New insight into *Corallium rubrum* fishery management: An application oriented synthesis of recent data

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Abstract

Recent studies on the population status of *Corallium rubrum* brought international concern over the sustainability of coral fisheries. The available data state with confidence that shallow water stocks in air diving range have been overexploited, so that expert consultations recommend a Mediterranean-wide protection of shallow water populations, and a management based on stock assessment and scientific monitoring.
The necessary revisions of current management measures include most importantly a larger minimum size limit, as the existing one is in most cases based on outdated practical considerations, rather than being based on recent scientific studies. However, geographic variability in environmental parameters influences coral growth rates and morphology to an extent that adequate size limits are likely to vary between 10 - 20 mm in base diameter. For this reason, number of branches and minimum height should be used as additional age limits. A sufficiently large part of the deep populations needs to be conserved through permanently protected areas (MPAs), as corals play a significant role in the ecosystem. Daily catch limits, as well as number of licenses must be carefully set, in order to avoid overharvesting from which the stocks likely take decades or centuries to recover. The key to set adequate harvesting guidelines are stock surveys prior to exposing an area to harvesting, and ongoing monitoring, yet most stocks have not been studied. Furthermore, control of illegal harvest and poaching is of urgent priority, as it is responsible for a large part of the observed overexploitation. Finally, it is recommendable that a cross-national management umbrella is established to support individual countries in the revision of their management.

Introduction

A series of GFCM consultation reports on the management of *Corallium rubrum* dates back to the early 1980s, and have provided an important basis of knowledge that fishery management and further studies have built upon (FAO 1983; FAO 1988). A major step forward in the management of coral fishing has been the ban of dredging in the early 1990s. However, recent studies on the population status of *Corallium rubrum* raised the alarm and in 2007 and 2009, the inclusion of Corallidae in CITES Appendix II was proposed by the US and EU. Therefore, in 2009 the US NOAA and the Italian Government hosted two workshops that accumulated the most recent information on the topic and discussed the benefits and costs of local management versus international trade control (see Bruckner & Roberts 2009; Bussoletti et al. 2010).

In early 2010, the Conference of Parties rejected the proposal to list the family Corallidae on the basis of 64 votes in favor, 59 against, and 10 abstentions (FAO COFI 2010), in part due to concerns over implementation issues. The vote does show however that managing red coral with just local enforcement instead with additional trade control is seen by many as a considerable challenge. Given the present situation, the question thus is how to face this challenge.

A major step forward towards improving red coral management was reaching an agreement among the scientific community that shallow water populations of *C. rubrum* in the Mediterranean are overharvested. Workshop attendants, including industry representatives, agree that shallow water harvesting should be banned (Bussoletti et al. 2010). Consequently, the next step is to develop efficient enforcement solutions that address these objectives.

In order to focus on identifying adequate management measures, this article summarizes the ecological status of *C. rubrum* only briefly, but provides references to studies published in the scientific literature. Detailed information on the ecology and history of precious corals and their fishery can be found in the before mentioned workshop reports, as well as summarized in Tsounis et al. (2010) and references therein.

Ecological status of *Corallium rubrum* populations

The main characteristic that differentiates *Corallium rubrum* from most harvested marine species is its extremely slow growth rate and long life span: Red coral reaches a maximum size of about 45 cm and an estimated maximum age of about 100 years. In fact, Corallidae are the slowest-growing organisms of any fishery known, past or present, and this has severe implications on the management of *C. rubrum*.

On the other hand, *C. rubrum* is also characterized by another life history trait, that is yet unknown in other species of its family, and that has helped its populations survive intensive exploitation: its uniquely early age of maturation among octocorals. Its reproductive capacity and general productivity can nevertheless not be described as anything but low, but the species is generally relatively persistent in its habitat. Therefore, the survival of the species does not seem imminently threatened, due also to its geographic distribution and broad depth range.

However, it is undeniable that shallow water populations are overexploited all over the Mediterranean. After some detailed case studies (Garcia-Rodriguez & Massó 1986; Tsounis et al. 2007) it became apparent during recent workshop discussions that only few locations in the Mediterranean harbor coral in habitats as shallow as 30 m, whereas many areas did so some decades ago (Tsounis et al. 2010). Thriving shallow water populations are usually located within Marine Protected Areas (MPAs). Unprotected populations are characterized by young colonies (Figure 1), while older colonies are missing (Abdelmajid 2009; Tsounis et al. 2007; Zoubi 2009). Today, 35-50 cm large corals can only be found in deeper water, while historical reports and anecdotal information confirms their presence in shallow caves and overhangs some 60 years ago (Tescione 1973; Liverino 1983; JG Harmelin pers. com). Conversely, studies on coral in deeper habitats show populations in better state (Rossi et al. 2008; Cannas et al. 2010).

An alarming fact is that recent population models show that young populations may not be able to recover from overfishing if a natural disturbance (such as epidemics or climate induced mass mortality events) further increases mortality (Santangelo et al. 2007; Bramanti et al. 2009). In cases where a population is extirpated by either harvesting or a combination of causes, the natural re-colonization process is extremely slow. Larvae cannot efficiently and directly travel to devastated habitats from remote populations, due to the short dispersal distance of red coral larvae (Costantini et al. 2007).

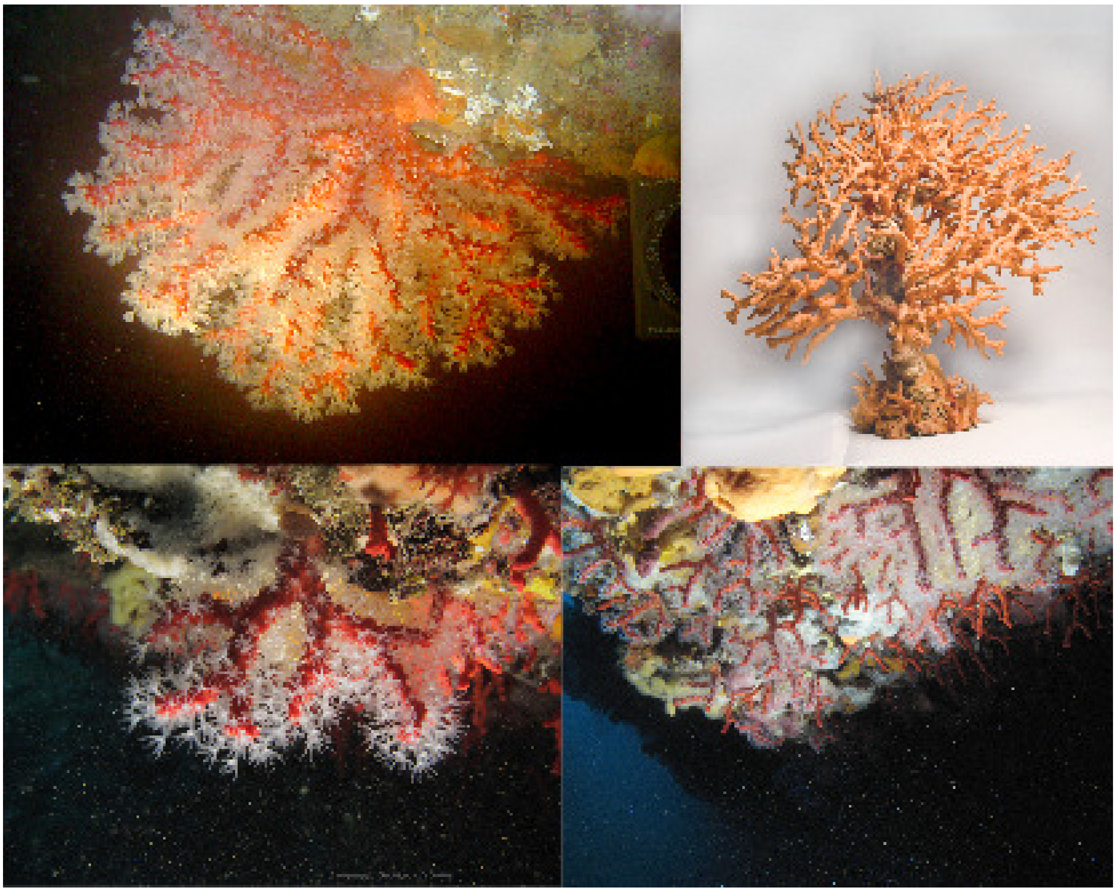

Figure 1: *Corallium rubrum* of rare size of ca. 200 mm *in situ* (top left); and 500 mm in a private collection (top right); typical young colony of ca. 50 mm (bottom left); typical coral patch in a young shallow water population (bottom right). Photos: courtesy of G. Tsounis.

History of harvesting

When evaluating the impact of past harvesting, several different phases of harvest need to be distinguished. Large-scale commercial harvest began in the early 1800s with hundreds of boats dredging for coral (Tescione 1973). We must therefore postulate that the populations changed dramatically, long before science could document the natural baseline. The number of boats fluctuated due to a variety of factors, among them political stability, market demand, taxation, and depletion of stocks followed by discovery of new ones. Dredging became more efficient during the era of industrialization when winch operated 7 meter long 800 kg metal dredges were operated from motorized boats down to 180 m depth (FAO 1988).

In the late 1970s FAO catch statistics revealed a decline in annual yield of the *C. rubrum* fisheries in the Mediterranean, which lead to FAO consultations and eventually a ban of coral dredges in 1994. It is generally accepted that the decline is due to resource depletion (Santangelo et al. 1993), while subsequent further decline in yield may be caused by stricter taxation laws and a ban of dredging following 1979 (FAO 1988).

With the commercialization of Cousteau's Aqualung after the second world war, SCUBA diving provided access to crevices and caves in shallow water that the dredges could not reach. After the EU banned dredging due to the damage it inflicts on the habitat, SCUBA remains the only form of harvesting today. The ban in 1994 represents a marked change in fishing effort, but it is evident that deep stocks exposed to dredging in the 1990s cannot have recovered to natural state in just two decades.

Yields have been stable during the last decades. However, it is well documented that divers used to work at about 35 m depth during the 1950s, and have to descend to ever greater depths, exceeding 120 m today, which indicates a gradual depletion of the stocks. Field surveys provide the most reliable indication of the state of the resource (especially given the fact that corals are sessile organisms), and indicate that in most regions corals are of extremely small size (see above).

Achieving a sustainable fishery

The goal of fisheries management goes beyond ensuring the survival of the targeted species. The objective is to manage the fishery in a way that it will sustain the applied fishing pressure indefinitely, by constantly renewing itself. This can be ensured using mathematical models such as the Beverton-Holt Maximum Sustainable Yield model that has been used to sustainably harvest black coral fisheries in Hawaii (Grigg 1976; Grigg 2001; Grigg 2010).

In contrast to Hawaii, the Mediterranean fishery began long before the populations were studied (Tsounis et al. 2010). Traditionally, the minimum size at which red coral can be harvested is 7 - 10 mm base diameter thickness in various countries. It is important to understand that the origins of the 7 mm size limit go back to practical considerations of the industry a few decades ago (FAO 1988). Since coral of smaller diameter was of little value and since *C. rubrum* reaches sexual maturity at an earlier age, 7 mm made sense as a first step to regulate fishing. In 1986 the maximum sustainable yield model was applied to *C. rubrum* (Garcia-Rodriguez & Massó 1986a; FAO 1988), but the resulting conclusions and recommendations have not yet been implemented into management plans. As mentioned above, however, recent studies demonstrate that a revision of minimum size and quotas is urgently necessary.

Quotas need to be set for each area separately depending on the stock size (see Grigg 1976; Tsounis et al. 2007). However, it is equally important that minimum size is adapted to each stock separately, as growth rates and colony morphology vary among areas, leading to a variation of minimum base diameter between 10 – 20 mm. While the lower value of 10 mm applies to coral in Sardinia that reaches a colony height of well above 200 mm at this diameter, it does not apply to coral at the Costa Brava in Spain, which reaches a comparable branching pattern and height at a much larger base diameter.

One other parameter that influences the model and thus minimum harvest size recommendation is the natural mortality coefficient. The most reliable empirical mortality value stems from a long term experiment (Garrabou & Harmelin 2002), yet it might not be representative for all habitats. However, even if assuming that natural mortality might be twice the known empirical value (which is unlikely for this long-lived species), the results indicate that the traditional size limit of 7 mm is too low.

Three modelizations are presented for minimum size limits, using a combination of minimum and maximum values of natural mortality and growth rates applied to coral with a morphology that is typical at the Costa Brava (for methods, see Tsounis et al. 2007). The results show that minimum harvest size should be between 22 - 49 mm in base diameter (Table 1). One problem that limits the precision of these data is that growth is assumed to be constant over the life span of the organism, which is unlikely to be the case. At this time, a minimum size of ca. 20 mm base diameter could be used as a first improvement within the context of an adaptive management. There is a risk however, that deep stocks might differ noticeably from the shallow populations these data are derived from. In any case, the minimum diameter recommendation should be combined or replaced with a minimum height and number of branches, as these are an important descriptor from an ecological point of view (see below). Keeping in mind that predicting growth in height is subject to morphological variability, a minimum size of at least 200 mm in height may serve as a rough initial estimate. In comparison, *Corallium secundum* in Hawaii is harvested when reaching 254 mm in height (Grigg 2010). Ultimately, number of branches is a promising proposition for a more universal size limit.

Hardly any corals of the here recommended minimum size are left in air diving range, so this revision coincides with the conclusion of the 2009 Red Coral Workshop in Naples, that "shallow water populations need to be fully protected from harvesting. The vertical distribution of these populations depends on local environmental characteristics. However, as a guideline for enforcement and management, these populations might be defined by the limits to which air breathing divers can descend (typically 70 m)" (Bussoletti et al. 2010).

Large Marine Protected Areas (MPAs) need to ensure a permanent reservoir of healthy populations. In shallow water, a tiny percentage of coral habitat is protected. Thus the vast majority of shallow water populations are in fact commercial stocks. If deep populations are exposed to harvesting, it is of paramount importance to conserve a sufficiently large proportion as MPAs. This holds true despite of the recent discovery of *C. rubrum* in depths of 800 m (Costantini et al. 2009), as historically red coral was found in 5 - 300 m depth, but is regarded as more common in 50 - 150 m.

Further research is a prerequisite to ensure sustainable harvesting, as mortality values, growth rates, and stock size are unknown parameters that are necessary to set sustainable quotas. Considerable research will be necessary to allow harvesting of even deeper populations by remote operated vehicles ("robot" harvesting). Unlike diving, this technology will provide an individual harvester with 24h potential access time to the stocks, so ways to reliably enforce ROV use would be paramount. At this moment, it is questionable that adequate enforcement could be guaranteed, and deep populations have practically never been studied.

Finally, red coral fishery management should embrace principles of modern habitat based ecosystem management, that strives to ensure exploitation levels that conserve biodiversity and overall productivity (Jones et al. 1994). Corals create habitat structure that other species use e.g. for nurseries, so the system can tolerate only a limited removal of biomass. Consequently, no stock should be depleted completely, as provisioned by rotation harvesting schemes that date back to the middle-ages. Recent studies on connectivity of red coral populations reveal that rotation harvesting leads to slower recovery of stocks (Costantini et al. 2007), and should therefore no longer be employed.

Table 1: Minimum size for various mortality coefficients and growth rates, based on a Beverton-Holt Maximum Sustainable Yield model[1]: Low mortality and high growth; low mortality and low growth; high mortality and high growth.

Mortality coefficient	0.0242[2]	0.0242	0.0484[3]
Max/Min Growth rate for base diameter (mm yr^{-1})	0.50[4]	0.24[2]	0.50
Age at maximal production (yr)	98	98	44
Base diameter at maximal production (mm)	**49**	**24**	**22**
Height at maximal production (mm)	200[5]	174[2]	200

[1]A detailed description of the model and methods used can be found in Tsounis et al. (2007).
[2]Most reliable value, from a long time experiment (Garrabou & Harmelin 2002)
[3]Hypothetical value, which is the twice the empirical one
[4]Maximum value 0.35mm + 0.15 (SD), from Marschal et al. 2004
[5]Rodriguez-Garcia & Massó 1986*b*

Enforcement and poaching

Poaching and exceeded quotas by licensed fishermen are perhaps the most severe problem that red coral management and conservation must face. In light of the absence of trade control trough e.g. CITES Appendix II, the implementation of management plans relies solely on local enforcement (One exception is the right of an individual country to list species in Appendix III prohibiting export, as in case of Germany and China).

Currently, there are sufficient indications to conclude that illegal harvest in one form or another occurs on an alarming scale in every Mediterranean country. Examples include anonymous internet site offering *Corallium rubrum* e.g. in Greece, repeated arrests of the same individuals by the Spanish Coastguard, and confidential information from coral divers who occasionally organize unauthorized coral harvesting expeditions across the Mediterranean and beyond. Some poachers work for licensed fishermen who then resell the coral at a profit, others sell overseas via Switzerland (anonymous sources). One very alarming notification is that dredges are still used, ingeniously sunk and retrieved only for immediate employment, and then sunk again until needed. ROVs officially on board for scouting and thus lacking a hydraulic arm can easily fitted with a net to tangle corals. Finally, even our own working group received inquiries from anonymous overseas buyers, probably in response to a private website hosting results of the group's conservation projects.

It is clear that more efficient enforcement is necessary, but is not clear how to achieve it. The difference in Hawaii is that black coral is difficult to hide on a boat due to its height of 1 - 2 m, and there are fewer ports and more frequent patrols. At the Spanish Costa Brava for example, it is fairly easy to avoid coastguard patrols on the water, since the low frequency of controls makes it possible to place a watch along the coast who contacts the poachers via radio long before the coastguard patrol approaches. The Costa Brava dedicated a specialized unit to track down coral poachers which identified about 20 individuals that illegally harvest coral, which is in stark contrast to the 9 legally licensed divers. Most of them are known to the local community as well, some have even published interviews stating they petitioned for harvesting licenses decades ago. One of them has been accused of burning down the house of a coastguard officer who convicted him. However, convicting the poachers is extremely difficult, since when a patrol approaches, there is plenty of time to abandon the coral bag and pickle, and remain with just ordinary dive equipment in the boat (although if depths allow, the coastguard divers sometimes recover abandoned gear and catch). Even if convicted, mere fines are given, except within a protected area. The fines in Spain do not discourage the poachers, as after repeated fines and confiscation of their equipment they continue poaching. Recently, representatives of the coastguard's coral unit exclaimed to the press that they do not have the means to control poachers, since these work 24 h, including at night.

Naturally, the international frustration has lead to propose the inclusion of Corallidae into CITES Appendix II in the hope of an effective solution via limiting sales of illegally harvested coral. The proposal was finally rejected by the CoP due to concerns over effective implementation and negative impact on the industry. In fact, the coral jewelry industry was extremely concerned over the necessity of paperwork for the multitude of single small items being shipped, and about the negative stigma associated with a listing. Solutions including trade control might be have an acceptable impact on the industry though, if the administrative burdens are minimized.

In order to limit poaching through local management, national laws need to be revised. While outside the scope of this analysis, one proposition could be to make poaching a police matter, so that apart from coastguard patrols, police investigations can contribute conclusive evidence in cases of doubt. It would allow to investigate notorious poachers. Penalties must be severe enough to discourage poaching. If enforcement continues to depend solely on on-the-water patrols associated with mild fines, it is questionable that poaching can be reduced without trade control. On the other hand, trade control on its own is unlikely to curb poaching of *C. rubrum* without more effective local management.

Finally, licensed fishermen need to be better monitored as well, so they do not exceed their quotas. The FAO collects data on the annual yield of each country, but what is missing, is crucial information on the size of the harvested coral. It is important for management decisions to exactly know what size of corals are being harvested.

Summary of recommendations:

Improved local enforcement against poaching through revising not only on-the-water vigilance, but also the legal system.

Legally binding transnational management umbrella, e.g. through the GFCM.

Revision of minimum size limits for each fishery in different geographic regions. Until then, a new size limits of 10 - 20 mm base diameter and 200 mm in height may serve as an initial estimate. Number of branches should be used as an additional descriptor.

Ban of shallow water coral harvesting in air diving range down to approximately 70 m depth.

Set appropriate quotas and number of licenses for deep stocks, before these are harvested. Where necessary, licenses can be withdrawn by not transferring licenses of retiring divers.

Stock assessment prior to harvesting, and ongoing scientific monitoring.

Improved landings recording of the fisheries. Most importantly, the size of harvested corals needs to be documented and published (e.g. via the FAO).

Large Marine Protected Areas. Only a fraction of the deep habitat should be harvested, in order to ensure high biodiversity and overall productivity of the entire ecosystem.

Creating a network of micro reserves within commercial stocks. The objective is to ensure gene flow between deep and shallow populations and between populations along the coast.

Rotation harvesting should be abandoned in favor of sustainable harvesting of each stock.

Identification of potential unfished virgin populations, and, if such populations exist, a fraction of them should be protected for future research, for example, as UNESCO World Heritage Sites. Further models for red coral habitat protection (especially in international waters) may be the example of UN VMEs, which are designed by NAFO.

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