Vol. 418: 299–303, 2010
doi: 10.3354/meps08898

MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser

Published November 18

REPLY COMMENT

Quantifying the decline in *Corallium rubrum* populations: Reply to Santangelo & Bramanti (2010)

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ABSTRACT: In the comment on Bruckner (2009; Mar Ecol Prog Ser 397:319–332), Santangelo & Bramanti (2010; Mar Ecol Prog Ser 418:295–297) suggest that the available data for *Corallium rubrum* populations cannot be used to make conclusions about population trends for the species throughout the Mediterranean. Their main concerns relate to (1) different methodologies used to sample populations; (2) insufficient population information from deep water; and (3) limited data on sampling area and density of colonies. While I recognize many of the limitations of the data, the conclusions in Bruckner (2009) were based on multiple datasets, including population demography and reproductive patterns, as well as landings data, trade statistics and biological information. The primary comparison involves differences between depths, levels of fishing pressure, and historic populations using information from representative habitats off Costa Brava, Spain; recent data were collected using similar methods and included size structure, reproductive information, and density and abundance of colonies. At the time of Bruckner (2009), most fisheries were in shallow water (<70 m depth), but they were already progressively expanding into deeper areas. Since publication of the manuscript, the fishery for *C. rubrum* has entered a new phase, SCUBA fishing using mixed gases and new technology (e.g. ROVs) to reach greater depths (70 to 150 m) and increase landings, mostly because shallow populations have been overharvested. This new trend is problematic, because the science does not exist to determine sustainable harvest levels at these depths.

KEY WORDS: Precious deep-sea coral · CITES Appendix II listing · Modular organism

INTRODUCTION

The intent of Bruckner (2009) was to evaluate the effect of harvest and international trade on all species of *Corallium* worldwide to determine (1) if the species meet the biological criteria adopted by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2007) for listing on Appendix II and (2) if a listing could help improve conservation of these precious corals. According to the provisions of CITES, a species listed on Appendix II is not necessarily threatened with extinction, but it may become so unless trade in specimens of such species is subject to strict regulation in order to avoid utilization incompatible with their survival. A species should be included in Appendix II if at least one of the following criteria is met: (1) it is known, or can be inferred or projected, that the regulation of trade in the species is necessary to prevent it from becoming eligible for inclusion in Appendix I in the near future[1]; or (2) regulation of trade in the species is required to ensure that the harvest of specimens from the wild is not reducing the wild population to a level at which its survival might be threatened by continued harvesting or other influ-

[1]Appendix I includes species threatened with extinction which are or may be affected by trade. Unlike species listed in Appendix II, which can be traded commercially under permit, all commercial trade of wild harvested specimens of species listed in Appendix I is prohibited.

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ences. Bruckner (2009) concludes that *C. rubrum* (and other species) met the requirements for listing: it is in trade, the species has declined to required levels, and trade is having a negative impact on wild populations. The evaluation was based on an examination of the area of distribution, population size, and declines in area of occupancy, abundance, or habitat, with consideration of quantitative metrics for historical extent and recent rates of decline, and a host of vulnerability factors (population age/size, life history traits, fisheries, trade and other impacts).

An assessment (FAO 2007) of a CITES Appendix II listing proposal for *Corallium* (CITES 2007) concluded that *C. rubrum* populations had not undergone a substantial decline, and thus did not qualify for listing. This conclusion was based on the high densities and abundance of *C. rubrum* populations in shallow water reported by Santangelo et al. (2007) and other authors. The FAO assessment failed to consider the modular life history of *C. rubrum*, or the reduction in the size and/or age of colonies in different populations as a result of overexploitation. Both factors have undeniable impact on reproductive success, and therefore, ability of populations to persist at sustainable levels. To highlight the importance of size (and number of polyps or 'modules') for sessile colonial animals, Bruckner (2009) conducted a simple size-based analysis to show how, by developing complex branching patterns, the number of polyps on a colony increases exponentially as the colony becomes larger and older. Using photographs and coral skeletons, the number of polyps and number of branches per colony for colonies of different sizes were determined and compared to published values on reproduction and size structure to estimate the potential reproductive output in different populations. The study considered 4 scenarios off Costa Brava, Spain: shallow-water habitats targeted by coral fisheries, shallow areas closed to fishing, deep-water populations that had not been fished, and historic population structure from shallow water (Garcia-Rodriguez & Massò 1986, Tsounis 2005, Tsounis et al. 2006, 2007, Rossi et al. 2008); these were compared to a thoroughly studied shallow-water population in Calafuria, Italy, that exhibited high turnover and was dominated by small, young colonies that had little commercial value (Santangelo et al. 2007).

SAMPLING METHODS

Corallium rubrum populations have been assessed through direct *in situ* counts, photographs and video, and by scraping all colonies from a given area; historic population data also consist of trawl landings and colonies selectively harvest by SCUBA fishers. In most locations (except Calafuria), coral recruits and the smallest juveniles are missing from size structure data. While small corals can make up over half the population in shallow water (Santangelo et al. 2007), they were not considered because they are not yet reproductively mature. By only considering those colonies that are reproductively mature, and comparing the percent of all reproductive colonies in each size class, these discrepancies in the datasets can be discounted.

DEEP-WATER POPULATION STRUCTURE

Quantitative data on population dynamics for *Corallium rubrum* are available from relatively few locations. Prior to 2009, most research had been done in shallow water (<50 m) off Spain, France and Italy, with a single deep-water study from Spain (Rossi et al. 2008). Bruckner (2009) focused on data from Spain (Tsounis 2005, Rossi et al. 2008), because all the variables considered in the study were available for this location. For comparative purposes, a well-documented population from shallow water (Calafuria, Italy) was used to illustrate reproductive output in noncommercial populations with high rates of turnover. While age at maturity, growth rates, fecundity and other biological attributes may differ between populations as a result of environmental gradients, colony density, and many other factors, the use of data from Spain allows comparison of the impacts of fisheries, the potential population structure in absence of fishing (deep water), and patterns of recovery when fisheries are closed. Even though few other quantitative data are available from deep water, video and still images and anecdotal reports suggest that other deep-water populations are similar, until exploited (colonies are larger and at a lower density, but they cover more extensive areas of substrate).

POPULATION DENSITY INFORMATION

Population density plays a critical role in many aspects of the life history of all corals, including *Corallium rubrum*, especially reproductive potential and recruitment. Nevertheless, it is extremely difficult to quantify the density of *C. rubrum* populations due to the patchy distribution of the coral. Existing density estimates vary 10-fold or more, which can be partially attributed to location, depth and habitat, and more importantly to sampling design. In shallow-water locations, *C. rubrum* tends to occur as crowded colonies in small patches, with fewer colonies at the outer perimeter of the patch; thus, measurements of the density can vary substantially within a patch depending on how it is assessed. For instance, a small quadrat placed within the center of a patch will contain many more colonies per unit area than a larger quadrat that includes the outer perimeter of the patch. While knowledge of density is necessary to fully characterize reproduction and recruitment potential of an entire population, the intent of Bruckner (2009) was to compare the potential reproductive output based on the percent of colonies in each size class occurring under different conditions, considering only reproductively mature colonies, rather than the absolute number of colonies. In this manner, confounding variables that affect reproduction (e.g. environmental differences, competition, predation, overgrowth) are separated from fishery impacts.

Current estimates of *Corallium rubrum* population density are available for areas off Costa Brava, Spain; these vary minimally between sites and/or depths when examined over entire depth gradients (Tsounis 2005, Rossi et al. 2008). For instance, sites (10 to 50 m depth) examined by Tsounis (2005) all had a similar density of colonies within each patch, and similar number and size of patches, while deeper sites (50 to 90 m) had a lower density of colonies in each patch, but patches were larger and more abundant (Rossi et al. 2008). By excluding density in these estimates, the potential decline due to fisheries may be underestimated, because reproductive output and recruitment decline as density increases (Santangelo et al. 2007, Bramanti et al. 2009). Hence, low-density populations consisting of larger colonies will produce many more planula per polyp than small, crowded colonies, and these have a higher likelihood of recruitment.

CHANGES IN SIZE STRUCTURE/ REPRODUCTIVE OUTPUT

In Bruckner (2009), I conclude that the changes in size structure (20–50 cm to <5 cm) observed in shallow-water populations reflect a potential net loss of 80 to 90% of the reproductive modules due to the reduction in size and loss of 1st-, 2nd-, 3rd- and 4th-order branches. This trend has been highlighted in several other studies (Garrabou & Harmelin 2002, Tsounis 2005, Tsounis et al. 2006, 2007, Rossi et al. 2008) and reflects only those shallow areas targeted historically and/or currently by fisheries, and not deep-water populations or shallow-water populations like Calafuria, which were never commercially viable. These conclusions are further supported by differences observed between shallow fished areas and adjacent marine protected areas (MPAs): colonies were substantially larger in an MPA, but still smaller than the historic size structure because the closure had not been long enough to allow full recovery (Tsounis 2005). In the section 'Other controversial statements', it is remarkable that Santangelo & Bramanti (2010) question the general Mediterranean-wide changes in *Corallium rubrum* populations, and suggest there is insufficient information to determine the causes for these changes. In red coral and all other precious corals fisheries, coral size (age) structure has been found to shift towards smaller/younger colonies with a notable absence of large colonies (Garcia-Rodriguez & Massò 1986, Grigg 2002, Santangelo et al. 2003). Other factors (e.g. predation, overgrowth, climate change) may impact all colonies regardless of size, but they are likely to have the greatest effects on the smallest colonies, with larger corals experiencing only partial mortality.

The statements brought into question by Santangelo & Bramanti (2010), 'Today, >90% of colonies in fished areas are 3 to 5 cm tall [and] <50% are sexually mature' (Bruckner 2009, p. 319), reflect the size structure and proportion of sexually mature colonies in shallow-water areas that were fished historically using SCUBA, and continue to be targeted today. There is an overwhelmingly large number of reports highlighting the widespread overexploitation of corals in shallow waters from fisheries (e.g. Garrabou & Harmelin 2002, Tsounis et al. 2006, 2007, 2010, Rossi et al. 2008). These studies conclude that areas subjected to SCUBA fisheries are far different today from what they were in the 1950s–1970s; the coralligenous zone in the Mediterranean is reported to have shifted from a forest-like structure to a grass plain due to the elimination of most large colonies of *Corallium rubrum* (Rossi et al. 2008). Furthermore, 89% of the colonies in fished areas in Spain were below legal size for harvest and the mean height decreased from 61.8 mm to 27 mm between 1986 and 2003. The statement by Santangelo & Bramanti (2010, p. 296): 'Only one of these populations (Cap de Creus) — which consists of small colonies located in a marine protected area — is still overharvested', makes no sense. This site was overfished in the past, but it has been closed and protected as an MPA for over a decade; the site now contains colonies that are larger in size than those in surrounding fished areas, though still smaller than sizes reported historically in this area (Tsounis 2005). Status reports presented at a recent workshop in Italy (Bussoletti et al. 2009) further support these conclusions, and the experts concluded that *C. rubrum* in all areas of the Mediterranean to 50 m depth were overexploited.

The statement that ' Bruckner (2009) fails to take into account the current diversification of today's red coral populations, which can be schematically divided into shallow-water populations, and deep-water ones currently undergoing commercial exploitation' (Santangelo & Bramanti 2010, p. 297) is somewhat misleading and confusing. The main point of Bruckner (2009) is that sites containing *Corallium rubrum* can be split into either (1) shallow-water areas historically or currently under pressure from fisheries that once contained large colonies but today are dominated by small (<5 cm tall) colonies, or (2) deep-water areas dominated by large colonies. It is well-documented that shallow-water populations of *C. rubrum* are dominated by small, crowded colonies and the small size in most areas is due to overexploitation, while deep-water populations are more sparse, with colonies being larger in size. The differences in size structure are primarily due to SCUBA fisheries, which have been active in shallow water since the 1950s and have progressively moved deeper as shallow areas are extirpated of commercial-sized colonies. However, an important point missed by Santangelo & Bramanti (2010) is that most fisheries, with exception of the Sardinia (Italy), still operate at depths of <70 m using conventional SCUBA, especially in Spain, France, Morocco, and Tunisia.

MANAGEMENT OPTIONS

A primary management recommendation proposed in Bruckner (2009) was an increase in the minimal allowable size for harvest. Part of the justification for this is based on new age/growth studies that show much slower growth rates than previously thought. While this indicates colonies harvested under the current minimum size are older than previously thought (and, thus, may have reproduced for a few additional years until reaching the minimum size of harvest), the main intent of this measure is to ensure all of the colonies reach 100% sexual maturity and reproduce multiple times before being removed. Allowing colonies to grow larger increases the potential for a greater number of reproductive events and, thus, their reproductive output per event would increase each year in proportion to the amount of growth (and number of branches) they produce over that longer time interval.

CONCLUSIONS

There is a critical need for more scientific research to characterize population dynamics, reproduction and other facets of the biology and ecology of *Corallium rubrum*, especially in deep-water areas. Given the large-scale changes to shallow-water populations as a direct result of overharvesting, fisheries should not be allowed to continue to expand into deeper water, until the science is available to establish rational management plans. Sardinia has taken innovative steps to conserve the resource, by increasing the minimum depth of harvest and the minimum size of colonies. However, recent data from Sardinia presented in the Italy workshop (Bussoletti et al. 2009) highlights the high percentage of undersized (7 to 9 mm diameter) colonies harvested from deep water, suggesting that populations in deep water may not be as robust as proposed. Landings from other countries also continue to be dominated by progressively smaller colonies, including a growing proportion of illegal, undersized corals (Tsounis et al. 2010). At a recent FAO meeting, many countries expressed concern over a proposed new minimum depth of harvest (70 m) because they lacked the technology necessary to work at these depths, and instead agreed to a minimum depth of 50 m; they also suggested an increase in minimum basal diameter from 8 to 10 mm, with a 20% allowance (GFCM 2010). Ultimately, these changes are likely to have minimal conservation benefits, as (1) colony height and branching pattern is much better measure than diameter; and (2) enforcement will be difficult and shallow-water exploitation will continue unless conventional SCUBA harvest is banned.

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Editorial responsibility: Karen Miller, Hobart, Tasmania, Australia

Submitted: October 6, 2010; Accepted: October 18, 2010
Proofs received from author(s): November 11, 2010