Superior Council for Scientific Research
Institute of Marine Sciences
Marine Biology and Oceanography Department

Long-term dynamics in the coralligenous community

analysis of red coral Corallium rubrum (Linnaeus, 1758) population dynamics using image processing of long-term photoquadrat series

Supervisor Joaquim Garrabou

Donna Dimarchopoulou

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1. Introduction

Mediterranean coralligenous communities have a high ecological, aesthetic and economic value as they host about 20% of the total Mediterranean species and exhibit great structural complexity. Some of the engineering species that construct them exhibit longevity and low dynamics, thus making these communities vulnerable to environmental and anthropogenic disturbances, such as fishing, pollution, invasive species, and mass mortality events (Ballesteros, 2006).

One of the many species dwelling in the coralligenous communities is the Mediterranean red coral *Corallium rubrum*. To investigate the status of the red coral populations, a full understanding of species population dynamics (estimation of longevity, size structure, growth rates, and response to mortality) is of great importance, as it gives us valuable information necessary for designing and implementing management and conservation plans, which will ensure the effective protection and/or recovery of the target species. Longtime monitoring is the most reliable way to enhance our understanding of growth and mortality of this species and to obtain the aforementioned information.

1.1 Corallium rubrum (Linnaeus, 1758)

The Mediterranean red coral *Corallium rubrum* (Order: Alcyonacea, Family: Coralliidae, Fig. 1) is an anthozoan species that forms individual arborescent colonies and grows on rocky seabottom at depths mainly between 20 and 200 m (Zibrowius et al., 1984). It typically inhabits dim-light environments, such as depths or dark caverns and crevices. It is distributed in the Western and Eastern Mediterranean from Greece and Tunisia to the Straits of Gibraltar including Corsica, Sardinia and Sicily, and in the Eastern Atlantic in Portugal, Morocco, Canary and Cape Verde Islands (FAO, 2015; Fig. 2). Due to the use of its calcified axis for jewellery, the red coral is of great interest to fisheries and has been commercially exploited since antiquity (Santangelo et al., 1993; Santangelo et al., 2007). This intensive exploitation has put great pressure on the coral colonies progressively restricting their occurrence, and therefore exploitation, at the deeper range of their bathymetric distribution (Chessa & Cudoni, 1988).

Figure 1. The red coral *Corallium rubrum*.

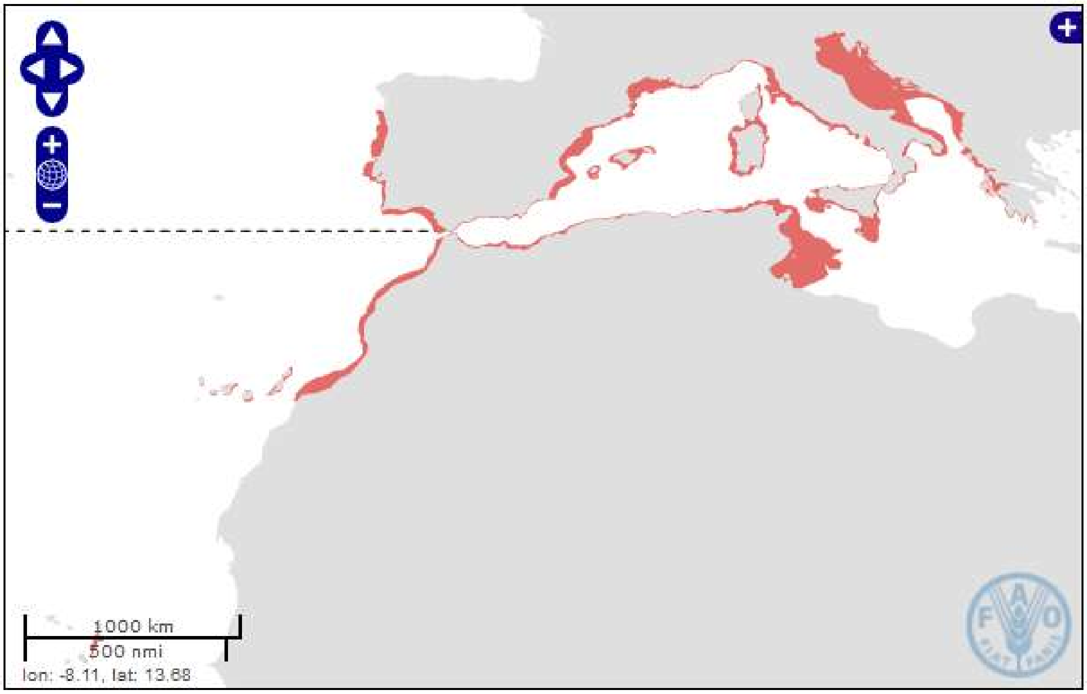

Figure 2. Geographical distribution of the red coral *C. rubrum*.

1.1.1 Growth rate

C. rubrum is a long lived animal that has a slow growth rate (Garrabou & Harmelin, 2002). Most of the times, the red coral growth rate is calculated as an annual increase of the colony's basal diameter in mm, whereas the studies calculating it as an annual increase of the colony's height are very few (see Table 3 for references). The former and most used method, when combined with age estimation by counting growth rings, is destructive as it requires the collection and fixation of colonies (Marschal et al., 2004; Bramanti et al., 2014). But it can also be non-destructive in those cases when the age is known and the measuring is conducted *in situ*, with a caliper for the basal diameter, or with a ruler for the colony height (Garrabou & Harmelin, 2002). However, *in situ* measuring increases the underwater work time and complicates the sampling procedure. On the other hand, the use of photographic surveys can provide the advantages of both fast underwater work as well as having no impact on the ecosystem (Bianchi et al., 2004).

The use of photographic monitoring in combination with photogrammetric techniques for measuring the colony size and for the calculation of red coral growth rates can be a valuable tool for researchers.

1.2 Photogrammetry

Photogrammetry is the science of "making measurements from photographs" (www.photogrammetry.com) and "obtaining reliable information about the properties of surfaces and objects without physical contact with them, and of measuring and interpreting information" (Schenk, 2005). The term is derived from the Greek words φως (phos=light) + γράφω (grafo=write) +μέτρο (metro=measure). Two types of photogrammetry can be distinguished, based on camera location during photography: Aerial and Close-range photogrammetry. In the former, the camera is placed on an aircraft and is usually pointed vertically towards the ground, whereas in the latter, the camera is close to the object and is normally hand-held. Typically, close-range photogrammetry is not topographic and its product can be drawings, 3D models and measurements of archaeological artifacts, accident scenes (www.photogrammetry.com) or, in this particular case, hard bottom benthic communities.

1.3 Aim of the project

The aim of this project was to study the population dynamics of the long-lived invertebrate *C. rubrum* in Grotte Palazzu, Scandola Nature Reserve within a ten-year monitoring period, through the analysis of long-term photoquadrat series collected in a non-destructive way. The information extracted, concerning size structure, growth rate in height, and mortality status, was used in order to explain the underlying mechanisms that resulted in the observed patterns, thus leading to the ultimate goal of the work which is to contribute to the conservation of the studied species.

2. Materials and methods

2.1 Study area

The shallow red coral population that was studied is in Grotte Palazzu in the Scandola Nature Reserve (Corsica, NW Mediterranean) (Fig. 3), at depths ranging from 19 to 22 m. This marine protected area is located in French territorial waters and covers an area of about 1000 ha. It was established in 1975 and since then human activities, such as scuba diving, recreational fishing, and collection of marine plants and animals, are prohibited. No poaching events have been recorded in the area.

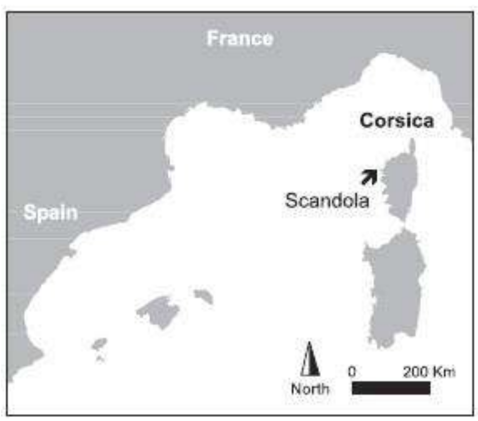

Figure 3. The study area located in the Scandola Nature Reserve, Corsica.
(*adapted from Linares et al., 2010*)

2.2 Coral population monitoring

Due to the red coral fragility, the monitoring was conducted with the application of a non-destructive photographic method (Kipson et al., 2011). Three randomly selected permanent plots were set up with PVC screws fixed to holes in the rocky substratum, as described in Linares et al.

(2010). A cord was deployed between the screws forming three sampling transects of variable length (1 m more or less), depending on the complexity of the substratum, and 40 cm width. The plots were set in November 2003 and calibrated quadrats (20 * 20 cm) were sequentially positioned and photographed along each transect, covering both the upper and the bottom area of the cord. Two photographs of a slightly different angle (~30°) were taken for each quadrat, using a Nikon D70 with housing and two electronic strobes, in order to apply photogrammetric techniques for the measurement of maximum colony height. The same photographing process was repeated again every year in a ten-year period, until June 2013. The red coral colonies depicted in the photoquadrats were individually identified and a unique ID was assigned to each of them. A total of 100 colonies could be measured during the whole study period and were therefore included in the present study.

2.3 The photogrammetric technique

This technique increases the quantity and accuracy of the measurements (in this case, the maximum height of each colony) as it obtains them in 3 spatial dimensions. The ARPENTEUR photogrammetric software package was used for measuring colony height. This tool was originally designed for architectural applications (Drap & Grussenmeyer, 2000) and was later on adapted to the monitoring of red coral populations *in situ* (Drap et al., 2013).

For the measurement of the colony height, the researcher uses the software to firstly create the stereo models of the two pictures of each quadrat. Then, the researcher points out the base and the branch tips of the colony by making equivalent points in the two pictures (Fig. 4). The measurement results are exported into a spreadsheet application.

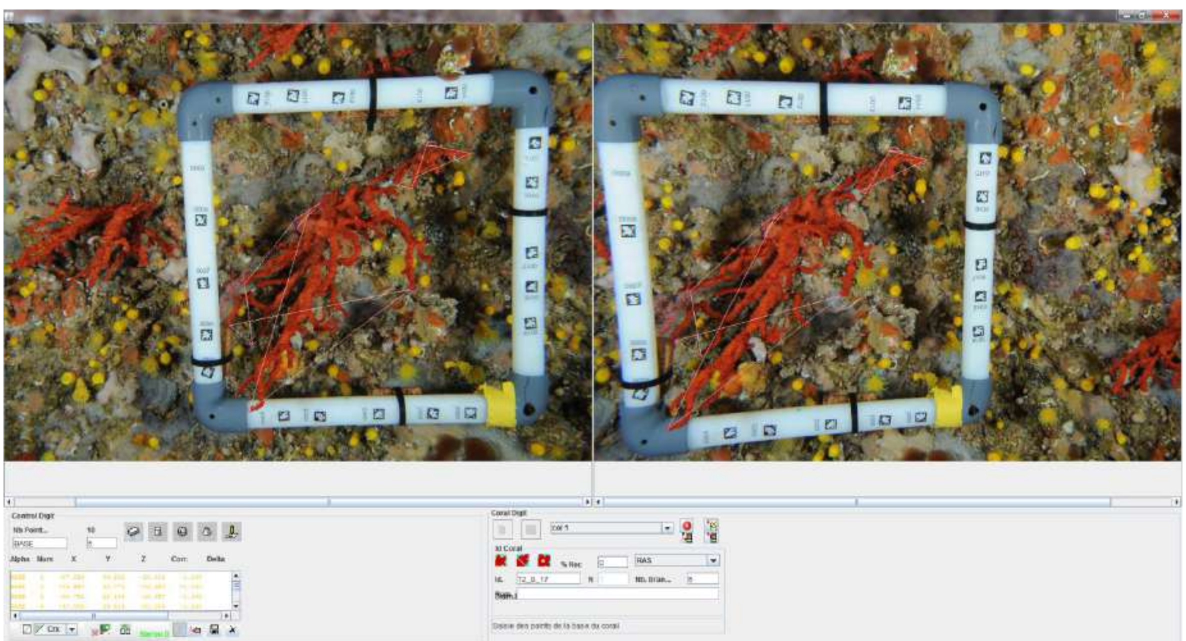

Figure 4. Example of the application of the ARPENTEUR photogrammetric software package to red coral colonies.

2.4 Estimated parameters

The different variables and parameters used in the present study can be seen in Table 1.

Table 1. Estimated parameters used in the present study.

Colony size (mm)	in 2003	in 2013	
size classes (mm)	0-30	30-60	60-90
	90-120	120-150	150-180
Growth rate (mm/year)			
Partial mortality	Necrosis	Breakage	Overgrowth
number of partial mortality events			
maximum percent necrosis during ten years of study			
number of years with necrosis			

Firstly, we measured the colony height in 2003 and 2013 as described in section 2.3. For studying the size structure of the population we used the colony height measurements in order to classify the colonies into the following size classes: 0-30, 30-60, 60-90, 90-120, 120-150, and 150-180 (mm). For the calculation of the mean growth rate we divided the height difference between 2003 and 2013 by the number of years of study.

Apart from measuring the colony height, we also visually estimated the type and percent of partial mortality for each colony for the whole study period. The different kinds of mortality that were taken into account were necrosis, breakage and overgrowth. Necrosis was categorized as type A (recent) and type C (old). From these records we extracted information about the number of partial mortality events, the maximum percent necrosis during ten years of study as well as the number of years with necrosis. Then, each colony was assigned to a label which resulted in its final mortality level (Table 2). For example, an "LLM" colony had low number of partial mortality events (0 or 1), low maximum percent necrosis (0%) and medium number of years with necrosis (1-6) and had a low overall mortality level (Table 2).

Table 2. Mortality level correspondence.

Number of partial mortality events	**Mortality level**
0-1	Low (L)
2-3	Medium (M)
4, 7	High (H)
Maximum % necrosis	
0	L
≤50	M
>50	H
Number of years with necrosis	
0	L
1-6	M
7-11	H

3. Results and discussion

3.1 Size structure

As reported before, size structure is a useful descriptor for the state of a population, as the observed shifts give us a hint about the responses of the species to environmental and anthropogenic factors (Tsounis et al., 2006).

The size structure results showed that the majority of the colonies of the studied red coral population were over 60 mm in height, in both 2003 and 2013 (Fig. 5). This is in accordance with another study of red coral populations in marine protected areas which showed that high percentage of the colonies belonged to the largest size classes (Linares at al., 2010). On the contrary, other shallow red coral populations, mainly in non-protected harvested areas, mostly consisted of colonies shorter than 60 mm (Garrabou et al., 2001; Garrabou & Harmelin, 2002). The size structure pattern depicted in Fig. 5 (i.e. the smallest colonies are the fewest and half or even more of the colonies belong to the 30-90 size classes) is similar to that of other recently studied populations (Monterro-Serra et al., 2015).

When comparing 2003 to 2013 in Fig. 5, a shift in the size structure characterized by the presence of larger colonies should be expected for this protected population where no poaching events have been reported. Instead, a shift to the left was observed which means that large colonies were lost from the population and the small/mid-sized ones became more abundant. This shows that implementing protection plans on red coral populations in order to remove anthropogenic disturbances such as fishing, might not be sufficient for their growth and recovery. Indeed there are other natural influences that still affect the system, such as mortality (which is discussed in section 3.2) and climate change (Torrents et al., 2008).

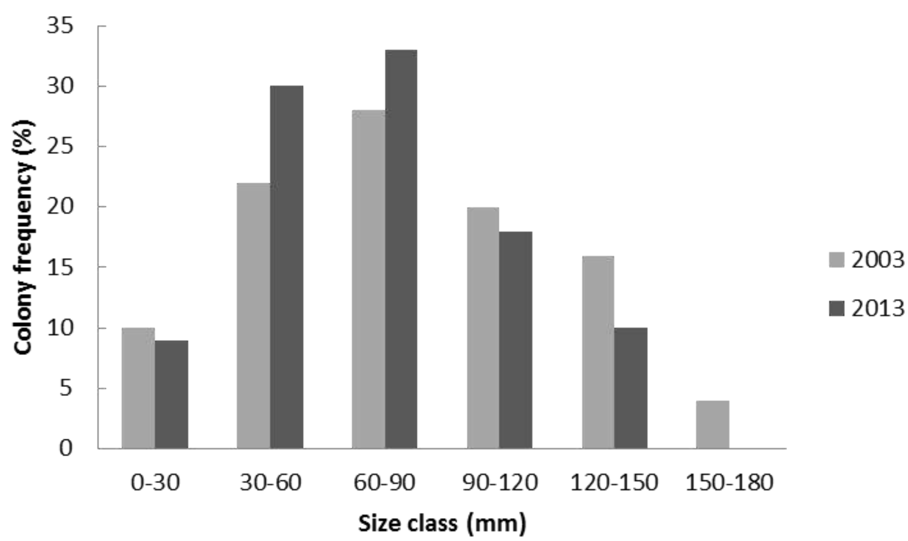

Figure 5. Size structure of the Grotte Palazzu red coral population in the years 2003 and 2013.

3.2 Mortality

As far as the mortality status of the studied population is concerned, we observed that only 40% of the colonies did not suffer any partial mortality events at all, whereas half of the population went through 1 or 2 different partial mortality events (Fig. 6A).

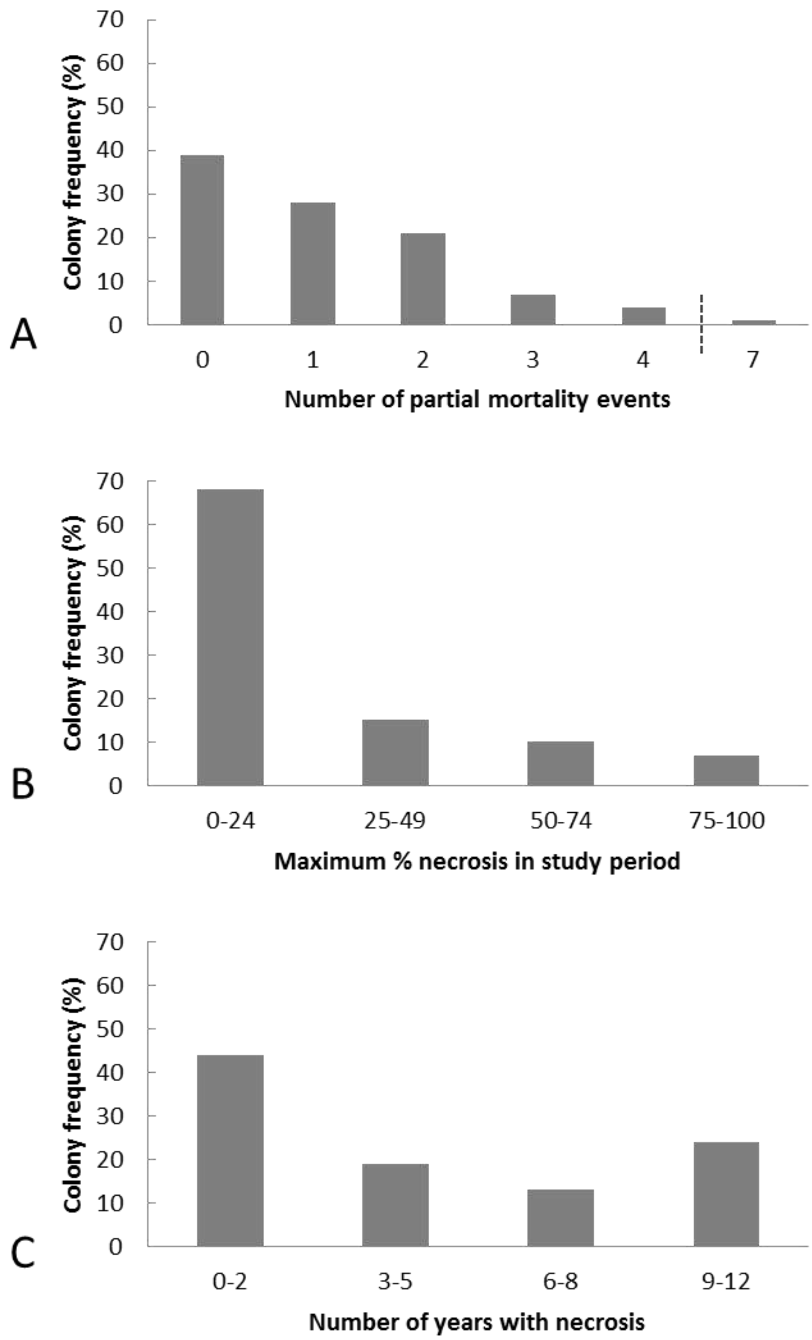

Figure 6. Mortality parameters of the Grotte Palazzu red coral population. A: number of partial mortality events, B: maximum percent necrosis and C: number of years with necrosis in the study period (2003-2013).
*35% of the 0-24 class in B corresponds to 0% **35% of the 0-2 class in C corresponds to 0%

When looking only into necrosis (i.e. colony parts initially displaying a change in color that then could result in a denuded skeleton and epibiosis), we could see that in most of the affected colonies no more than 24% of the colony surface showed necrosis during the ten-year study period (Fig. 6B). But those colonies that did suffer from necrosis remained in this situation for several years, a high proportion of them even for the biggest part of the study period (Fig. 6C).

We can also observe that in the years 2003-2008 31-39% of the colonies suffered from necrosis (Fig. 7). That percentage increased to 47% in 2009 and 44% in 2010, falling again to the previous levels from then on. During these ten years of study, at least 31% of the colonies were always affected by necrosis. For most of the years this was mainly old necrosis, except for 2003, 2009 and 2010 when increased number of recent necrosis events appeared (Fig. 7). The observed increase in the events of recent necrosis could be an indicator of mass mortality events. Two mass mortality events have already been recorded in the NW Mediterranean in 1999 and 2003 -one of them directly affecting the studied region- and were shown to have affected the rocky benthic communities including red coral populations (Garrabou et al., 2001; Garrabou et al., 2009). Apart from the 2003 event that seems to have affected the studied population, our results indicate a possible new mortality event in 2009-10.

The high percentage of colonies with old necrosis could be showing a highly affected population that is possibly undergoing the long process of recovery. The persistent necrosis possibly affects the growth rate of the colonies as discussed in section 3.3.2.

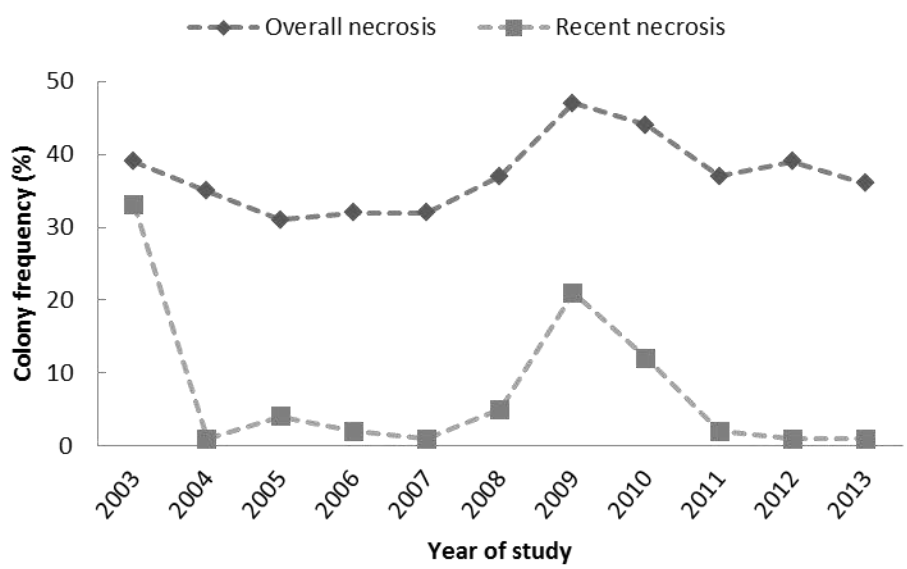

Figure 7. Percentage of colonies of the Grotte Palazzu red coral population with necrosis (overall: recent and old, and recent only) in each year of the study period.

The overall mortality level of the population, when taking into account all the parameters of Fig. 6, is medium for half of the colonies, low for 35% of them and high for 15% percent (Fig. 8). The fact that the majority of the colonies suffer from some kind of mortality shows the long time span of the impact of mass mortality events and indicates how slow the recovery process can be for a species with such a life history (high longevity, slow growth, low recruitment).

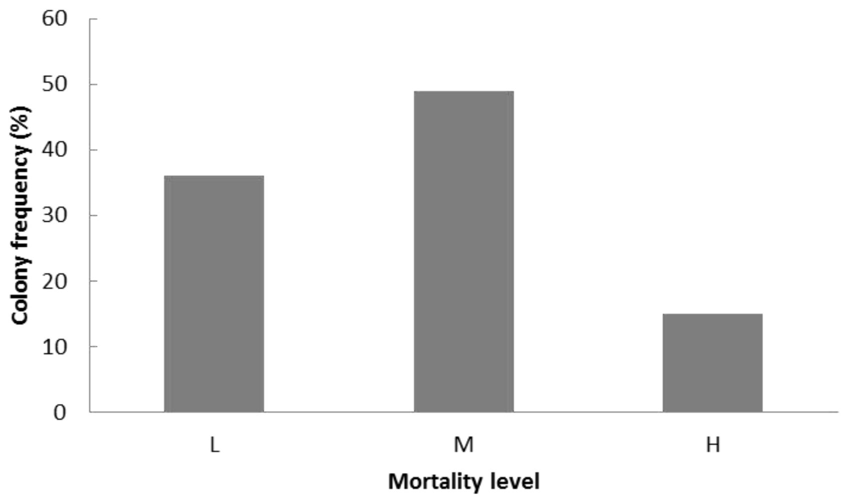

Figure 8. Mortality level (L: low, M: medium, H: high) of the Grotte Palazzu red coral population.

3.2.1 Relationship of mortality and colony size

Regarding the colony size, it seems that the mortality level gets higher as the colony size increases (Fig. 9). This observation could explain the negative growth rate of the bigger colonies, as shown in Fig. 10A, C of the following section 3.3.

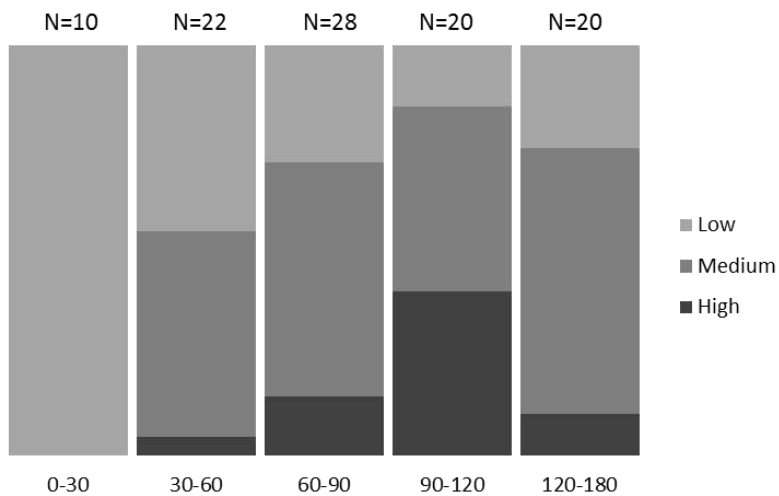

Figure 9. Mortality level (L: low, M: medium, H: high) by size class of the Grotte Palazzu red coral population.

*N is the number of colonies in each size class

3.3 Growth rate

The average growth rate for colony height was -0.88±2.35 mm/y showing that the studied population grew smaller even though it lay within a protected area. This could be linked to mortality, as discussed in section 3.2. It might also be attributed to environmental parameters, such as ocean warming and acidification, which have been shown to affect the growth of red coral, as well as other coral species, both in the Mediterranean Sea and in the neighboring Red Sea (Cantin et al., 2010; Bramanti et al., 2013; Cerrano et al., 2013; Foden et al., 2013).

The average positive (which indicates growth capability) and negative growth rate was 1.19±0.87 and -2.25±1.99 mm/y, respectively, agreeing with previous studies that have repeatedly shown that red coral is a very slow growing species, both in terms of basal diameter growth rate as well as height growth rate (Table 3). It seems to be growing quite as slowly as other octocorals (Roark et al., 2006) or even more slowly (Matsumoto 2004; Torrents et al., 2005; Noe et al., 2006; Noe et al., 2008) thus having one of the slowest growth rates among octocoral species.

Table 3. Growth rates calculated for *C. rubrum*.

Reference	Site	Growth rate (mm/year)	
		Colony height	Basal diameter
Garrabou & Harmelin, 2002	Marseilles, France	1.78±0.7	0.24±0.05
Marschal et al., 2004	Marseilles, France		0.35
	Medes Islands, Spain		
Bramanti et al., 2005	Calafuria, Leghorn, Italy	1.83±0.15	0.62±0.19
Torrents et al., 2005	Marseilles, France	2.4-3.4	0.36-0.51
Gallmetzer et al., 2010	Corsica, France		0.2
Santangelo et al., 2012	Calafuria, Italy		0.68±0.02
	Elba Island, Italy		0.59±0.19
	Medes Islands, Spain		
Priori et al., 2013	Tuscany Archipelago, Italy		0.26
Bramanti et al., 2014	Portofino, Italy Cap de Creus, Spain		0.24
Present study	Corsica, Italy	1.19±0.87	

3.3.1 Relationship of growth rate and colony size

We observed a negative relationship of growth rate and size class, as both overall and negative growth rate showed a decreasing trend in which the large colonies seemed to exhibit high negative growth (Fig. 10A, C). When taking into account only the positive growth rate, there was not such a trend to be observed which means that the colonies that grew bigger did so regardless of their size (Fig. 10B).

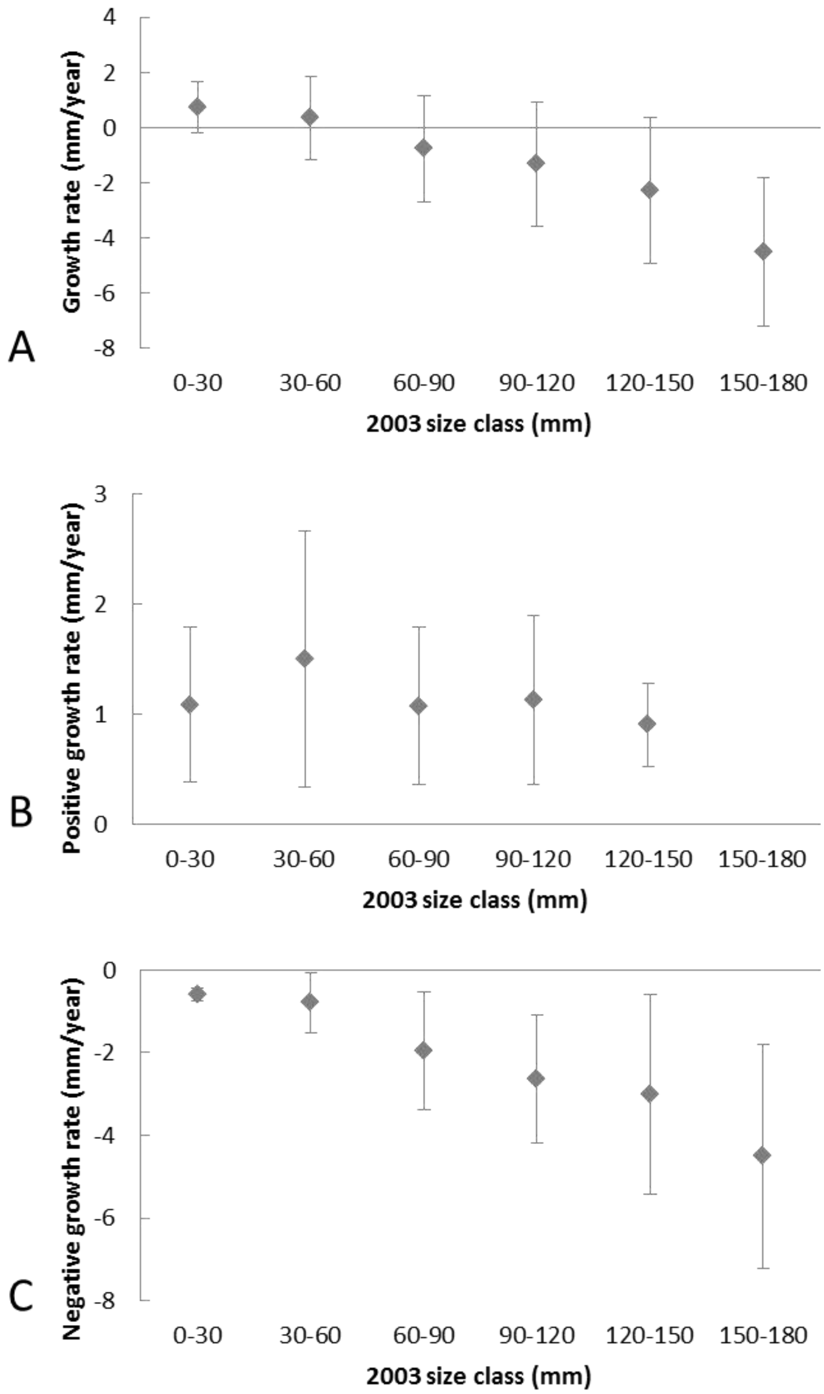

Figure 10. Means (±SE) of overall (A), positive (B) and negative (C) growth rate of the Grotte Palazzu red coral population as calculated during a ten-year period of study (2003-2013).

3.3.2 Relationship of growth rate and mortality

When correlating growth rate to mortality level, we observed a decreasing trend (Fig. 11) which showed that the higher the mortality level, the more negative the growth rate. This finding supports the assumption that mortality could explain the overall negative growth of what was expected to be a rather pristine undisturbed population. As stressed by Garrabou et al. (2001), mortality events could increase the growth of healthy colonies due to the lack of interspecific competition for food. But then again, affected colonies could display a reduction in their growth as they need to invest great amounts of energy in injury repair and competition with epibionts, a long process that extends the effects of the mortality events in time.

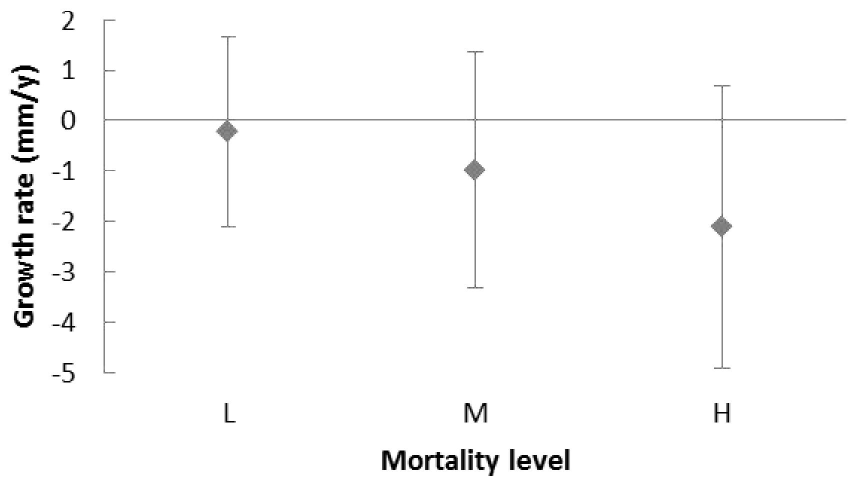

Figure 9. Relationship between mean (±SE) growth rate and mortality level (L: low, M: medium, H: high) of the Grotte Palazzu red coral population.

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