

Demography of long-lived octocorals: survival and local extinction.

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Abstract. Gorgonian corals are slow growing, long lived species whose three dimensional colonies form dense canopies on Mediterranean reefs. As they are habitat forming, the ecology of the reef community depends in a large part on their survival. The red coral *Corallium rubrum* is a precious gorgonian whose heavily harvested populations have changed their size and age structure in shallow waters. In general gorgonians show low recruitment and low population growth rates. In 1999 and 2003 two mortality events, putatively linked to Global Climate Change, (GCC) affected a population of the red gorgonian *Paramuricea clavata* at the Western edge of the Gulf of La Spezia (NE Ligurian Sea Italy). The availability of pre and post mortality demographic data allowed us to follow the trajectory of this population over 12 years. In the first years population density decreased drastically and 90% of the colonies died or suffered partial mortality; moreover recruitment decreased to 40% and the dominant size classes shifted towards a smaller size. In the subsequent years population density increased, damaged colonies recovered and recruitment reached six times that of 1998. While the populations of both species recovered, an increased frequency of mortality events with GCC could lead to local extinction (*C. rubrum*) or to a new stable structure reached at a lower density (*P. clavata*).

Key words: Gorgonians, Mass mortality, Global Climate Change, Recovery, Demography.

Introduction

Conservation of harvested, long lived, slow growing species is one of the most difficult challenges facing conservation ecologists (Dobson 1998; Dayton 2003). Whales, turtles and sharks are generally considered typical of long-lived marine animals, but gorgonians are also remarkably long-lived, as the lifespan of some species exceeds a full century (Roark et al. 2006). Long-lived species play a paramount role in the structure and function of marine ecosystems. In particular, patches of long-lived, three dimensionally structured gorgonians, increase habitat complexity and modify local hydrodynamics, thereby increasing local biodiversity and promoting a nursery effect (Gili & Coma 1998). The study of their demography is thus basic to our understanding of the whole community dynamics (Margalef 1992).

The red coral *Corallium rubrum* (L 1758), the precious coral *par excellence*, is a long-lived, slow-growing gorgonian endemic to Mediterranean and neighboring Atlantic rocky bottoms, where it dwells between 20 and 800 meter depth (Costantini et al. 2010). The bright red, calcareous axial skeleton of this sea fan represents highly valuable raw material for carving art objects and jewelers. Ever regarded as precious and magical, red coral has fascinated

mankind since antiquity. Pierced beads of red coral were found in Mesolithic burial sites (Cicogna and Cattaneo-Vietti 1993).

Harvested and traded since ancient times (Tsounis et al. 2010), red coral is becoming a paradigmatic example of an over-exploited marine resource as a large part of known populations show a drastic reduction in colony size (e.g. the size structure changes in Spanish harvested and protected populations reported in Fig. 1, after Tsounis et al. 2007). Moreover, some coastal populations, living in the shallower portion of the species bathymetric distribution range, were recently affected by anomalous mortality events linked to Global Climate Change (Garrabou et al. 2001; Bramanti et al. 2005).

In this note we present some simulations of the temporal trends of a red coral population impacted by mass mortality set out by means of a discrete size/age structured demographic model based on Leslie-Lewis transition matrix (Caswell 2001).

The red gorgonian *Paramuricea clavata* (Risso 1826) is the largest Mediterranean gorgonian, forming dense canopies and bars on rocky cliffs exposed to intense streams. Over the period 1998-2010 we studied a population affected by two anomalous mortality events associated with anomalous

temperature increases recorded in 1999 and 2003 (Garrabou et al. 2009; Cupido et al. 2009). The availability of demographic data collected before and after the two events (Cupido et al. 2009) allowed us to examine the changes this population faced during its drastic collapse and the following recovery. After the anomalous mortality events, population density reduced by 80%, and the dominant size class shifted towards smaller sizes. In the following years (2007-2008), the population reached about 1/2 of the original density and recruitment increased by about 6 fold (Cupido et al. 2009). This series of demographic data allowed us to project its trends over time.

The two octocorals are both long-lived, gonochoric, characterized by an early age at first reproduction and a 1:1 dominant sex ratio. However they exhibit large differences in population density and in reproductive features (Table 1), since *C. rubrum* is a planulator characterized (in shallow populations) by a high colony and recruitment density (Bramanti et al. 2005; Santangelo et al. 2012) and lower population reproductive output (Santangelo et al. 2007) while *P. clavata* is a surface brooder with a recruitment rate about 30-100 fold lower than the former one and of a population reproductive output about 20-50 fold higher (Table 1).

Our aim is to develop demographic models suitable for the populations of each species on the basis of previously explored relationships linking adult density and population age structure to reproductive output and recruitment (*sensu* Hughes et al. 2010).

Material and Methods

The *Corallium rubrum* population in this study dwells between 20 and 50 m depth in small crevices spread over a rocky subvertical cliff at Calafuria (Livorno, Italy 43° 30' N, 10° 20' E). This population has been studied since 1987. Details on sampling techniques, on setting out the life table and the Leslie-Lewis transition matrix (Caswell 2001) of this population have been previously described (Santangelo et al. 2007; Bramanti et al. 2009). Here we present the simulated trends of this population when repeated mortality events co-occur with harvesting of larger classes.

The *Paramuricea clavata* population dwells on a rocky vertical cliff at the western side of the Gulf of La Spezia (44°01'N, 09°50'E; Ligurian Sea, Italy), between 17 and 25 m depth, at the upper limit of the summer thermocline in that area. This population was heavily stricken by the anomalous mortality events that occurred in late summer 1999 and 2003 in the NW Mediterranean (Garrabou et al. 2009; Cupido et al. 2009). Sampling was carried out annually before (1998) and after (2004-2010) the two mortality events. Due to the limited spatial extent of the

population (a few thousand m²) and the need to avoid any further damage to the stricken population, sampling was carried out by SCUBA diving on 12 random and 12 permanent 1 m² plots only by non-destructive methods (photographic recording of plots and collection of a single 3 cm long tip from each colony).

Colony and recruit densities, population size/age structure, fertility, fecundity were measured and the reproductive output of the population was estimated. Details on sampling techniques have been described previously (Cupido et al. 2009).

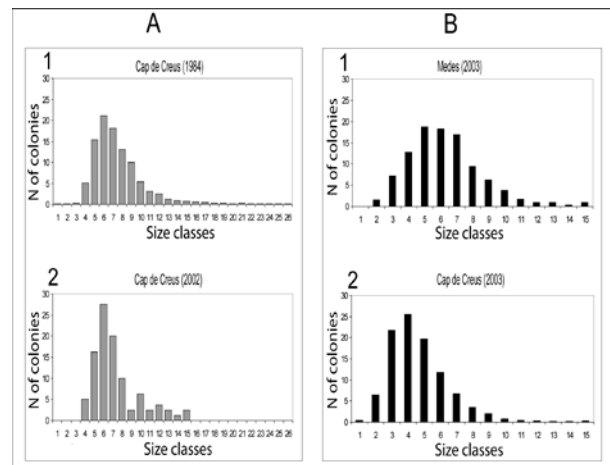


Fig 1 Colony size distribution in Spanish fishing crops (Cap de Creus) in 1984 (a1) and in 2002 (a2). The 2002 curve exhibits half the skewness of the 1984 curve due to the lack of larger colonies. Colony size (height) distribution in Spanish populations in a MPA (Medes Islands) (b1) and in a non-MPA (southern Cap De Creus; (b2). Despite the lack of colonies beyond class 15th in both, current Medes colonies are significantly larger.

Species	<i>Corallium rubrum</i> ^{2,3,4} (shallow populations)	<i>Paramuricea clavata</i> ^{1,2}
Reproductive features	Planulator	External brooder
Adult density	200-3000 col m ⁻²	12-53 col m ⁻² *
Polyp fecundity	0.9-3 planulae/polyp	13-28 oocytes/polyp
Size (height) / age at first reproduction	1-2 cm 3 – 10 y ^o °°	8.5-11 cm 3-7 y
Population Reproductive output	38x 10 ³ planulae m ⁻²	730-2000 10 ³ oocytes m ⁻²
Recruit density	18-340 rec. m ⁻²	0.5- 2.6 rec. m ⁻²

Table 1: The main population features of the two gorgonian corals (¹Cupido et al 2009; ²Torrents & Garrabou; ³Gallmetzer et al. 2010; ⁴Santangelo et al. 2003, 2012 and references herein; other references in the text).

Results

The availability of a reliable, exhaustive demographic data set on a red coral population has enabled us to simulate population trends over time as function of different combinations of environmental and harvesting pressures (Fig. 2).

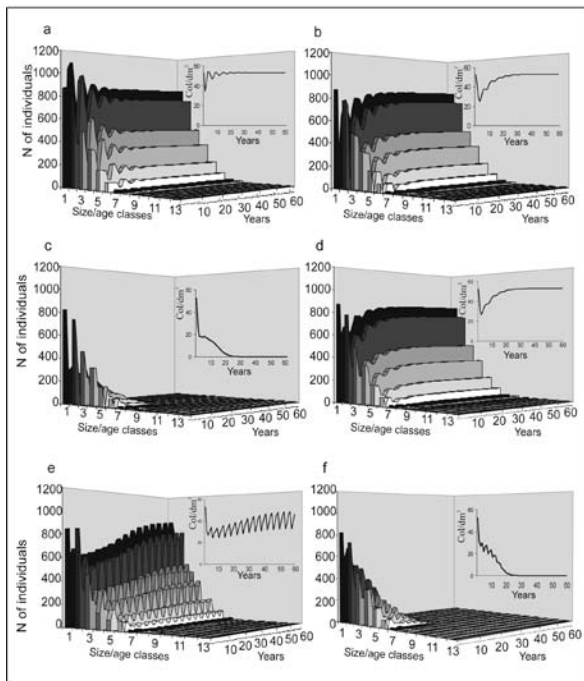


Fig. 2: Red coral population trends under different mortality pressures. Different gray tones represent different size/age classes. At the right side overall density trends are reported. **a.** Mortality increase: if mortality exceeds recruitment only once (negative net recruitment), the population recovers. **b.** Harvesting pressure: if all the classes ≥ 5 are harvested the population recovers in about 30 years. **c.** Combined effects of mortality increase and harvesting: if such harvested colonies are affected by a single anomalous mortality event the population collapses. **(d)** If all classes ≥ 5 survive, the population survives; it also survives mortality events having a 4 year periodicity **(e)** but a 3 year periodicity **(f)**, cause the population to go extinct.

If mortality exceeds recruitment only once (i.e. a negative net recruitment occurred, as in 1999; Bramanti et al. 2005), the population recovers in about 20 years (Fig. 2a). If harvesting affects all colonies of classes ≥ 5 the population recovers in about 30 years (Fig. 2b). If such harvesting co-occurs with a single anomalous mortality event, the population irremediably decays to extinction in about 25 years (Fig. 2c). If all the colonies ≥ 5 survive and anomalous mortality events recur with a 4 year periodicity, the harvested population, despite wide oscillations, eventually still survives and recovers in about 60 years (Fig. 2e). However, a periodicity of 3 years leads to population extinction in about 20 years (Fig. 2f). Clearly, class 5 survival, as well as limited recurrence of anomalous mortality events, is crucial for population recovery. Thus, there is a threshold to the effects of repeated anomalous mortality events combined with harvesting pressure, beyond which the population loses resilience and collapses.

The impacted *P. clavata* population showed, during the years 2004-2006, a drastic decrease of colony and

polyp density (the overall number of polyps found on the colonies living in 1 m^{-2}) which reduced by 80% and 90% respectively (Fig.3a, b). In the following years (2007-2010) the population recovered reaching about $\frac{1}{2}$ and $\frac{1}{5}$ of the original colony and polyps densities. Recruitment, reduced in 2004, 2005 to 80% and in 2006 to 40% of the original 1998 values sharply increased from 2007 to 2010 exceeding 5-6 fold the pre-mortality densities (Fig.3c).

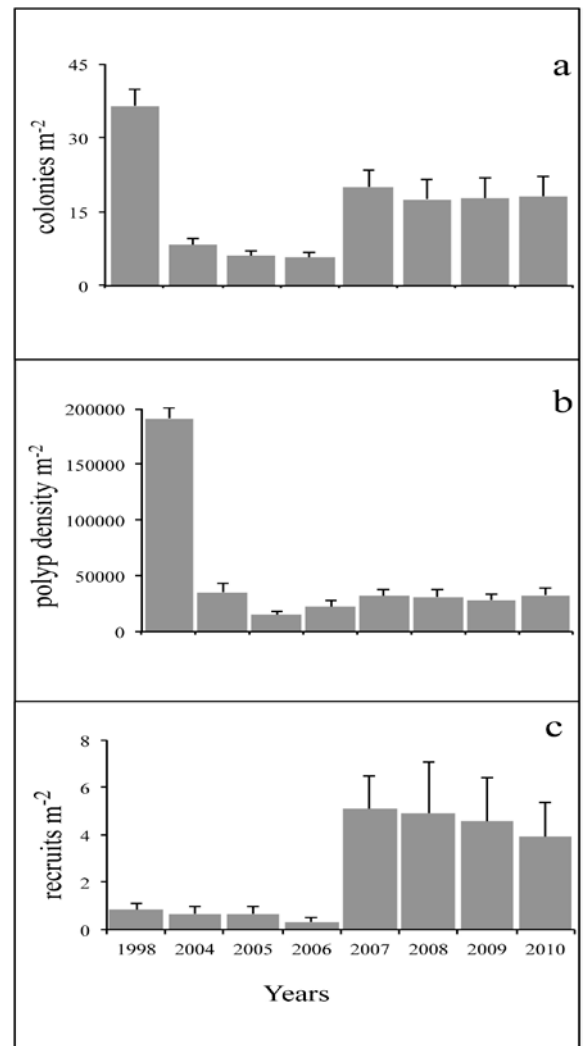


Fig. 3: *Paramuricea clavata* population colony **a**, polyp **b**, and recruitment **c**, density trends between 1998 (pre mortality) and 2004-2010 (post mortality) period.

In order to build a discrete mathematical model based on the available field data, colonies were placed into 10 size classes defined on the basis of the mean annual colony growth rate. Then annual transition matrices were built on data of fixed plots where colonies were labeled and their size and survival were recorded each year over the period 2007-2010. Finally the three transition matrices obtained were averaged (Table 2). Moreover, in order to describe the input of

new colonies into the population, we calculated a function providing the number of recruits at different polyp densities. In the diagonal of the matrix (Table 2) are reported the percentage of colonies which transit from one class to the following each year (in bold), the percentage of colonies which transit to larger classes, the percentage of colonies which remain in their size class (they don't grow) and the few colonies which, losing their apices, transit to the previous, smaller class (e.g. line 5, row 4). On these bases simulations of population trends have over time been produced (Fig. 4).

class	1	2	3	4	5	6	7	8	9	10	>10	surv
1	0.18	0.38	0.1	0	0	0	0	0	0	0	0	0.67
2	0	0.21	0.38	0.19	0	0	0	0	0	0	0	0.78
3	0	0	0.27	0.4	0.16	0	0	0	0	0	0	0.83
4	0	0	0	0.24	0.4	0.24	0	0	0	0	0	0.88
5	0	0	0	0.11	0.37	0.31	0.09	0	0	0	0	0.88
6	0	0	0	0	0.12	0.38	0.32	0.11	0	0	0	0.93
7	0	0	0	0	0	0.09	0.41	0.28	0.14	0	0	0.93
8	0	0	0	0	0	0	0	0.49	0.43	0	0	0.92
9	0	0	0	0	0	0	0	0.22	0.49	0.25	0	0.96
10	0	0	0	0	0	0	0	0	0	0.67	0.25	0.92
>10	0	0	0	0	0	0	0	0	0	0	0.72	0.72

Table 2: Transition matrix of the impacted *Paramuricea clavata* population based on the colonies of different size found in the fixed plots during the period 2007-2010. In the diagonal are reported the probability of the colonies in each size class to survive and pass to the following classes. Some few colonies (e.g. 11% of colonies in class 5) reduce their size and go back to the smaller class 4). Survival of each class is reported in the last row.

According to the data in the transition matrix (Table 2) the simulated population cannot reach its pristine values assuming damping oscillations around density values and stabilizing at density values which are about 5 fold lower than those recorded in the pre-mortality 1998 population (Fig. 4).

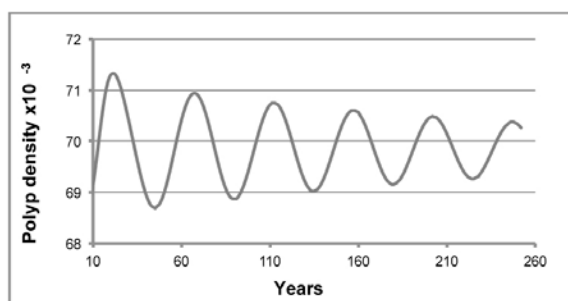


Figure 4: Simulation of *P. clavata* population trends; dumping oscillations stabilises around a polyp density which is about 1/5 than recorded in the pre-mortality population.

Discussion

The two Mediterranean gorgonian corals *Corallium rubrum* and *Paramuricea clavata*, exhibiting contrasting demographic features, have been impacted

by anomalous mortality events that deeply affected their demography.

The precious overharvested Mediterranean red coral is an historical example of a species subject to selective harvesting since some thousand years (Tsounis et al. 2010). Harvesting have changed the structure of several populations, living in the shallower portion of the species bathymetric distribution range, shifting colonies towards smaller size and higher densities and reducing population life-span (Tsounis et al 2007; Bramanti et al. 2009). In 1999 some shallow red coral populations suffered a dramatic mortality increase linked to an anomalous temperature increase (Garrabou et al. 2001; Bramanti et al. 2005). We simulated by a Leslie-Lewis transition matrix the trends of a population (which demographic features were known) under increasing harvesting pressure, associated to anomalous mortality events which frequency progressively increased. The population examined showed a high resilience to increased mortality, due to high population density, small size and early age at first maturity and high recruitment rates, however an increased frequency of anomalous mortality events, if associated with harvesting of medium sized colonies (size class 5) leads the population to extinction. This finding suggests that red coral shallow populations could go extinct if harvesting continues and the frequency of mortality events increases.

The red gorgonian *P. clavata* is not harvested and is considered to be provided of low turnover and low recruitment (Linares et al. 2007). The population we studied was impacted two times by anomalous mortality events, inducing drastic changes in its size/age structure, reducing the abundance of larger colonies and the overall density. However an about 6 fold increase in recruitment occurring 4-6 years after mortality events allowed to the stricken population to recover. The impacted population exhibited, after the first two years since the mortality events unexpectedly fast dynamics: gorgonians have been generally considered as species exhibiting slow population dynamics (Gotelli 1988; Lasker 1991) but this population showed a relatively fast recovery. After 7 years however, population density reached only 1/2 the original values and stabilized around these lower values. This trend is even more evident if the average densities of polyps recorded in the last years are examined: these values reached 1/5 that of the pristine population and stabilized. Simulations also suggest that the population will remain stable at these density values in future years.

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