200 m) on the Alboran Island shelf showed almost no epibionts (Fig. S1A,B in the Supplement). In the few cases in which epibionts were detected, we corroborated coenosarc scars adjacent to the epibiont attachment point (Fig. S1C in the Supplement). The relationship between epibiosis and mortality in the Chafarinas population and fishing activities is also supported by the fact that epibiosis and mortality are statistically higher in zones A and C, where fishing pressure is higher than in reduced-fishing zone B. About half (44.6%) of the colonies originally growing in zone A are currently dead, and about 82% of the surviving colonies show substantial epibiosis. Similar though less intense negative effects have been described for the population of *Paramuricea clavata* in the Ligurian Sea (Mediterranean), where frequent recreational line fishing has damaged 22 to 37% of colonies growing to a depth of 20–25 m (Bavestrello et al. 1997). Likewise, lost hook-and-line fishing gear at the coral reefs of the Florida Keys National Marine Sanctuary has had a serious impact on sponges and benthic cnidarians, causing tissue abrasions that lead to partial individual or colony mortality (Chiappone et al. 2005). Branching gorgonians (Octocorallia) were the most frequently affected organisms (56%), followed by milleporid hydrocorals (19%) and sponges (13%). Our finding that small-scale gillnetting by local fishermen is severely impacting the population of *E. paraplexauroides* is also consistent with the conclusions of another recent study assessing the impact of artisanal fishing fleets in Baja California, Mexico (Shester & Micheli 2011), in which gillnetting

reportedly damaged or removed about 17% of gorgonians within a distance of 1 m from the net.

In summary, unregulated local fishing activities are extremely harmful to the Chafarinas population of *Ellisella paraplexauroides* (Figs. 2B & 9), while recruitment in recent years appears to have been moderate to low. The next step of research should be to determine whether recruitment is failing to compensate for the combination of natural plus fisherman-driven mortality in this population and to elucidate the magnitude of the imbalance. In the meantime, if the regulation of fishing activities is not efficiently enforced within at least the SCI perimeter of the Chafarinas Islands, this unique population of *E. paraplexauroides* may be at high risk of rapid and dramatic decline in the short term, and annihilation in the long term. A conservation strategy giving the species protected status would ensure the preservation of this rare gorgonian in the Mediterranean Sea.

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The following supplement accompanies the article

The rare, giant gorgonian *Ellisella paraplexauroides*: demographics and conservation concerns

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Supplement. Additional photographs of gorgonian populations, obtained by ROV exploration during the LIFE+ INDEMARES expedition in September 2011, and summary of data

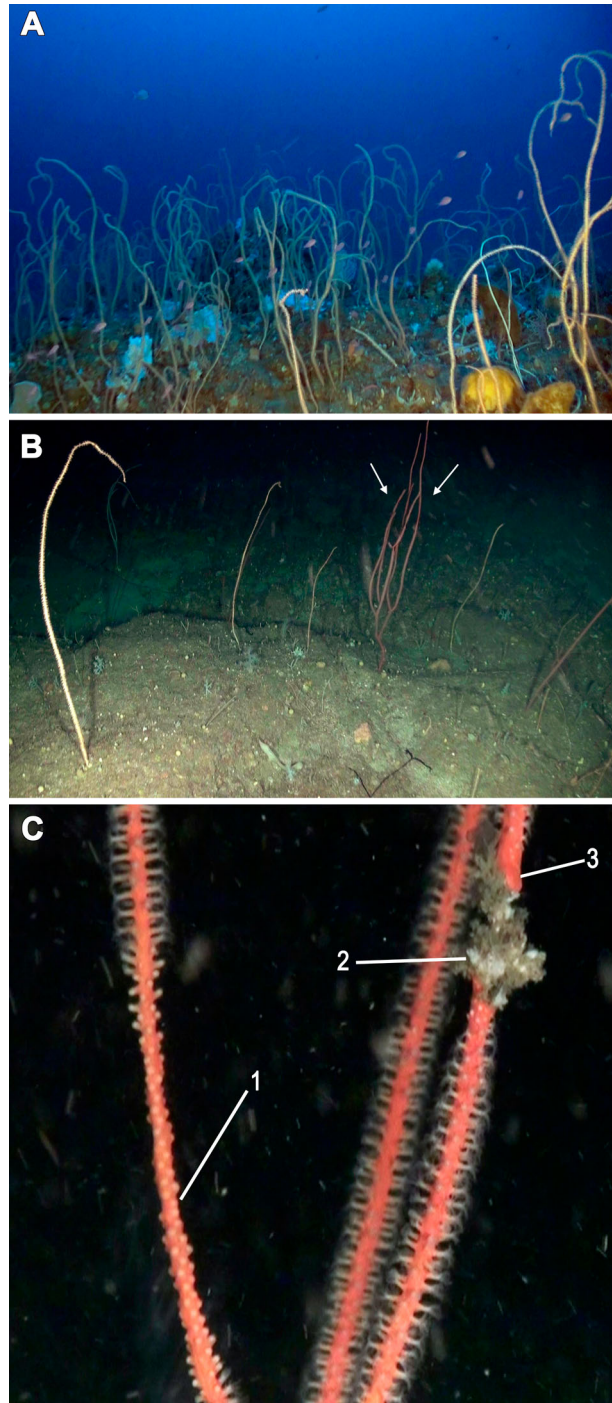


Fig. S1. Gorgonian populations on the deep shelf (70–150 m) of Alboran Island. (A) General view of a rocky area at 108 m with high density of the gorgonian *Viminella flagellum* and complete absence of *Ellisella paraplexauroides*. (B) General view of a less dense population of *V. flagellum* at 112 m, including only an isolated colony of *E. paraplexauroides* (white arrows). Note that this colony lacks epibionts, as typically found for most colonies growing on the deep shelf of Alboran Island. (C) Detail of an Alboranian colony at 120 m, showing a branch portion with (1) retracted polyps and (2) a small epibiotic load. The attachment of the epibionts was probably facilitated by a previous physical injury, as indicated by (3) the adjacent healing scar

Table S1. Summary of statistics (counts, average \pm SD, maximum value) for the main variables analyzed in the study. Data are detailed for each study zone (A, B, C), as well as for the 3 zones pooled (i.e. at the population level)

	A (Congreso)	B (Isabel II)	C (El Rey)	Population
Quadrats (1 × 1 m)	250	252	258	760
No. living colonies	62	188	195	445
No. dead colonies	52	26	92	170
Density (colonies m⁻²)				
Ave	0.25	0.75	0.76	0.59
SD	0.67	1.03	1.12	0.99
Volume (ml)				
Ave	50.89	57.69	38.32	48.25
SD	71.30	53.44	47.79	54.60
Max	511.39	357.88	453.94	511.39
Biomass (g)				
Ave	79.36	90.08	59.56	75.21
SD	112.26	84.14	75.25	85.97
Max	804.41	562.73	713.97	804.41
Height (cm)				
Ave	64.13	87.32	69.60	76.32
SD	23.14	28.29	24.73	27.74
Max	118.92	167.36	137.66	167.36
No. of tips				
Ave	15.71	18.12	15.18	16.50
SD	12.90	11.84	11.58	11.94
Max	70	71	72	72
No. of fouled colonies	52	112	138	302
Incidence of epibiosis (% m⁻²)				
Ave	82	59	73	68
SD	37	44	39	42
Epibiotic load				
Ave	16.54	1.37	6.65	5.80
SD	34.19	2.84	19.34	18.76
Incidence of mortality (% m⁻²)				
Ave	44.66	12.15	30.87	25.83
SD	39.90	28.48	38.55	37.07