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The importance of demographic approach to conservation and management of Mediterranean red coral (*Corallium rubrum)*

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Demographic models are fundamental to foster conservation and management of endangered or overexploited species matching harvesting to population growth rates. Such models are widely applied by conservation biologists. Mediterranean red coral (*Corallium rubrum*) is object of harvesting since ancient times and in the last years the need for conservation and management plans for this species emerged. Two different kind of populations can be distinguished: 1) shallow-water populations (up to 50 meters depth), characterized by colonies with small size, few braches, high density and limited economic value. 2) Deep populations (below 50 m depth) characterized by large, sparse colonies with high economic value. Demographic data of the life table obtained for the coastal population under study were included in a non-linear, discrete, age-structured dynamic model, based on a Leslie-Lewis transition matrix. The model, taking into account the reproduction of the entire population, is more suitable for populations structured in several reproductive age classes (like red coral) with respect to classical fishery models. We applied such model to simulate the population trends under different scenarios. As deep dwelling populations actually show the dominance of sparse, large/old colonies, while shallow are mainly characterized by crowded, small/young colonies and high recruitment rate, we simulated the shift from the former to the latter structure. Our results suggest that a dramatic mortality increase of larger–older colonies (due to overfishing) could have determined the population structure we found. On the basis of our simulations it is possible to give some suggestion; as recently proposed in the course of different workshops on red coral management, the banning of harvesting on coastal populations could be an effective measure. Concerning deep populations a rational management would be possible only if planned on the basis of a sound demographic approach and sound demographic data.

Introduction

The precious red coral (*Corallium rubrum* L 1758) is a clear example of an overharvested species which populations have been severely depleted (Tsounis et al, 2010). The so called "*Mediterranean red gold*" is one of the most precious marine species. Exploited since ancient times, red coral has been always present in Mediterranean culture and art and its trade created an important source of work for coral fishermen and manufacturer. Especially in Italy, in Torre del Greco, manufacturing of red coral, and precious corals in general, took a master role and became a reference for the manufacturing of all species of precious corals (Cicogna and Catteneo-Vietti 1999; Santangelo *et al*. 2004; Tsounis et al., 2007). Due to its wide geographic and bathimetric distribution we are not facing the risk of an ecological extinction for this species but an economical or local extinction is possible (i.e. a population of a low growing species, with positive density-dependence, can survive to overfishing but can not reach again a size/age structure and/or a density suitable for commercial harvesting).

Mediterranean red coral dwells on rocky shores with a bathymetric range comprised between 10 and 500 meters (Weinberg 1978; Rossi et al., 2008; Costantini et al, 2010.). It is structured in genetic differentiated populations (Abbiati et al, 1993; Costantini et al., 2007). From a demographic point of view 2 different kind of populations can roughly be distinguished: 1) Coastal shallower populations (up to 50 meters depth, Fig 2), characterized by colonies with small size, few braches, a small average basal diameter (4.6±1.12 mm), a high density (33 colonies/dm^{-2}) and with a limited economic value due not only to size but also to boring sponges, which affect more than 50 % of colonies (Corriero et al., 1997). 2) Deep populations (below 50 m depth) characterized by large, sparse colonies with a high economic value.

Until 1994 red coral has been harvested using highly destructive trawling devices known as "*St. Andrew Cross*" and "*Ingegno*" whose utilization has been banned in Mediterranean sea since 1994 due to Italian researchers involved at that time in a common Italian preliminary research project on red coral (for details see Cicogna and Cattaneo 1999). As a consequence of this intervention, during the last 20 years red coral in Mediterranean sea has been harvested only by scuba divers, putting beyond reach of fishing the populations dwelling below150 meters depth.

Demographic models

Demographic models, based on life-history tables and Leslie-Lewis transition matrixes are commonly applied to foster the conservation of several marine species: e.g. the loggerhead sea turtle *Caretta caretta* (Heppel et al., 1996) and the Right whale *Eubalena glacialis* (Fujiwara & Caswell, 2001). Such models could help to assess population status, to examine the causes of poor performances, and to make projections of population trends and viability overtime (Ebert 1999; Beissinger & McCullough 2002). Taking into account demographic parameters Population size/age structure, mortality, reproductive output), matrix population models are a powerful tool for conservation, with respect to classical fishery models based on "yield per recruit" (Beverton and Holt 1957). Because different kinds of models exist, which model is chosen, as a mathematical analogue of the population, needs to be based on the natural history of the organism. The populations of red coral (as well as those of other octocorals) are composed by several reproductive generations and thus require models structured in age classes to take into account the reproduction of the entire population (Pastor, 2008). On the basis of the age-size structure determined for the coastal population under study, a static life-history table, in which survival and reproduction coefficients of the different size-age classes were reported, was set out (Santangelo et al. 2007). The demographic data in the life-table were included into a non-linear, discrete, age-structured population dynamic model, based on a Leslie-Lewis transition matrix (Caswell 2001), in which non linearity occurs only for the first age class (recruitment). As our field data indicated that some density-dependence of the recruit-per larvae-ratio actually occurs in some shallow populations (Caley et al. 1996; Garrabou and Harmenlin 2002; Kaplan et al. 2006), such density-dependence was incorporated into the model by a function, which fitted on observational data, increases at low densities and then decreases to zero (Santangelo et al. 2007).

Simulations

Studies on different populations indicates that shallow water populations are vulnerable to mortality events due to global warming: some red coral shallow populations suffered mass mortality events associated with a sharp increase of water temperature occurred in 1999 and 2003 in the Western Mediterranean sea (Cerrano *et al.* 2000; Garrabou *et al.* 2001; Bramanti *et al.* 2005 Garrabou et al 2009). The application of demographic data to our model, allowed us to simulate the effect of mortality events and of fishing pressure on two red coral coastal populations. It was also possible to simulate the coupled effect of the two mortality sources (mass mortality and fishing). The results showed that the combination of the two effects could bring some populations to a rapid decline or even to local extinction (Santangelo et al., 2007). In order test the effect of a protection of the bigger/older colonies we simulated an increased survival of older classes. Results showed that in 25 years the population reach the recruitment saturation (Santangelo et al., 2007).

As long-lived species dynamics are deeply affected by life-span width, a shortened life-span could greatly limit population growth rate (Fujiwara and Caswell 2001). As the shallow-water red coral populations show a dramatically reduced maximal colony size (Santangelo and Abbiati 2001; Tsounis et al. 2007) and a shortened life-span (to about 13 years, i.e. less than 15% of the potential species life span; Garrabou and Harmelin 2002), we simulated the effects of life-span increase (miming fishing enforcement) on population dynamics. Moreover, as several populations of gorgonians, are mainly composed by bigger-older colonies, we simulated also the increase of survival of some classes (leading to an increase of older colonies in the population) to test its effect on recruitment. The final goal was to set out the model in a way suitable to produce the adults/young ratios really found in some gorgonian populations. Results of the simulations showed a competition between young and adult colonies that changes the ratio between the different classes leading to different structures scenarios in which alternatively small-young crowded colonies or few, sparse older colonies dominate the population. As both structures can be found in the field (the former kind in shallow water, overharvested populations and the latter in deep-dwelling, populations, less suitable to exploitation), we suppose that overharvesting, increasing the mortality of bigger-older colonies, determined the structure we find in the shallow population (Bramanti et al., 2009). Simulations also show that an increase of survival and life-span leads the population to oscillations. Such oscillations became even deeper and increase the length of their period when life span is further increased. It is worth to underline that a mortality decrease leads to an oscillation increase, but the increased density of bigger-older colonies (which density-dependence effect is peculiar of a modular animal, depending on the number of modules) controls such oscillations preventing thus population extinction. These findings are in agreement with the general ecological theory on mortality and density-dependence stabilising effects on oscillating population dynamics (Ricklefts and Miller 2001). A reduction of density-dependent mortality of any origin (e.g. predation, inter or intraspecific competition, parasitism (Santangelo and Bramanti, 2006)) leads populations to oscillating behaviours, which can increase in width and frequency leading to chaotic behaviours and even population extinction.

Conclusions and management reccomendations

Some shallow-water populations are composed by small, crowded colonies and, according to our simulations, show a good, albeit slow, recovery capability. For such populations, a single anomalous mortality event may have limited effects on survival (Santangelo et al., 2007). Some other shallow populations are characterized by low densities and low recruitment rates, probably due to a recent overexploitation (Tsounis et al., 2006). For such populations the recovery capability after a perturbation (i.e. mortality or overexploitation) could be limited. There is no real risk of *global extinction* for this species, due to its early sexual maturity (Torrents et al., 2005), wide bathymetric and geographic distribution range, comprehensive of several MPAs (Bramanti et al, submitted). Nevertheless, an increased frequency of anomalous mortality events, superimposed to overharvesting could lead shallow populations to local extinction (Linares et al., 2005; Santangelo et al., 2007).

According to the results of the last 20 years of scientific research on red coral, it seems clear that the exploitation of shallow population must be avoided also taking into account the risks represented by the new source of mortality due to global warming associated mass mortalities. The exploitation of deep dwelling populations needs a careful management based on sound population and fishing data and reliable analysis of demographic trends (Sanatngelo et. Al, 2009; Santangelo and Abbiati, 2001).

Only a constant feedback between scientist and decision makers could ensure the effective renewability of the resource. Moreover different populations show different characteristics as recruitment rates (Bramanti et al., 2003), mortality rates, growth rates, sex ratio and in general a different dynamic (Santangelo et al., 2003). Basing on this assumption, the management of red coral has to be thought taking into account the differences between populations. Otherwise we could face the economic extinction of one of the most precious marine species and loose an old artistic handcraft tradition. Sustainable fishing plans based on population growth rates on one side and an effective enforcement on the other side (Grigg, 2001), are the only way to obtain the conservation of exploitable populations of the Mediterranean red coral. For depleted populations, recovery project based on transplantation techniques could be proposed (Bramanti et al., 2007).

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