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Short communication

Growth patterns in mesophotic octocorals: Timing the branching process in the highly-valuable Mediterranean *Corallium rubrum*

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ABSTRACT

This study examined colony growth in the long-lived red coral *Corallium rubrum*, a slow growing octocoral endemic to the Mediterranean Sea and neighboring Atlantic areas and one of the most valuable of all marine species. Age and growth rate were determined on 165 sections of colony bases and branches by means of a validated age dating method in populations living between 50 and 130 m in the NW Mediterranean. The ratio between minimum and maximum diameter remained constant, indicating proportional growth of colony bases. No significant difference was found between the growth rate of bases and branches. A significantly different branching pattern (colony height/number of branches) and average growth rate were found between the colonies of the different geographic areas. As growth rate decreases with age, this was due to the different age structure of the two samples. The maximum lifespan was found to be 106 years, a value not determined previously for *C. rubrum* colonies, and the average age of colonies at first branching was about 10 years. Linear growth varied widely between colonies as well as between branches in the same colony, confirming the lack of any strict relation between height and age. The study illustrates the growth of a mesophotic, heavily exploited Corallidae.

1. Introduction

Long-lived species are fundamental in structuring marine ecosystems, and usually play a key role in marine food webs (Paine, 1980). Gorgonian corals are modular, long-lived 'ecosystem engineers', providing shelter to other organisms and increasing habitat complexity and biodiversity with their three-dimensional structure (Cupido et al., 2009; Rossi, 2013). The need for a more efficient 'plankton capturing net' induced gorgonian corals to evolve complex, highly branched colonies. Although a tree-like shape is dominant in gorgonian corals, different species show large differences in their branching patterns (Brazeau and Lasker, 1988; Sanchez, 2004; among others). Moreover, even single species can exhibit a great degree of morphoplasticity (e.g. Gori et al., 2011).

Widespread throughout the Mediterranean and adjacent Atlantic rocky bottoms between 20 and 600–800 m depth (Costantini et al., 2010; Tsounis et al., 2010), the temperate gorgonian *Corallium rubrum* (L.1758) exhibits wide variability in growth forms, presumably linked to local hydrodynamics (Pedoni, 2009). This long-lived, slow-growing octocoral is one of the world's most economically valued marine species, and has thus been subjected to long-lasting, historic exploitation (Liverino, 1983). For this reason, management plans, based on a sound knowledge of demographic features, are needed, especially for the deeper populations (living 50–200 m depth) that are currently the primary targets of commercial fishing (Tsounis et al., 2010).

Age determination is a basic step in the demographic study of long-lived, slow-growing species. In particular, knowledge of colony growth rate, lifespan and age structure are essential for understanding the population dynamics of corals (Santangelo and Bramanti, 2010; Bramanti et al., 2014). In previous papers red coral age was determined by a suitable dating method by considering the whole colony as a single individual (Marschal et al., 2004; Gallmetzer et al., 2010; Priori et al., 2013; Bramanti et al., 2014), while no research has been carried out on the modular growth of colonies. Dating different portions of a colony could furnish highly relevant information on branching process timing. Bulk collection of colonies from mesophotic, commercial populations of *C. rubrum* has provided the opportunity to make a first analysis of branch growth in this octocoral. The following note aims to: (1) assess whether there are any morphological differences in growth pattern

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between colonies from different geographical areas; (2) estimate *the age at first branching* for red coral colonies; (3) determine the age of branches at different levels of the colonies, and (4) test whether any relationship exists between the linear length and age.

2. Materials and methods

2.1. Colony sampling and analysis

Two areas of the NW Mediterranean, at 50–130 m depth, in the North (42°47′ N, 9°58′ E; 42°32′ N, 10°07′ E) and Central Tyrrhenian Sea (40°41′ N, 13°53′ E; 40°36′ N, 13°31' E) were mapped by multibeam echosounder to locate rocky, vertical slopes, outcrops and boulders where red coral colonies were then identified by remotely operated underwater vehicle (ROV - Priori et al., 2013; Angiolillo et al., 2015, Fig. 1). Overall, 127 colonies (71 in the North, and 56 in the Central Tyrrhenian) have been sampled via rebreather diving and ROV (selective sampling methods towards larger colonies; Santangelo and Bramanti, 2010); each colony was numbered and photographed. As the sampling methods caused many colonies to lose some portions, height and branch number were recorded only on a subsample of intact colonies (n = 88). Only a portion (75%) of the sampled colonies was undamaged or slightly damaged by boring sponges and boring polychaetes, and was therefore suitable for age determination (n = 95; Marschal et al., 2004). Thirty-six of these 95 colonies were suitable to assess branch growth by cutting sections at different levels of the skeleton axis and branches. Overall 165 sections (95 at basis and 70 along the colonies) have been examined.

The minimum and maximum colony diameters were measured by caliper 1 cm from the base (Priori et al., 2013) and averaged. The maximum height of colonies (the distance from the base to the top) was also recorded. A branching order has been assigned to each colony following the method of Brazeau and Lasker (1988). A more detailed description of the sampling areas and methods adopted is reported in Priori et al. (2013) and Angiolillo et al. (2015).

2.2. Colony and branch age estimate

Colony age was determined on thin-sections by the organic-matrix-staining dating method (OMS), based on toluidine-blue staining of the organic matrix concentric rings which are deposited yearly in the axial calcareous skeletons of colonies (Marschal et al., 2004). For this analysis, thin sections (~50 microns each) of each colony axis were cut at 1 cm from the base (where diameter was measured), stained and examined by stereo microscopy (20-40x). Three transects, starting from the centre of the section, were examined independently by 3 different researchers, and the number of growth rings counted and averaged (Priori et al., 2013). As annual growth rings develop only after 4 years of colony life, 4 years were added to the ages determined by the ring counts (Marschal et al., 2004; Gallmetzer et al., 2010; Priori et al., 2013; Bramanti et al., 2014). Individual growth rates were determined by dividing the mean colony diameter by its age.

Age and diameter were also determined in 106 thin sections performed along successive points from the basis to the apex of the colonies (n = 36; Fig. 2). Statistical differences in growth between branches and bases were tested by Student's t test for paired samples. To estimate colony growth in height (mm/y), the linear distance between two consecutive points was measured with a wire (black line, Fig. 2).

The age at which red coral colonies produce their first branch (henceforth, '*age at first branching*') was unknown. The first branch is not necessarily that nearest to the colony base. In red coral each new ramification begins as a bulge (arrow, Fig. 2), which can sprout even in the most proximal portion of the axis (the oldest) and/or on already formed branches. Since diameter is an increasing function of age, the widest branch was considered to be the oldest. The age of first branching thus corresponds to the difference in age measured between the colony base and the base of its largest branch 1 (Fig. 2).

Statistical differences in height/branch number ratio, base and branch growth rate, age at first branching and linear growth between the two geographic areas have been examined by Student's t test.

3. Results

The number of branches in each colony, which varied between 1 and 42, was plotted against its height (Fig. 3). The modal age and mean annual growth rate (measured at the colony basis) were 26–30 years and 0.24 ± 0.08 mm/y, respectively (n = 95). On the basis of the height to branch number ratio, there was a significant separation of the samples into two geographic groups ($t = 5.49$, $p < 0.01$), one of which (Central Tyrrhenian) is made up of taller, less-branched colonies (height ≤ 19.25 cm, branch number ≤ 10 and maximum branching order ≤ 5), while the other (North Tyrrhenian) is composed of smaller, more branched ones (height ≤ 14.9 cm, branch number ≤ 42 and maximum branching order ≤ 7; Fig. 3).

Significant differences between the colonies of the different geographic areas were found in growth rate (0.26 ± 0.07 vs. 0.21 ± 0.08 mm/y in North and Central Tyrrhenian Sea, $t = 3.59$, $p < 0.01$) and maximum life span (89 vs. 106 years, n = 51 vs. n = 44, respectively; Fig. 4).

The ratio between the minimum and maximum basal diameter (0.88 ± 0.08, mean ± SD) tended to remain constant, although with some small oscillations independent of colony age, indicating that the two diameters grow proportionally. This allometric relation did not differ between the two geographic areas ($t = 0.97$, n.s.). As this relation was examined only in colonies older than 10 years, it remains unknown whether the *isotropic* growth encountered occurs in younger colonies as well.

Successive sections cut from the basis to the top of the colony axis and branches revealed a regularly decreasing age, further confirming the reliability of the growth ring counting dating method (Table 1). The average growth rate of branches was similar to that at the colony bases (0.19 ± 0.08 vs 0.21 ± 0.07 mm/y, mean ± SD; $t = 1.37$, n.s); only the apical branches (3–4 in Table 1) exhibited higher growth rates (22.3%, Table 1). No difference in branch growth rate was found between the two study sites ($t = 0.56$, n.s.).

The average age of the largest branches examined was approx. 30 years, while that of the colonies to which they belonged was approx. 41. The average age of colonies at first branching was 10.4 ± 9.0 (mean ± SD; Table 1) and did not differ between the two geographic areas ($t = 1.15$, n.s.).

The relation between age and mean branch diameter was well fitted by a *monotonic power curve* with positive exponent ($R^2 = 0.74$, $p < 0.01$; Fig. 5a), while the relation between age and growth rate followed a regularly decreasing pattern fitted by a power curve with negative exponent ($R^2 = 0.71$, $p < 0.01$, Fig. 5b).

No relation was found in the age difference between two consecutive sections and their linear distance ($R^2 = 0.0055$; Fig. 6). Furthermore, mean linear growth rate in height was highly variable (3.22 ± 3.87 mm/year, mean ± SD). No significant difference in linear growth rate was found between the two geographic samples examined ($t = 0.77$, n.s.).