Proceedings of the International Workshop on Red Coral Science, Management, and Trade: Lessons from the Mediterranean

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Edited by
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Proceedings of the International Workshop on Red Coral Science, Management, and Trade: Lessons from the Mediterranean

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Last but not least, a particular thanks is due to all the scientific contributors and managers who assured the Workshop full success in the respect of competing different positions.

The Workshop Coordinators
David Cottingham
Ezio Bussoletti

Preface

STATEMENT OF ALDO COSENTINO
General Director, Protezione della Natura
MATTM

Following the commitment taken in occasion of the last COP, the Italian Government has organized this International Workshop on the Mediterranean Red Coral (*Corallium rubrum)* jointly with U.S. Government. Aim of this event, which followed that held in Hong Kong in March 16th-20th 2009, was to define a management strategy for the Mediterranean Red Coral analyzing the various problems of conservation and the most suitable methods of sustainable harvest.

Despite different positions on the subject, we believe that everybody shares the wish to implement a process able to improve the relationships between "science" and "political decisions" in order to use them for a better support, in a qualified and not a prioristic approach.

This is one of the major rendez-vous that the international community concerned in biodiversity protection will face in 2010; in this sense UNEP is operating helping States to better define the mechanisms allowing the scientific results to be promptly available and fully understood by "political stakeholders" so that they could be able to identify strategies and initiatives responding to the actual needs for a correct survival and development of our planet.

When we talk of "conservation" and "sustainable use" of biodiversity, it is important to be aware that we operate in a peculiar situation in which science, integrated with international legislation, can make the difference between an efficient and a not efficient choice. On purpose I state "efficient" and not right or wrong.

In fact, when we talk about the genus *Corallium*, as well as other marine organisms, once the biologists have correctly identified the species distribution, they have to be able to understand all the parameters necessary to guarantee their sustainable utilization. The question arising at this stage is then: which is the best international instrument capable to regulate and control that any use is performed following the due rules?

In the case of *Corallium rubrum,* as well as other marine species, international trade represents an important element of its management; however, we should evaluate how reasonable and justified is to consider the control of trade as the best choice rather than the control of more critical parameters.

We believe that we need to understand the difference between the various available instruments in order to use those which appear the most suitable, case by case, to get the maximum efficiency.

Instruments of "knowledge" are the IUCN "red lists" which, however, pertain to a global level. If a species is globally threatened, this does not mean necessarily that it is so in every area where it is present. Then, red lists are an important instrument which however needs to be re-applied and tested in the field to get the best and more realistic results.

The Washington Convention is another fundamental instrument of safeguard; we all know, however, that it became really operational and useful only when countries felt committed to it, deciding its application in the due form.

This Workshop represents in my view an important step ahead in the knowledge of the Mediterranean Red Coral as it has been possible to compare the experience of different and very qualified scientists representing the leading front on the subject. We have also compared this knowledge with that of experts operating in areas other than the Mediterranean Sea. This has allowed filling knowledge gaps of scientists who did not worked in this region and, then, did not share the day by day history of care and harvest of the Mediterranean precious coral in the last 150 years as it occurred in Italy.

We had hoped, taking advantage of the Workshop, to arrive to a shared, agreed position on a strategy concerning the care, safeguard and harvesting of this species on the ground of the positive Italian experience on the subject as a result of an activity existing for one and a half century and which sustains the economy of a sector of our country where about 15,000 persons are involved.

Concerning the scientific results and the further needs of knowledge, the Workshop was a clear success as all the attendants arrived to a shared position agreed unanimously and is reported in the Appendix of the present publication. Important statements are done on future actions devoted to deepen the research filling the present gaps. Indications on sustainable management measures and enforcement in the Mediterranean are also given.

Unfortunately, attendants were not able to arrive to a similar shared position on trade related issues. While some participants stressed the importance of an inclusion in CITES Appendix-II for Mediterranean Red Coral according to the U.S. official position, others, according to the Italian official position, disagreed, mainly because of serious economic and bureaucratic implications of a listing, as the source appears not in danger and is managed in a sustainable way. This document reports also the report of the trade group.

Despite a full consensus was not reached, we consider that the Workshop has been a success as put together experts and experiences coming from different parts of the world allowing people to discuss, compete, agree or friendly disagree and always in a very open minded atmosphere.

In conclusion, this event, as well as the Hong Kong workshop, represents an important step ahead, providing a useful contribution to the general problem: the journey has started and we all hope to reach some useful results enabling us to provide significant solutions to policy-makers in the near future.

Aldo Cosentino

STATEMENT OF JAMES BALSIGER

Acting Director, National Marine Fisheries Service
National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration's Coral Reef Conservation Program was pleased to co-sponsor the International Workshop on Mediterranean Red Coral (*Corallium rubrum*) in Naples in September 2009. The workshop brought together leading scientists and managers from the Mediterranean and around the world to discuss the status of *Corallium rubrum* and its management. The presentations highlighted the most current information available on the status of Mediterranean populations of *Corallium rubrum* as well as the importance the trade plays in local economies and traditions. This workshop and a similar workshop on red and pink coral trade held in Hong Kong in March 2009 enabled scientists, resource managers, and diplomats to learn about these precious corals. Improving our understanding of coral biology and how to manage it is a key to its long-term sustainable use.

The spirited discussions during the workshop lead to common understandings and broad acceptance of the current state of Mediterranean red coral resources and the knowledge gaps that the scientific community needs to address. When the research and management plans called for by working group participants are completed, they should lead to greatly improve management throughout the range of the species. Representatives of governments from many Mediterranean countries spoke of their commitment to preparing the plans, conducting the research, and managing the stocks better.

Some of the most contentious discussions at the meeting focused on the appropriateness of additional measures to monitor and regulate red coral trade. Some participants expressed their view that each country should adopt its own management regulations without involvement of international organizations. Because of a lack of meaningful coral management in many countries, the United States representatives and others felt that international oversight of national programs could provide an impetus for better national management. From that perspective, a listing on Appendix II of the Convention on International Trade in Fauna and Flora (CITES) would build on national management by ensuring that all exporting countries implemented sustainable management strategies. While it is regrettable that participants at the workshop did not agree on the role of red coral trade and management, the information presented at the Workshop laid the basis for future productive discussions on the science and management of *Corallium rubrum*.

The United States would welcome opportunities to participate in those discussions on research and management in hopes that all nations develop, adopt, and implement effective measures to better understand and manage these precious resources.

Thank you,

James W. Balsiger

Table of Contents

Executive Summary

The Italian Ministry of Agriculture and Ministry of Environment and the U.S. National Oceanic and Atmospheric Administration convened the International Workshop on Red Coral Science, Management, and Trade: Lessons from the Mediterranean in Naples Italy in September 2009. Scientists, managers, representatives of the coral fishery and manufacturing industries, policy makers, and environmental organizations from Europe, Africa, Asia, and North America attended the workshop. The workshop provided an opportunity to discuss the best available science on the natural history of Mediterranean red coral (*Corallium rubrum* L.) and how it is managed throughout the region and utilized around the world.

The workshop was the result of deliberations on a 2007 proposal by the United States to list red and pink corals in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). CITES member nations did not adopt the U.S. proposal in 2007. While the international community recognized the conservation needs of these species, questions were raised about species distribution and biology, domestic management practices, product identification, and other issues related to implementation of a CITES Appendix-II listing. The United States held a workshop in Hong Kong in March 2009 to address these issues, with an emphasis on Pacific species. The Naples workshop focused on the Mediterranean red coral, *Corallium rubrum*.

Corallium rubrum is widely distributed throughout the Mediterranean Sea and into the neighboring Atlantic Ocean from Portugal to Cabo Verde. It is slow-growing and inhabits a wide depth range from 15 to 600 meters, and possibly even deeper. In shallow waters (between about 15 and 70 meters), *C. rubrum* colonies grow in caves, crevices, overhangs and other protected interstices in dense patches with as many as 127-1300 colonies per square meter, the majority of which are less than 5 cm tall, with dense patches confined to small areas with large expanses of uncolonized habitat. In deeper waters, between 70 and 130 meters, coral colonies tend to be larger and more dispersed, and typically settle on open surfaces. It is rare to find colonies that reach their historical maximum size of 30-50 cm, except in areas where fisheries have never operated. Below 130 meters, colonies tend to be even larger and less dense.

C. rubrum has been harvested for more than two thousand years. As early as the 1800s, fisherman from Italy, Spain, and France sailed to North Africa in search of new stocks as local areas were depleted. Traditional harvest techniques included free divers and non-selective coral dredges such as the famed St. Andrew's cross and the "barra italiana," both of which harvesters dragged across the sea floor to ensnare broken colonies of coral. The invention of SCUBA in the 1950s allowed fishermen to harvest red coral more selectively and efficiently. It also lead to over-exploitation of coral beds within 15-50 meter depth, especially in areas that were inaccessible to coral dredges. As SCUBA technology improved, divers began to harvest down to depths of 100-130 meters. The high value of red coral and the boom and bust exploitation patterns made for unstable yields, with various peaks and drops; the progressive overexploitation of red coral in shallow water forced divers to descend to greater depths in search of new resources. The last major peak recorded lists 100 t in 1978, but since then landings have remained below 30 t, on average.

Although effective management of red corals is lacking in many Mediterranean nations, others have taken steps to promote sustainable harvesting. Since 1994, European Union countries have banned the use of the St. Andrew's cross because it unselectively destroys coral populations and habitat. Most but not all nations in the region ban harvest of colonies smaller than 7 mm basal diameter, while some countries have no minimum size of harvest, relying instead on a quota or limits on license numbers. Some governments, like Sardinia and Morocco, have developed coral management plans and regulations that establish harvest quotas and restrict access to coral beds. In some countries, poaching has become a growing problem and illegal use of coral dredges are still occurring.

Artisans along Mediterranean coastal communities have worked raw coral into precious jewelry and handicrafts for centuries. Red coral jewelry and carved pieces became a staple in trade between Europe and Asia and the Americas. It is highly prized in many cultures around the globe. Since 1805, the center of the red coral processing and manufacturing industry has been Torre del Greco, Italy. In Torre del Greco, many artisans working in small family businesses convert raw coral into precious jewelry and artistic crafts, which are shipped and appreciated throughout the world.

After listening to a series of presentations on the biology and ecology of red coral and its importance in local cultures, and trade, workshop participants divided into 2 working groups on 1) science and management, and 2) trade. Abridged conclusions of the working groups are presented below. The complete statements of the working groups can be found beginning on page 208 of this report.

Abridged Conclusion of the Science Working Group

The working group reached consensus on the following conclusions and presented them to the plenary of the Workshop, which approved them:

1. A comprehensive Mediterranean approach to red coral management – for example through the General Fisheries Commission for the Mediterranean (GFCM) – based on a common assessment of current management, monitoring, and research findings across the region is needed.
   a. Local management plans under this Mediterranean 'umbrella' are needed to improve management.
   b. A working group needs to develop these plans and to seek funding to develop and implement them.
2. Management should be based on key scientific parameters such as population structure, density genetics, colony and population growth rates (reproduction and recruitment), and connectivity.
3. Management should be adaptive based on feedback from fishery dependent and independent data, and input from relevant stakeholders.
4. Populations above 50 meters depth are well studied, at least in Spain, France, and Italy, but deeper water populations and populations in other countries are poorly known. Extrapolating from shallow water studies (in selected locations) may not be appropriate.
5. The majority of shallow water populations are, or have been, over-exploited, and the overall extent of red coral populations and of their decline is not known at a Mediterranean scale. Therefore, there is a clear need to determine the extent of populations and their

decline (or recovery) trends.

6. Shallow water (less than 70 meters) populations need to be fully protected from harvesting.
7. Deep water populations (from 70-150 m) are a priority for research and fishery management because a) these are thought to contain abundant resources and fisheries are rapidly expanding into these areas because shallower areas cannot support commercial fisheries, and b) demographic parameters of deep-dwelling populations are poorly known.
    a. These deep water populations should be managed by selective harvesting using appropriate size limits based on suitable demographic models.
    b. The deepest populations (> 150 m) are not currently harvested and should not be harvested in the future, as they could provide refugia for the species.
8. The decision to ban non-selective gears was a major step forward in the regulation of the fishery. Management measures and enforcement in the Mediterranean overall should be improved.
    a. Such management measures should be population-specific and include, but not be limited to, minimum basal diameter[1] and height of colony and branching pattern, quotas, regulation of collection methods, harvest reporting and monitoring, rotating harvest and an increase in the number and extent of no-take zones/protected areas.
    b. Management measures should be adaptive and be informed by proper and comprehensive scientific research on, *inter alia*, stock status and management models.
    c. Absence of scientific information is not a sufficient excuse not to manage populations on a precautionary basis, but it is an important incentive to study deep-dwelling populations.
9. Management regimes that are not adequately enforced fail to yield the anticipated conservation benefits.
    a. There is a strong need for existing and future management measures to be properly enforced with *inter alia* sufficient resources and penalties – including confiscation – that are commensurate with the offence and represent a meaningful deterrent.
10. The working group emphasised the need for further research to underpin the management and conservation of the species.
    a. Research should be collaborative and the results shared between Mediterranean countries and internationally.
    b. Regular stock assessments and national reporting, in the context of regional management, is desirable.

Conclusions of the Management and Trade Working group

It was not possible for the workshop, when considering the report of the trade working group, to reach any appropriate consensus on trade related issues because some participants objected to any reference to any CITES listings, while others felt that discussion of the implications of a hypothetical CITES Appendix-II listing were essential. The final report of the working group, pages 211-213 of this report, represents general agreement of the working group but consensus was not reached on all of the text.

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[1] For instance, the working group felt that the minimum basal diameters used in some areas (typically 7 mm) should be increased to enable sustainable fisheries.

White Papers and/or Abstracts

Section I

Mediterranean Red Coral (*Corallium rubrum*): Historical Assessment

THE PRECIOUS RED CORAL OF THE MEDITERRANEAN: AN HISTORICAL, CULTURAL, AND ECONOMIC HERITAGE

Caterina Ascione

Since the most ancient times, coral has had an extraordinary power of attraction for all peoples. Its history is lost in the mists of time, and is intertwined with the ongoing development of Mediterranean civilization from East to West.

It is the history of gods and men, of fears to be overcome, of magic and rituals, of ornaments and talismans. Both an amulet and a jewel, then.

The unique biological parabola that is the distinctive characteristic of coral, the complex mythological content that surrounds it, tying it to the blood of the head of the Medusa that Perseus decapitated, blood that would color and petrify the sea algae, the extraordinary ambiguity of its nature, in a sense part of all three kingdoms – animal, vegetable, mineral – brought ancient peoples to attribute protective and curative qualities to the "red tree."

Diverse cultures have indicated it is an antidote for poisons, a remedy against the bite of scorpions, able, if mixed with grains of corn during planting, to prevent drought, to keep away the plague, calamities, and parasites.

Coral is the exaltation of the symbol of the life force, of the balance between life and death, of the possibility of rebirth, subordinate to the complete transformation of one's essence. In this sense, associated to the figure of the Saviour, it indicates, in early Christian symbolism and sacred iconography, the blood pact and redemption, the Cross, the palingenesis of Resurrection, wonderfully expressed in that marine element that, according to a millenary belief, did not die when brought to the surface but, on the contrary, transmuted into a mineral on contact with air, becoming perfect and incorruptible, fons vitae perennis.

In addition to being a talisman, a protection for good health and good luck, able to keep away negative influences and neutralize the evil eye, coral has always been a widely used ornament, too, both plebeian and not.

The art of working coral has criss-crossed the Mediterranean: from Marseilles to Genoa, from Trapani to Leghorn to Naples, finally coming to Torre del Greco, a coastal city briefly mentioned in various documents and diaries as a continuous font of men dedicated to harvesting the bounty of the sea, both fish and coral.

The tie between Torre del Greco and coral has been often noted. A very ancient tie that has had two phases: harvesting, testified to from remote times, and the working of the raw material, which began early in the 19th century. A tie, beyond the economic and productive aspects, that has brought about a true culture of coral that has affected both the life and customs of this place.

Coral harvesting, concentrated in the difficult and dangerous waters of the Mediterranean, is a particularly fascinating and dramatic chapter in the history of the city. The earliest documents, indeed the first to mention Torre del Greco as an autonomous civitas, go back to the end of the 15th century. It deals with a request to abolish the taxes imposed on coral fishermen. The tax itself is indicative of a large-scale and financially conspicuous activity, extant for some time.

Leaving aside anecdotes, detailed and vivacious though in large part invented, among the historically significant milestones that should be mentioned are: the founding of the Pio Monte dei Marinai in 1639; a charity created thanks to the initiative of 58 ship owners, with its seat in the church of Santa Maria di Costantinopoli; the promulgation of the Codice Corallino in 1789, a document of great legal importance that aimed at creating definitive regulations in the turbulent world of coral fishing. At the beginning of the 19th century, a new and decisive chapter begins, regarding the relationship between Torre del Greco and coral.

On the 27th of March, 1805, Paul Bartelémy Martin was given a ten-year concession for the working of "red gold." This was the decisive step towards the creation of a complete economic cycle – harvesting, working, sales – that many had supported and requested. Only a few decades later, in 1837, with the end of the concession, there were already numerous shops and eight large factories with more than fifty workers. The entire population seemed, therefore, to be involved in activities tied to coral, not only in harvesting and decoration, but also in related concerns, from supply to shipbuilding.

From the very beginning of coral working in Torre del Greco, the manufactures were quite diversified: not only necklaces of innumerable types – pallini, barilotti, cannettine, to mention only a few – but also the creation of jewelry and other luxury items was a distinctive feature, using complex and refined sculpting techniques.

The rigorous lines of Neoclassic style marked the early works. From the middle of the 19th century, instead, the rise of archeological and neo-Renaissance styles enriched the various methods of decoration: mythological figures, putti, cherubs and later baccanti, unicorns, amphorae, combined and mounted in imposing and wondrous jewels. Virtually in the same years, the consecration of the naturalistic style offered the artisans the possibility of creating a vast production of "flowers, leaves, and fruit" compositions: splendid bracelets and necklaces celebrate the high level of technique of the master sculptors, surprisingly almost all anonymous.

For almost all of the 19th century, only Mediterranean culture was harvested and it was this coral, with its shapes and dimensions, that set the outer and inner limits of production, that naturally was also conditioned by the political and economic events, in particular on Europe and northern Africa. Great interest and surprise were the result of the French government's decision in 1875 to prohibit harvesting with metal tools, which were damaging the coral banks and the seabed, and to allow coral harvesting on the Algerian coast for a limited number of boats, restricted to only three areas with a ten-year rotation, in order to allow the abundant re-growth of the banks. It was the first time that the quantity of coral brought to market was subject to limitations, to protect both the raw material, and prevent excessive exploitation.

In those very years an unexpected event shook the world of coral: the discovery of the Sciacca banks, a finding that moved the major interest to the coast off Sicily, towards the island of Pantelleria. The report by Giovanni and Riccardo Canestrini, on the behalf of the Ministry of Agriculture, Industry and Commerce, studying the case, makes a significant point: "The coral harvested (in the sea off

Sciacca) is dead, that is, lacking the shell or sarcosma, in which the polyps live and reproduce (… This) was announced in the report to the Ministry of Agriculture, Industry and Commerce on the results of the search among the coral banks off Sciacca (…) We certainly brought up thousands of samples from these banks and many showed the recent fractures caused by our tools, but no samples were found with a sarcosma" (Giovanni and Riccardo Canestrini, Il Corallo in the Annali dell'Industria e Commercio, 1882).

Wide and rich banks, but of dead coral, with no trace of sarcosma or polyps. These very characteristics made reproduction of the banks impossible. The events that the followed the singular harvest at Sciacca are well known: an excessive abundance of coral gave rise to a crisis, caused by market saturation and depreciation of a large part of the production. In just ten years, the excess of supply made its dramatic effects felt and many manufacturers were forced to close. The grave crisis and the recognized inadequacy of the Sciacca coral, by now devalued and unsuitable for detailed and elaborate workings that the market wanted, caused some companies, in the second half of eighties, to put aside the supplies already acquired and to try other sources. A new type of coral was discovered in the markets at Madras and Calcutta: it came from Japan.

Coral which was highly-prized and morphologically different from that previously used. Above all, imported coral. This broke the continuous economic cycle (harvest-manufacture-sales) that had marked Torre del Greco for the entire 19th century. The need to invest large amounts of capital for the purchase of the raw material caused a severe selection process among the companies of the sector. Its value heavily influenced production, which abandoned lower levels and moved up to luxury jewelry, the prerogative of the upper middle class and an aristocratic elite. Modernist and Art Decò influences inspired original geometric creations, with strong chromatic contrasts (red and white matched with black onyx or green malachite) and heterogeneous pairings of materials: iridescent pearl with nuances of coral, with inserts in tortoise shell, painted wood and plastic.

The predominant use of Oriental coral in the most expensive and exclusive production did not mean that Mediterranean coral was no longer used, which on the contrary was kept alive to safeguard the harvesting of raw material, fundamental for the economy of Torre del Greco. This was used primarily for low-cost items and necklaces in traditional styles, both for domestic and foreign markets. In the 1950s, after World War II, there was a increase in sales, slow at first but slowly growing. With the reopening of the North African markets, in Nigeria, in the United States, and in the Far East, demand grew for both raw and worked coral, which in the meantime had been rediscovered by important jewelers such as Cartier, Boucheron, and Van Cleef.

This represented a new phase for Torre del Greco, which continues today. A story which is the history of the very city and its people: a unique culture, a universal treasure, an Immaterial Patrimony, as cited by Article 2 of the Convention for the Safeguard of Immaterial Cultural Patrimony of UNESCO, it is "transmitted from generation to generation, constantly recreated by the community and those related to it, in conformity with its environment, by their interaction with Nature and their history, and gives them a sense of identity and continuity, by so promoting the respect of the cultural and creative diversity." A patrimony, therefore, to be protected and safeguarded from destruction.

Today a renewed sensibility imposes the need to take a different view of the sea and its treasures, coral among these. And it points a way, perhaps the only one which can actually be undertaken.

The eco-sustainable exploitation of the resources that the Earth offers. Intelligence and rigorous regulation. In the case of coral, the adoption of a system under strict control regarding times, areas and methods of harvesting would be not only a guarantee of the on-going defense of coral species, but also the certainty, historically documented and proven, of the safeguard of employment levels and quality of production, and therefore the maintaining over time of a profitable relationship between supply and demand, with undoubtable advantages for the continuing stability of the market and prices. A wise choice, and above all with excellent returns, both in terms of ecology and economics.

LACAZE-DUTHIERS' LEGACY: ADVANCES IN SCIENTIFIC KNOWLEDGE OF *CORALLIUM RUBRUM* FROM FRENCH WORKS AFTER 1864

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Introduction

The French Mediterranean coast has been for centuries the center of active harvesting, manufacturing, trading and scientific study of precious red coral. Antique vestiges found at Marseilles, the oldest port in France, attest that red coral was already collected there 26 centuries ago. This activity was permitted by the abundance and easy accessibility of red coral stocks along the Provence coasts. This opportunity was also seized by naturalists, such as L.F. de Marsigli and J.A.Peyssonnel, the last actors with opposite opinions of the old controversy about the mineral, vegetal, or animal nature of the red coral, which was solved at Marseilles in the early 18th century (McConnell 1990).

The scientific knowledge of *Corallium rubrum* benefited greatly from the work by Lacaze-Duthiers (1864) during his stay at El Kala (Algeria), where he was commissioned by the French government. This major step was followed by a long gap of nearly one century in French research devoted to the precious coral, except for two papers. The renewal of interest for *C. rubrum* started at the end of the 1950s when SCUBA diving became a common tool for studying hard bottom communities. This method was particularly workable in the NW Mediterranean as red coral commonly thrives there at shallow depths, especially along the French coasts. The number of references increased noticeably from the 1970s and reaches now 60 (including the works realised at the Centre Scientifique de Monaco). One of the conclusions of the first FAO meeting on red coral held at Mallorca in 1983 was that all questions addressed by Lacaze-Duthiers were still unsolved. Uncertainties concerned particularly the growth rate of colonies and thus the capacity of red coral banks to replenish after exploitation. Since then, significant advances were provided by works realized in France and Monaco, which are resumed below, while the entire list of references is given in bibliography.

Habitat Distribution of Red Coral

The ecological attributes of *C. rubrum* and features of its distribution among hard-bottom habitats were described in a series of papers (Bianconi et al. 1988; Laborel and Vacelet 1961; Stiller and Rivoire 1984; Weinberg 1975, 1978, 1979a, 1979b, 1979c). The most outstanding peculiarity of the Mediterranean red coral compared to all other *Corallium* or *Paracorallium* species is its capacity to occupy near-surface habitats as well as much deeper biotopes. On the upper side of this range, patchy populations bordered by photophilic algal assemblages can be found in cavities and overhangs at few meters below the surface (3-6 m). On the opposite, deeper side of this distribution, *C. rubrum* can coexist with the bathyal cold-water coral *Madrepora oculata* at several hundred meters depth and short distance from the coast. This was observed, for example, on the abrupt walls of Cassidaigne submarine canyon, near Marseille, at 200-325 m (Bourcier and Zibrowius 1973; Laborel et al. 1961; and unpublished ROV observations during Hermes and AAMP surveys, 2009). Although these nearshore and deep-water habitats may appear in stark contrast, they share some common environmental characters, such as dim light, steep slope (i.e. limited sediment deposits), and circulating water.

Thermal Sensitivity of Red Coral

Field evidences indicate that the upper depth at which *C. rubrum* occurs presents a great geographical variability around the Mediterranean, hypothetically related to local surface temperatures and deepening of the thermocline in summer (Laborel and Vacelet 1961; Stiller and Rivoire 1984). Moreover, red coral is subjected to mass mortality in the shallower sites when positive thermal anomalies happen during summer periods (Garrabou et al. 2001, 2009; Harmelin 1984). The sensitivity of red coral to high temperatures had thus to be tested experimentally.

The thermo-tolerance patterns of red coral were studied by O. Torrents by experiments in thermo-regulated tanks with four types of thermal regime applied during two consecutive years to specimens coming from shallow and deeper sites. The responses (coenenchyme necrosis, polyp activity, calcification rate) of red coral colonies in experimental conditions were similar to those observed during mortality events and brought precise information on the thermo-tolerance limits of this species. Long exposure of colonies to 24° C and shorter exposure to 25° C are critical to both shallow and deep specimens; necrosis occurs in less than five days if temperature is higher than 25° C and deep populations are more sensitive than shallower ones (Torrents et al. 2008).

These experiments confirm the particular thermal sensitivity of *C. rubrum,* and therefore that (i) the shallower populations of the NW Mediterranean are under the threat of global warming, and (ii) high summer temperatures are a key factor of its exclusion from shallow depths in the warmer regions, such as the eastern Mediterranean (Zibrowius 1979).

Diet of Red Coral

As other azooxanthellate passive suspension-feeders, red coral depends entirely on food supplied by the water movements. This constraint limits, for example, its penetration inside caves when confinement predominates. Red coral is known to consume particulate organic matter, both live and detrital. However, feeding experiments by Picciano and Ferrier-Pagès (2007) showed that red coral is also able to prey effectively on bacterioplankton. Although pico- and nanoplankton represent only 4.5% of the total carbon ingested, this food appears to be essential in terms of nitrogen and phosphorus.

Resilience of Harvested Populations

It is evident from field observations that, at least in some regions such as Provence (France), red coral persists in shallow sites despite a long history of harvesting pressure and easy accessibility. Thus, how these shallow populations can persist and replenish?

The study of reproduction of *C. rubrum* (Torrents et al. 2005) showed that the size of the smallest fertile colonies was surprisingly small, only 2.4 cm in average (height), the smallest being 1.5 cm tall. Thus, these smallest fertile individuals are far below the threshold size that can trigger a selective harvesting. This feature together with the poor dispersal of larvae, which favour self-seeding in populations aggregated in cavities (Weinberg 1979b), allow local populations to persist with small colony size in highly frequented sites. However, age analysis showed that these small fertile colonies were not juvenile, but 7-10 years old (Torrents et al. 2005). It was also clear from this study that the larval productivity increases considerably with the colony size. Therefore, conservation of large-sized colonies, most efficient in producing larvae and icons of the Mediterranean landscape heritage, is imperative. This is particularly acute when local populations are formed of scattered colonies, more subjected to the hazards of recruitment than patchy populations.

Recruitment Patterns and Colonization

Underwater observations show that assemblages including red coral in dimly-lit habitats are dominated by long-lived, highly-competitive components (sponges, tunicates, bryozoans, serpulids, scleractinian corals, etc.) (Laborel and Vacelet 1961; Bianconi et al. 1988; Weinberg 1978). How does *C. rubrum* participate to the establishment and functioning of this type of communities? Limestone panels deployed in 1969 within a *Corallium*-rich community were photographically monitored yearly since 1979, i.e. two years after a first pulse settlement of red coral colonies. Only another recruitment event was observed during the 22 years-long monitoring, but survivorship of colonies was high (60%). *In situ* measurements of colony branches showed that linear growth was in average only 5.6 mm year^{-1} (Harmelin 1984), while measurements of the basal diameter of 22-year old colonies showed that the radial thickening of branches was very slow, only 0.24 mm year^{-1} (Garrabou and Harmelin 2002). This long-term colonisation experiment brought indisputable indications on the red coral growth rate, but could hardly be repeated for testing the variability of growth in diverse conditions.

Skeleton Features and Growth Rate Determination

The tree-like growth-form of red coral suggested the possible use of dendrochronology to date colonies. The first attempt was made by Dantan (1928), who made horizontal cross sections in the axial calcified skeleton and found a few concentric zones, e.g. only five rings in a 1 cm thick branch. To validate this technique, he proposed another pioneer idea: monitoring of transplanted colonies by divers. However, this petrographic method leads to a considerable over-estimation of growth-rate because apparent rings are pluriannual, as proved by tests on colonies from panels, i.e. of known age (Marschal et al. 2004).

Another approach was to look for patterns in the organic part of the calcareous skeleton. Fundamental advances in the biochemical characterization of the organic matrix of *C. rubrum* and its role in biomineralization processes were done by D. Allemand and his team at Monaco (Allemand 1993; Allemand and Grillo 1990, 1992; Allemand et al. 1994; Grillo et al. 1993). Biochemical evidences show that spicules and axial skeleton have a different origin although the organic matrix is present in both skeletal elements with a water-insoluble fraction (76-80%) and a soluble matrix, which is richer in proteins.

The finding by C. Marschal (Marschal 2004; Marschal et al. 2004) that the organic matrix reflected an annual periodicity in its concentration resulting in concentric dark and clear rings was a major step. The annual periodicity of these rings was validated first with colonies of known age settled on panels (Garrabou and Harmelin 2002) and also by using repeated calceine staining on colonies transplanted during fixed times. The organic matrix method, now used in routine, allowed for example to show evident differences in growth rate at small spatial scale according to the exposure of colonies to water circulation.

A quite different approach, based on features of the calcareous skeleton mineralogy, was tested by D. Vielzeuf. Mineralogical analyses of skeleton cross-sections showed that the magnesium/calcium ratio presents oscillations, which are annual with more magnesium deposited during the warm season. Interestingly, the comparison of the two methods, organic matrix and magnesium cartography, on the same skeleton sections, proved that they are perfectly congruent (Vielzeuf et al. 2008).

Biocalcification and the Skeleton Construction

It was admitted, following Lacaze-Duthiers (1864), that the construction of the axial skeleton resulted from the incorporation and cementation of spicules. It was argued that spiny protuberances occurring at the surface of the axial skeleton were spicules in the process of being incorporated. This hypothesis was tested with different modern tools. Biochemical analyses and other methods such as radioisotope incorporation were used by D. Allemand and his team to trace the uptake of calcium and describe the calcification of the axis (Allemand 1993; Allemand and Grillo 1990, 1992; Allemand and Bénazet 1992; Allemand and Bénazet-Tambutté 1996; Grillo and Allemand 1990). It is now proved that the skeleton growth follows two different patterns, one at the tip of branches, where spicules are incorporated, and another in the rest of the colony with the activity of a peripheral skeletogenic epithelium which is responsible of the axis thickening.

The mineral microstructure of the axial skeleton has been recently studied by Vielzeuf and his team. The outstanding hierarchic structure of the biomineral skeleton was revealed from the nanoscale to the macroscale with nanograins, fibers, blades, and microprotuberances (Vielzeuf et al. 2008, in press). This microstructure approach also allowed to confirm that microprotuberances are not partly incorporated sclerites, as believed by Lacaze-Duthiers.

Red Coral Color

The color of the skeleton of *C. rubrum* is a fundamental attribute for jewelry, which may vary among regional populations from dark red to pink, but also within local populations with occasional albino colonies (Harmelin 2000). The red color was first attributed to iron oxide (Ranson and Durivault 1937). However, analyses by resonance Raman spectroscopy (Merlin and Delé 1983; Merlin and Delé-Dubois 1985) indicated that carotenoids were responsible of the skeleton red color. The use of high-performance liquid chromatography (HPLC/DAD and HPLC/MS) by Cvejic et al. (2007) on both soft and hard tissues confirmed the carotenoid origin of the pigmentation and more precisely showed the presence of canthaxanthin, a dominant carotenoid in aquatic animals. Canthaxanthin is contained in the organic matrix and its concentration is notably greater in spicules than in the skeleton. Carotenoids are provided by a wide variety of food items and their role in the skeleton is still unknown, as well as the origin of the wide variety of tones.

Size Structure in Harvested vs. Non-Harvested Populations

It is manifest from underwater observations in the 0-60 m zone that large colonies are now extremely rare while they were accounted to be not infrequent during the 50s or early 60s even at shallow depth. On the other hand, the difference in colony size structure between populations located in harvested zones and those in areas protected for long is also visually obvious. These size differences were evidenced by direct measurements (basal diameter, height, width) of the largest colonies found in multiples spots within a region including harvested and protected sites (Garrabou and Harmelin 2002; Harmelin et al. 1999). The "harvesting erosion" affecting the size of colonies is impressive: the mean basal diameter of the largest colonies was 6-7 mm in unprotected sites versus 12 mm in a marine reserve. Precise *in situ* measurements of colonies are time-consuming and entail long decompression stages. Now this method is advantageously replaced by the underwater photogrammetry of colonies (Graille 2007), which can provide rapid and reliable size data. Photogrammetric surveys of harvested populations compared to those sheltered in three marine protected areas have confirmed the obvious effect of harvesting on the population size structure (Bianchimani 2005) and the existence of size thresholds that determine collect attractiveness.

Conclusions: Lessons to Management

The Mediterranean red coral presents an outstanding capacity to cope with different local conditions leading to a broad ecological distribution. However, a particular sensitivity to warm temperatures and thus to global change can be a grave threat to the shallowest populations. It is a remarkable model for biomineralisation studies with peculiar patterns of skeleton structure and growth. It is now proved that its growth is very slow, even in the most productive sites. However, despite harvesting, it is not a threatened species thanks to its capacity to reproduce at very small size. The large, very old colonies (equivalent to the biggest trees in forests) are no longer present in most sites and will soon totally disappear. Permanent sanctuaries of significant size must be established all around the Mediterranean in order to allow some local populations to reach a natural size structure including very old colonies in the next centuries. Harvesting must be strictly controlled everywhere with size limits, education and precise registration of professionals, and with eradication of poaching. Regulations should be adapted to local conditions.

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THE HISTORY OF RESEARCH AND HARVESTING OF THE MEDITERRANEAN RED CORAL: POTENTIAL AND LIMITS

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Summary

The history of the research on the Mediterranean red coral (*Corallium rubrum* L 1758) is strictly intertwined with that of harvesting. For more than three centuries all the information on red coral habitat and all the material examined by naturalists was gathered by fishermen; moreover, the oscillating succession of red coral fishing vicissitudes deeply affected the development of red coral research. Up to the XVII century, red coral was considered to be a plant, and the first naturalist who stated the animal nature of red coral was the Neapolitan alchemist Farinella, and only subsequently Peyssonel in 1723 confirmed this statement. A following milestone in red coral research was the beautiful book of the French scientist Lacaze-Duthiers, who, in 1864 published: *History naturelle du corail.* Only in the second half of the XX century the research on red coral started again and *in situ* researches were carried out by Laborel and Vacelet (1958, 1961) and Weinberg (1978, 1979a, 1979b), who described the sensitivity of red coral to light, sedimentation, hydrodynamics, and the red coral habitat selectivity. In the same period, a team of Italian researchers (Barletta, Marchetti, Vighi 1968) described, on the basis of data collected directly by SCUBA diving, several red coral populations living in shallow-waters (between 20 and 50 meter depth) along the Italian coasts. Moreover, they described for the fist time the reproductive cycle of this species. In 1986, Spanish researchers (Rodriquez and Massò 1986) described red coral population size structure and allometric relationships on the basis of Catalan fishing crops; moreover, they try to determine the age of red coral colonies. In 1991 and 1994, after two meetings organised by FAO in Torre del Greco and Alger, and the submission of a Spanish proposal to include red coral in CITES Appendix-II, new impulse was given to red coral research by the Italian Government, who funded two preliminary research projects. These researches led to two basic books on red coral biology and ecology (*Red coral in the Mediterranean Sea, Art history and Science* 1993; *Red Coral and other Mediterranean Octocorals: Biology and Protection* 1999). It will be worth to remember that nearly all the papers already published deal with shallow-water populations which have a limited economic value. More recently red coral research was addressed towards the study of population structure and dynamics by means of demographic models (Abbiati et al. 1992; Santangelo et al. 2004, 2007; Bramanti et al. 2009). This approach, widely applied in Conservation Ecology, will supply the tools to match harvesting to population growth rate fostering both conservation and rational management of the populations of this precious species, if sound data on deep-dwelling populations will be at least gathered and enforcement will be really applied at local population level.

A Long History

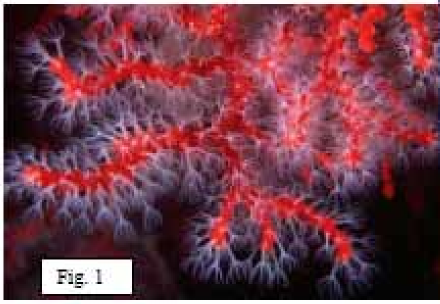
The history of the research on the Mediterranean red coral (*Corallium rubrum* L 1758) is strictly intertwined with that of harvesting as oscillating succession of red coral fishing vicissitudes deeply affected the development of red coral research. Moreover, along three centuries all the material examined by naturalists was gathered by fishermen. This first phase continued up to the second half of 1950s, when SCUBA-Diving techniques allowed to researchers to observe red coral populations directly in the field.

Three different phases in red coral research can thus be sketched:

1. XVII-XIX Naturalists gathered all the samples they examined and all information by fishermen.

2. Since 1950s to nowadays SCUBA-Diving scientists acquired the possibility to collect their data directly *in situ*; these studies were limited to the shallower portion of red coral bathymetric distribution (20–50 m) At the same time electron microscopy allowed to gain insights into the small-scale structure of the red coral skeleton.

3. More recently, the use of ROV and submarines has extended research to deeper populations and new, reliable methods allow to determine colony age and to apply demographic models, structured in age classes, which will foster a rational management of this precious Mediterranean resource.



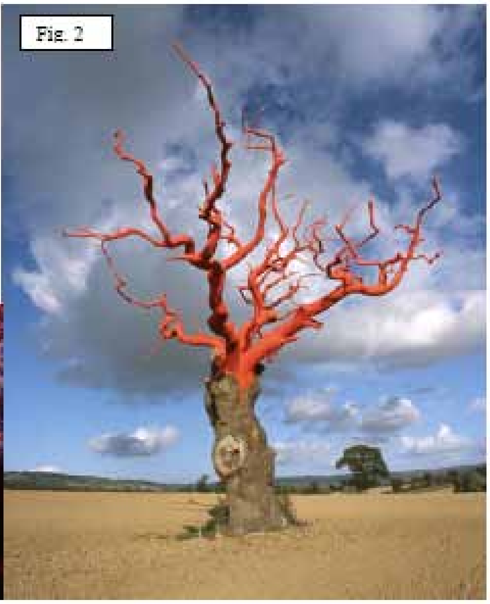


Fig. 1. Red coral colony with expanded polyps in a crevice at 35 m depth.

Fig. 2. Red coral, flowered plant or animal? The truth revealed in the XVIII century.

In the course of the long history of red coral exploitation (two thousand years, at least) and the even longer history of red coral use as precious raw material for carving talismans, art objects, and jewellery, several legends and fancy hypotheses raised on its origin and real nature. Up to the XVII century, red coral was considered firstly to be a mineral and then a plant. The first naturalist who stated the animal nature of this species was the Neapolitan alchemist Finella in 1649; only later the Italian naturalist Cestoni (1718), and finally the French physician Peyssonnel (1725) confirmed the animal nature of red coral.

The fist naturalist who tried to estimate the growth rate of red coral colonies was the Italian botanist Marsili (1725), who observed at about 5 meters depth red coral colonies living in a shallow-water, shaded cave. Red coral still dwells nowadays at such depth in some long, dark, cold caves like those at Capo Caccia (Sardinia) and near Marseille.

In 1785, Cavolini provided a microscopic description of the skeleton of red coral. Linnaeus in his “Sistema naturae” (1758) named the species *Madrepora rubra* and finally Lamark (1816) gave to the species its present name: *Corallium rubrum*.

The British naturalist Ellis, in 1753, discovered the similarities between gorgonians and *Corallium rubrum,* which was thus included in the Family Keratopytae = Gorgonacea.

A following milestone in red coral research was the beautiful book of the French scientist Lacaze-Duthiers, who, in 1864 published: *History naturelle du corail.* This eminent naturalist gave an exhaustive description of geographic distribution, ecology, and colony anatomy (Weinberg 1993). His skill in observing and describing by drawing magnificent color plates (Fig. 3) of the main morphological features of red coral at a macroscopic and microscopic scale was incredible, if we consider the limited microscope supply researchers have at that time. It is worth to remember that, also in this case, top-quality research was produced in the framework of a fishing campaign promoted in Algeria by the France Government.

Lacaze-Duthiers’ high quality observations and insights were confirmed only at the beginning of XX century, when more efficient microscopic tools were developed by two German researchers (Koch 1991; Müller 1910), working at Stazione Zoologica di Napoli.

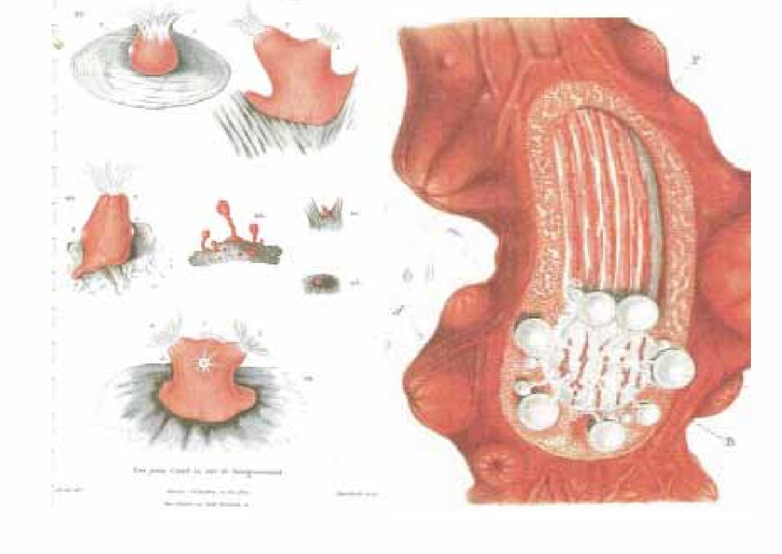


Fig. 3. From Lacaze-Duthiers (1964). At left: the first description of red coral recruits; red coral female polyp with oocytes in two different phases of their reproductive cycle.

In the mid XX century, the research on red coral received new impulse due to SCUBA diving gears development. *In situ* research was carried out by Laborel and Vacelet (1958, 1962) and then Weinberg (1978, 1979a, 1979b), who described the sensitivity of red coral to light, sedimentation, hydrodynamics, and red coral habitat selectivity. Carpine and Grashoff described the features of red coral sclerites and the geographic distribution of the species (Carpine and Grashoff 1975). At the same time, a team of Italian researchers (Barletta, Marchetti, Vighi, 1968) described, on the basis of data collected directly by SCUBA diving, several red coral populations living in shallow-waters (between 20 and 50 meters depth) along the Italian Western coasts. Moreover, Vighi described for the fist time by means of histological tools, the reproductive cycle of red coral (Vighi M.; Etude sur la reproduction du *Corallium rubrum* Vie et Milieu 1972).

Overfishing at Alboran and the Following Research Impulse in Spain

In 1983, the discovery of rich red coral banks at Alboran (Santangelo et al. 1993b) led to their uncontrolled harvesting and to a consequent rapid depletion by fishermen from Sicily; all this led to the first submission of a proposal of red coral inclusion in CITES Appendix-II, by Spain, the country to which Alboran Islet and surrounding sea belong, with the aim to control overexploitation by controlling trading. Under this new situation the Spain Government fostered and funded some research on red coral. This is a further example of the way in which the oscillating succession of red coral fishing vicissitudes deeply affected the development of red coral research.

The results of these researches were collected in a monographic volume of the *Boletin Espanol de Oceangrafia* (1986) dedicated to different topics of red coral natural history (Figs. 4, 5, 6). There the Spanish researchers Garcia-Rodriquez and Massò (Garcia-Rodriquez and Massò 1986) described for the first time the frequency distribution of size and the allometric relationships of red coral colonies in Spanish fishing crops. Moreover, they tried to determine the age of colonies to convert the size structure they found in an age structure but, unfortunately, their *petrographic* method revealed to be erroneous (Garrabou and Harmelin 2002). Only 18 years later a new, reliable method, based on organic matrix staining of thin-sections of colony skeleton revealed the real annual growth rings of red coral (Marschall et al. 2004).

39-E

BOLETIN
INSTITUTO ESPAÑOL
DE
OCEANOGRAFIA

MADRID, 1986

VOLUMEN 3
NUMERO 4

Fig. 4. Survivor curve (Number of colonies of different size/age) drawn by Garcia-Rodriguez and Massò on the basis of Spanish fishing crops (Cala Sardina Gerona) (Garcia-Rodriguez and Massò 1986).

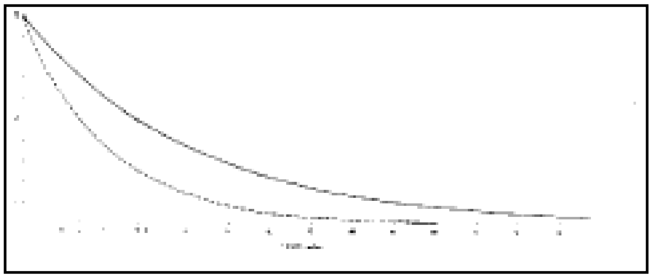


Fig. 5. Summary of the papers on red coral in the Spanish Boletin del'Istituto Espanol de Oceanografia dedicated to red coral in 1986.

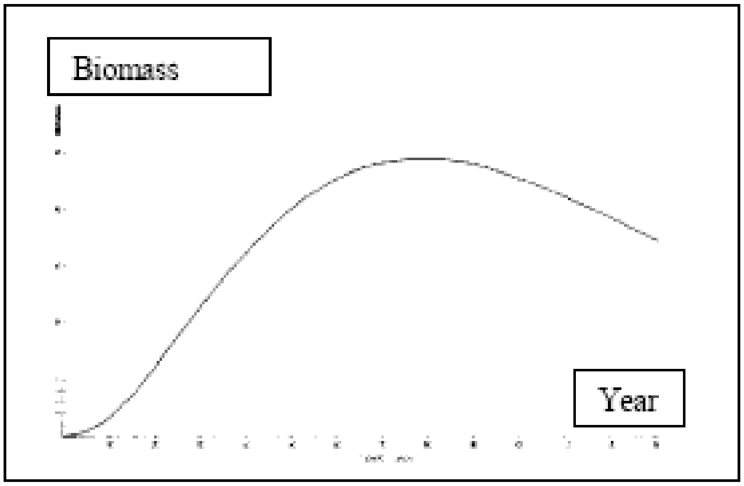


Fig. 6. Garcia-Rodriquez and Massò applied the Beverton and Holt yield per recruit model to find the age of maximum yield. Their result was 80 years, not far from the values found by Tsounis et al. (2007); this model will be discussed in paragraph 9 and following).

Between 1988 and 1994, after two meetings organised by FAO at Torre del Greco (1988) and Alger (1989), a new impulse was given to red coral research by the Italian Government, who funded two preliminary research projects. These researches led to two basic books on red coral biology and ecology (*Red coral in the Mediterranean Sea, Art history and Science* 1993; and *Red Coral and other Mediterranean Octocorals: Biology and Protection* 1999; Fig. 7). It will be worth to remember that nearly all the papers already published at that time (and nowadays too) deal with shallow-water populations which have a limited economic value.

Fig. 7. Red Coral and other Mediterranean Octocorals: Biology and Protection, 1999.

A real, positive contribution to rational management and conservation of red coral derived from these researches: in 1994 highly unselective, destructive fishing gears (*Ingegno* and *St. Andrew Croix*), which were trawled on red coral banks heavily damaging both red coral populations and the surrounding benthic community, were banned by the European Countries and, within a few years, from the whole Mediterranean Sea. Nowadays fishing is allowed by SCUBA diving and pick only (a quite selective fishing method!) in the whole Mediterranean.

Shallow and Deep-Dwelling Populations

This schematic subdivision has not any genetic implication (also if some genetic difference between shallow and deepest-dwelling populations has been recently found: Costantini et al. 2009), but it is operative, based only on some different gross features characterising red coral populations living at different depths.

According to of the current literature, two main conclusions can be drawn on shallow-water populations:

1. The majority of papers deal with such populations living within the bathymetric range between 20 and 50 meters (5 meters in caves);
2. These populations show some common dominant features: small colony size, small age-size at firs maturity (Santangelo et al. 2003; Torrens et al. 2005; Tsounis et al. 2006), high densities, high incidence of boring sponges (more than 50% of colonies are affected by boring sponges Corriero et al. 1997). It leads, together with small colony size, to a limited economic value of these populations. Shallow-water populations resulted to be genetically structured at a small spatial scale (Abbiati et al. 1993; Costantini et al. 2007). These populations show high reproductive output (Cattaneo-Vietti et al. 1993; Santangelo et al. 2003) and high recruitment rates (Bramanti et al. 2003, 2005, 2007).

These shallow-water populations thrive at a depth that can easily be reached by scuba divers, thus they have been or are still now deeply harvested (Santangelo et al., Tsounis et al. in press); their peculiar size/age structure in which small/young colonies are dominant is the consequence of the overharvesting they suffered in the past, and the highest density (up to 3.000 col. m^2) some of them show could be the consequence of overharvesting (Bramanti et al. 2009).

In recent years (late summer 1999), some shallow-water red coral populations have been affected by mass mortality associated to anomalous temperature increase in the Eastern Ligurian Sea (Calafuria-Italy; Bramanti et al. 2005), as well as Western Ligurian Sea (Calafuria), and in the Gulf of Lion (Marseille; Garrabou et al. 2001). Mass mortality events affecting shallow-water populations occurred also in Corsica and North Sardinia. Such mass mortality events (putatively linked to global climate change: Santangelo and Fronzoni 2008) affected the populations of several benthic suspension-feeders in the Ligurian Sea (Cupido et al. 2008).

Being composed by small-sized colonies, shallow-water populations have a limited economic value, but they are important ensuring a pool of breeders for the species. Moreover, due to their beauty, red coral colonies are an important attraction for touristic diving. MPAs which harbor red coral populations have a unique value for both conservation and recreational diving.

The Deep-Dwelling Populations

The populations composed of larger colonies having a higher economic value (up to 20 fold higher than the smaller shallow ones) generally live at a deeper depth (60-150 meters); in these populations, colonies are more sparse and less affected by boring sponges than in the shallower populations. Also, in some preliminary studies recently carried out (Angelillo et al. 1999; Bavestrello et al. 2009; Pedoni et. al. 2009), nothing is known about colony growth, population age, sexual structure, age at first maturity, reproductive output, recruitment, and natural mortality of these populations. It is worth to recall that Rivoire (Rivoire 1991) reported a wide mortality of unknown origin in the red coral populations living between 80 and 200 meter depth in the Western Ligurian Sea and in the Gulf of Lion (Rivoire 1991).

One of the few papers dealing with deep-dwelling populations was published in 2008 by the Spanish research team working on red coral at Barcelona ICM by Rossi and German and Italian co-workers (Rossi et al. 2008). This study presents the first quantitative data gathered by a ROV survey on the spatial distribution and structure of a population extending between 50 (common SCUBA limits) and 230 m depth, and compared it with the shallow populations previously studied in the same area. The findings suggest a lower exploitation level in deep-dwelling populations at Cap de Creus.

Increased Knowledge on the Bathymetric Distribution Range of Red Coral and its Implications for Conservation and Management

Recently (Costantini et al. 2009; Taviani et al. in this volume), the bathymetric limits of red coral distribution have been greatly expanded: from 350 to 600-800 meter depth. As no commercial exploitation never occurred at this depths, there is a large area in which red coral lives still unexploited (Taviani et. al. in this volume).

Three different depths and exploitation levels can be thus distinguished: a shallow one (20–50 m.), in which red coral has been (over)harvested in the past, and in some area (like Cap de Creus, Spain) still nowadays, a second, deeper one (between 60–150 m) in which the main part of commercial harvesting occurs and a third one (from 150 to 600 m and more) in which deepest populations have never been harvested (until now). Such deepest populations too, if undisturbed, could represent a pool of sure breeders for the species. Both shallow and deepest populations must be protected.

Tools for a Sustainable Management of Red Coral Harvesting

In order to simulate population growth and exploitation, some population models have been applied to red coral; in particular, two different kind of models have been applied: Beverton and Holt model (or “yield per recruit model;” Beverton and Holt 1957; Garcia-Rodriquez and Massò 1986; Grigg 1984, 2001; Tsounis et al. 2007; Goffredo and Lasker 2008), and life-history table and Leslie-Lewis matrix model (a discrete, age-structured demographic model; Abbiati et al. 1992; Santangelo et al. 1993a; Ebert 1999; Caswell 2001; Santangelo et al. 2007; Bramanti et al. 2009). Moreover a “rotating harvesting strategy,” on which basis exploitation in different countries should be regulated according to colony growth rate (biomass), was proposed by Caddy (Caddy 1989, 1993). The objective of Caddy’s management proposal was to define harvesting strategies which take into account the time intervals since the resource was last harvested and the time the resource needs to reach the optimum yield. Caddy calculated, on the basis of the Beverton and Holt model, the best yield in biomass (the best colony age for harvesting), integrating it in a “rotating harvesting plan” at a Mediterranean spatial scale. The limits of rotating harvesting are due to the difficulty to apply such a model at a Mediterranean level, coordinating fishing enforcement for many years (10–15) in several different countries and to the characteristics of the Beverton and Holt models, as will be explained in the following paragraph. A rotating harvesting strategy could be successfully applied to red coral management, but it needs to be applied at a local level to single populations (Abbiati et al. in this volume).

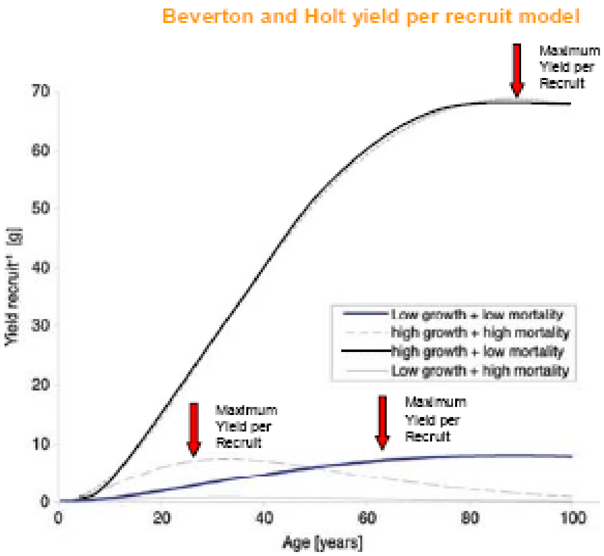


Fig. 8. Yield per recruit curve for the Cataluña *C. rubrum* population (Modified from Tsounis et al. 2007, 2009). Different ages of maximum yield have been found according to different growth and mortality rates of an initial cohort. A maximum yield after 96 years was reached when a colony growth rate overestimating growth, (Garcia-Rodriquez and Massò 1986; Marschall et al. 2004) was applied.

Virtues and Limits of the Beverton and Holt Models

- Beverton and Holt "*yield per recruit"* models are based on: **population biomass growth** (weight) and **mortality**. They aim at finding a trade-off between biomass growth of an initial cohort (first age class) and the loss of biomass over time due to mortality: there will be a time at which the difference between yield growth and mortality loss (in biomass) will reach its maximal value.
- One of the main advantages is that **data can be collected only once** (in a single harvesting/sampling season).
- Such "simple" models could be useful to initiate a harvest regime, but the effects of reproduction and density-dependence of biomass growth, which play a major role on the growth of a real population, are not included in the model; moreover the original model assumes that all the colonies above a determined (age) size will be completely removed (Goffredo and Lasker 2008).
- Beverton and Holt models have been recently applied to the Cataluña red coral population by Tsounis (Tsounis et al. 2007). Tsounis applied to the model different growth rates and different mortality rates gathered from the literature obtaining the times of maximum yield reported above (Fig. 8).

New Tools for Red Coral Management and Conservation: The Demographic Approach

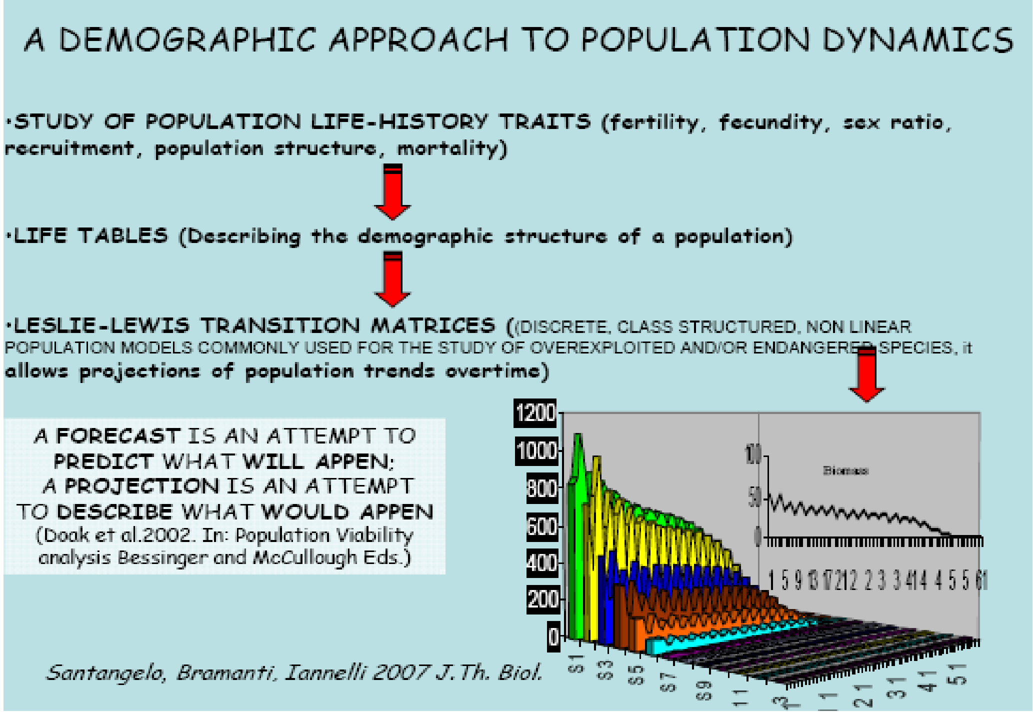
More recently, red coral research was addressed towards the study of population structure and dynamics by means of demographic models (Santangelo et al. 2004, 2007; Bramanti et al. 2009). This last approach, widely applied in Conservation Ecology (Dobson 1998; Ebert 1999; Fujiwara and Caswell 2001), will supply the tools to match harvesting to population growth rate fostering both conservation and rational management of the populations of this precious species, if sound data on deep-dwelling populations will be at least gathered and enforcement will be really applied at local population level. The compilation of life-history tables greatly helped to foster the progression of species and populations towards survival; they supply the drastic data on population structure and demography (density, number of colonies in each size/age class, reproductive output, mortality). These data are then included in an algebraic matrix (Leslie-Lewis transition Matrix; Caswell 2001), which allows to project population trends overtime (Fig. 9).

The main advantages of these models are:

1. Contrary to Beverton and Holt models, the contribution of each cohort to population growth rate by reproduction (and survival) is now included into the model.
2. The model allows to simulate every possible variation in harvesting intensity and a selective harvesting affecting different age classes in a different way.
3. Demographic models too (as Beverton and Holt models) can be applied to a data set collected only once (in a single harvesting/sampling season, under the assumption of population steady-state).

To apply demographic models, based on Leslie-Lewis transition matrixes to deep-dwelling populations (those having the major economic value), it needs to be known:

- Colony growth rate
- Population size-age structure and density
- Reproductive output and mortality rates (mortality can be gathered by the population size-age structure, under the assumption of population steady-state)



A DEMOGRAPHIC APPROACH TO POPULATION DYNAMICS

•**STUDY OF POPULATION LIFE-HISTORY TRAITS** (fertility, fecundity, sex ratio, recruitment, population structure, mortality)

•**LIFE TABLES** (Describing the demographic structure of a population)

•**LESLIE-LEWIS TRANSITION MATRICES** ((DISCRETE, CLASS STRUCTURED, NON LINEAR POPULATION MODELS COMMONLY USED FOR THE STUDY OF OVEREXPLOITED AND/OR ENDANGERED SPECIES, it allows projections of population trends overtime)

A **FORECAST** IS AN ATTEMPT TO **PREDICT** WHAT **WILL APPEN**;
A **PROJECTION** IS AN ATTEMPT TO **DESCRIBE** WHAT **WOULD APPEN**
(Doak et al.2002. In: Population Viability analysis Bessinger and McCullough Eds.)

Santangelo, Bramanti, Iannelli 2007 J.Th. Biol.

Fig. 9. Sketch of the steps for demographic modelling. In the simulation different colors represent different age classes.

This last approach, widely applied in Conservation Ecology, will supply the tools to match harvesting to population growth rate fostering both conservation and rational management of the populations of this precious species.

Some Conclusive Remarks

From this condensed revision of the scientific research on the Mediterranean red coral *Corallium rubrum,* some focal points can be stressed. There is no real risk of global extinction for the species, due to its early sexual maturity, wide bathymetric and geographic distribution, comprehensive of several, connected populations (Monte-Luna et al. 2007). Nevertheless, an increased frequency of anomalous mortality events, superimposed on overharvested shallow-water populations, could lead some of them to local extinction. Moreover, economic extinctions of some populations (i.e. overharvested populations that cannot be further harvested for a long while) have happened and will happen in the future.

Corallium fishing in the Mediterranean and in the Pacific are completely different. Contrary to Pacific species, which are harvested mainly by trawling, the Mediterranean *Corallium rubrum* is harvested only by SCUBA diving and by pick. As pick-harvesting could be highly selective, culling of larger-older colonies within the populations can be planned. Recent development of demographic models for age-structured populations supply the tolls to plan sustainable harvesting matching exploitation to population growth rates (Grigg 2001; and in this volume).

Rotating harvesting strategies, suggested in the past by Caddy (Caddy in FAO 1998) could be successfully applied at regional or national scale.

Shallow-water populations have been and are overharvested. The Cap de Creus shallow population has been and is nowadays heavily harvested; moreover, harvesting rates recently increased after the proposal of inclusion of red coral in CITES Appendix-II was known by poachers. These populations, of limited economic value, should be protected. Similarly, the deepest red coral populations, recently discovered, should remain unharvested.

Deep-dwelling populations (those living between 60 and 150 meter depth), having a higher economic value, should be harvested following selective exploitation plans based on sound demographic data. As there is no knowledge on the demographic features of these populations (i.e. colony growth rate, age structure, reproduction and reproductive output, genetic structure), research efforts must be addressed towards such populations and common research projects must be fostered and funded at an European and Mediterranean level.

A demographic approach, based on life tables and transition matrices, could supply the tools to match harvesting to population growth rate fostering both conservation and rational management of this precious species, if sound data on deep-dwelling populations will be at least gathered and enforcement will be really applied at local population level.

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IDENTIFYING POPULATION DECLINE IN *CORALLIUM RUBRUM* BY USING HISTORICAL INFORMATION

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Introduction

Corallium rubrum has been fished for 5000 years, and since the 1800s its fishery reached an industrial scale with several hundred boats dredging the Mediterranean for this valuable resource of the jewelry industry. Dramatic yield declines occurred in the 1980s, and the second FAO ad hoc *Corallium rubrum* consultation in 1988 concluded that the species was already overharvested (FAO 1988; Cognetti 1989). Subsequent research confirmed not only that the yields had dropped, but throughout the Mediterranean the known red coral populations in diving range consisted entirely of much smaller colonies (ca. 3 cm on average) than the maximum size of the species (more than 50 cm) (Garcia Rodriguez and Massó 1986; Santangelo et al. 1993; Santangelo and Abbiati 2001; Garrabou and Harmelin 2002; Santangelo et al. 2007; Tsounis et al. 2007).

Despite of these studies, recent efforts to improve its management and conservation were slowed down by discussions over the extent of the decline, as management or conservation organs like FAO and CITES need to quantify population decline precisely. However, in the case of precious corals, a precise estimate will probably never be possible, since ecologists have to deal with a lack of a natural baseline. In other words, we cannot know the population structure of undisturbed populations, because the first studies on its population status have been conducted only in recent decades, while fishing began five millennia ago (Tescione 1973). This makes it difficult, but not impossible, to identify decline and propose more effective management measures.

In order to provide the best possible estimate of population trends, we briefly summarize the most important historical information that is scattered among grey literature and has therefore been unavailable to ecosystem managers looking at scientific texts. It is the only information available that allows an evaluation of the early state of *Corallium rubrum* populations in the Mediterranean Sea. The purpose of this summary is therefore not to review recent scientific studies and their application in precious coral management. For a detailed review of precious coral fisheries please refer to Tsounis et al. (2010). This summary attempts to briefly present a historical frame that may serve to understand the extent of fishing impact on *C. rubrum* populations, and put the modern studies into context.

The Two Different Fractions of Corals Harvested

a) Dredging

Information from the period when dredging was still allowed is scarce, but data compiled in Tescione (1973) show fluctuating yields of up to several metric tons per year throughout centuries. Fortunately, the FAO started compiling continuous yield statistics in the 1970s, which was early enough to document the depletion of the coral fraction accessible to dredges: The data show a dramatic decline beginning in about 1980 which reached its low point *before* Spain prohibited dredging in its waters in 1986 (Cognetti 1989). Sardinia followed this example soon afterwards (Cognetti 1989), and in 1994 the EU banned dredging. It is important to understand that this decline occurred before dredging was banned or fishing effort decreased, and is therefore a strong indication that dredging had removed all coral that grew in exposed positions. In fact, most fisheries experienced a similar decline due to the industrialization after the 2nd world war, and show similar decline curves (Pauly 2002).

Furthermore, instead of neglecting the structure of coral habitat and its relation to the fishery, we can identify two different coral fractions within the populations. These fractions are determined by their position in their habitat, which affects their accessibility to different harvesting methods: Coral may grow in an exposed position on top of the substrate, or rather cryptic in crevices, cave entrances and overhangs. Dredges however only access the exposed part of the population. We postulate therefore that dredging with the "Saint Andrews Cross" and the "Barra Italiana" removed the vast majority of exposed coral on the rocks, down to the limit of 100 – 200 m, as evidenced by the above mentioned collapse. The recovery of the populations began only in the late 80s/early 90s, so if they immediately re-colonized the free habitat, today the colonies may have reached 25% of the maximum size (extrapolating linear growth in relation to *C. rubrum* maximum lifespan of ca. 100 years). However, there are indications that other deep coral species grow much faster than red coral (Orejas et al., submitted), and may have occupied habitat freed up by dredging (Rossi et al. 2008).

We furthermore argue that intensive dredging over centuries may thus well be the reason that *C. rubrum* appears to grow a cryptic, sciafillic species. It is found in shady places only, but light levels and other abiotic factors have not been found to affect larvae behavior or survival in both, larvae and adults (Weinberg 1987, 1979). Historical information reports that red coral was present at only few meters depth (Tescione 1973), which has been confirmed in recent surveys, where (small) colonies were found at 7.5 m depth at Cap de Creus (Tsounis et al. 2006).

b) Scuba Diving

A second phase of the industrial fishery began in the 1950s with the invention of the Aqualung. SCUBA divers were able to access the second fraction of colonies, hidden in caves, overhangs and crevices that dredges cannot reach. Historical information from this period of coral fishing reveals that even a surprisingly small fishing effort allowed extremely high yield initially: The first SCUBA harvester was the sport diver Leonardo Fusco, who became a professional coral diver in 1954 after discovering red coral while free diving in Palinuro near Naples (Liverino 1983). In his first season he harvested 250 kg. Quickly the small circle of SCUBA pioneers in Italy (Guido Garibaldi, Alberto Novelli, and Ennio Falco) became coral fishermen and discovered further banks in Sardinia, Elba, and Corsica (Roghi 1966). The fishery evolved similarly at the Costa Brava (Spain): At Cap de Creus, the diver George Kontos began to fish coral in the 1950s, but also other red coral fishermen (e.g. the Boix brothers or Narcís Flaqué) collected huge amounts of red coral at the Montgrí Coast and the Medas Islands. It has been reported that in some cases, they collected all large colonies from a cave of almost 100 meters length in less than one week (Plujà, pers. com.). These caves contain only very few tiny *C. rubrum* branches today (pers. obs.).

One of the most spectacular and valuable source of *C. rubrum* was discovered at that time in the legendary Capo Caccia Cavern in Sardinia at a depth of 37 m (Liverino 1983). Liverino (1983) reports that in 1956 divers worked at 30 – 35 m, but in 1958 at 40 – 45 m. By 1964 an ever growing group of divers was working at depths of 72 m, and inevitably a long list of accidents were the result of the spreading 'coral fever' among the young divers (Liverino 1983). Leonardo Fusco reported that in 1955 he harvested at 60 m in the Gulf of Naples but in 1964 he had to descend to 90 m. Similarly, the pioneer Fausto Zoboli is reported to have said that he worked as one of the first at 60 m in 1964 (near Rome), while in 1971 he was forced to work at 100 m in Alghero, Sardinia (Liverino 1983). Others similarly documented that by the late 1950s divers in France and Italy already had to descend to depths of 80 m, and at times to even more than 100 m, to find coral (Galasso 2000). In 1974 helium based mixed gas diving techniques developed by the French ocean engineering company COMEX started to spread among coral divers, permitting them to work at 120 m for 20 min without the dangers of nitrogen narcosis (Liverino 1983).

The 14 mile long Scherchi Channel from Sicily to Tunisia was regarded as a coral 'el dorado,' with 80 divers from Italy, France, and Spain harvesting 70 – 120 t in 1978, starting at 60 m and gradually working their way down to 130 m. This submarine canyon was described as an oasis for marine fauna and flora, uncontaminated and exceptionally rich in rare species. In 1979 there were 366 boats at work (283 of them were registered in Italy) and 150 divers (Liverino 1983). It thus appears that the operating depth of the divers reached a limit of SCUBA in the late 1970s/early 1980s, at about the time when the yields collapsed. We therefore conclude that the second fraction of corals (especially large colonies) was largely depleted down to 130 m in the early 1980s.

Furthermore, the management measures (or their degree of efficiency) that led to this situation are more or less still in place today, since they have not been significantly revised during the last decades. Thus the trend of depletion of 35 – 40 m habitats in the 1950s, then intermediate depths at 60 – 70 m, and today's harvesting at 90 – 150 m depth, will continue deeper and deeper if management is not fundamentally revised.

The fact that enormous amounts of coral were harvested initially by a small number of divers implies that large colonies existed in shallow water. The extremely large annual yield of several hundred tons until the 1980s implies another significant conclusion in the case of such a slow growing species. If we extrapolate from today's young populations with today's relatively low yields, to determine what kind of populations afforded several hundred tons of annual yield for decades, it becomes unquestionable that vast *C. rubrum* "red forests" disappeared before they could be documented. These tons of *C. rubrum* were creating a habitat complexity that must have been comparable to coral reefs. The extremely slow growth rate of *C. rubrum* (Marschal et al. 2004) lets us conclude that the populations cannot have recovered yet from such an intensive fishery.

Trends of Colony Size through Time

The above conclusions are furthermore confirmed by comparisons of the size of the corals in time. The size of the largest coral colonies that can be found in a population is a good descriptor for the degree of the fishing pressure they are exposed to, as the fishery is size specific. Furthermore, historical reports on the size of corals in their habitat exist, and enable us to make comparisons: In the 1960s corals as large as a man's palm could still be found in 35 m depth in Cap de Creus in Spain (J.G. Harmelin and A. Plujà, pers. com.), whereas today this size of colony can only be found in marine protected areas, and only beyond safe SCUBA limits (pers. obs.).

In other precious coral populations, such as black coral in Hawaii and New Zealand, we know that a considerable percentage of old, large individuals exist in undisturbed populations (Grange 1997; Grigg 2001). The fraction of old colonies in a population is a function of the natural mortality (Grigg 1976). Like most precious coral species, *C. rubrum* is characterized by low mortality (Garrabou and Harmelin 2002), and we can therefore expect large colonies in undisturbed populations. In fact, video footage from coral divers in Sardinia (90 m depth) confirms that large corals of more than 45 cm are frequent in undisturbed or moderately harvested populations (M. Scarpati, pers. com.).

In contrast to these few fairly well preserved populations, surveys in Spain show that the average size of shallow water populations is ca. 3 cm of height, while deep populations reach 10 – 16 cm (Rossi et al. 2008). Most data in Italy and France originate from the Marine Protected Area in Calafuria, while unprotected populations are hardly studied (the difficulty of finding unprotected coral in diving range is the reason).

Deep populations are slightly larger, as they are recovering since 1986, but still only ca. 25% of the potential maximum size. Finally, analyzing the catch of poachers working in shallow water (less than 70 m) confirms that they are not able to find any large colonies either (Tsounis et al. 2007). Shallow water populations are therefore overexploited. It is alarming that their young populations do not appear to have the resilience to survive a combination of anthropogenic impact and natural catastrophes (Santangelo et al. 2007; Bruckner 2009).

Remarkably, we can deduce a considerable decline without the existence of abundance data, which are less useful in these species (Tsounis et al. 2010). Size structure immediately reflects overfishing, since coral fishing is always size specific, targeting large individuals first. Considering the biomass removed before the 1980s, the gradually increasing operating depths and the small colonies that remain in overharvested stocks, we have no doubts that this species meets any criteria for decline. The data imply that the biomass present today is only a minute fraction of the natural state some centuries ago, while the trend is continuing decline.

Implications for Management

This summary demonstrates that a century ago the Mediterranean Sea was still inhabited by red coral populations that can be described as underwater forests. Corals in general are regarded as ecosystem engineers that increase biomass and biodiversity of their ecosystem. In the case of deep corals, they are assumed to be fish nurseries, and management plans in the US do not need to prove this in order to conserve deep coral habitat (Magnuson-Stevens Fishery Conservation and Management Act). However, during the recent consultation-workshops the focus has been on single species extinction and local extinction rather than using a holistic habitat conservation approach. It should be stressed that the habitat function of large *C. rubrum* colonies needs to be taken into consideration. Marine protected areas in the Mediterranean are rather small and not all of them contain red coral populations. Also, the protection started only very recently, just a few decades ago, so that their populations are still young and recovering.

The implication of the above for sound management starts with increased minimum size limits and decreased yield quotas. Above all, poaching must be stopped and yields of legal divers better controlled. Furthermore, rotation harvest schemes should be abandoned as, even at small scale, populations and patches should not be harvested in a way that completely depletes the largest size class (Tsounis et al. 2010). Populations consisting of only young colonies recover slower, and do not provide their ecological services as fish nurseries. It is known for example, that another Mediterranean precious coral (*Gerardia* sp.) is crucial to several shark species as they lay their eggs in its branches (Öztürk, pers. com.). Care must also be taken to not interrupt continuous populations, as this can interrupt the gene flow (Costantini et al. 2007).

The above arguments lead to the conclusion that populations with only small, unbranched colonies should be allowed to recover, instead of continuing to be harvested. Unfortunately this is the case in all known shallow water populations, so that a ban of coral fishing in shallow water must be recommended. Industry representatives characterized today's shallow water populations as having little commercial value (Ciro Condito, pers. com.).

Finding a way to implement these conclusions and install new management plans is a challenge however, as twenty years ago a FAO workshop already reached the same conclusions that we reached today: *C. rubrum* is overharvested, and a cross-national management plan should be created under the responsibility of the General Fishery Commission of the Mediterranean (GFCM) (Cognetti 1988).

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MULTIDISCIPLINARY DATA ON THE STATUS OF RED CORAL (*CORALLIUM RUBRUM*) RESOURCE IN SARDINIAN SEAS (CENTRAL WESTERN MEDITERRANEAN).

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Abstract

In this study, data gathered from several fields are presented in order to give an historical and actual picture of the status of the red coral resource in Sardinian seas. A review of historical data is provided and the first picture of spatial distribution and genetic structure of red coral populations in deep waters of Sardinian seas (below 80 meters) are illustrated. The historical analysis shows that no variation occurred in mean yields/boats in the last four centuries, suggesting that the amount of red coral in Sardinian seas is not decreased with time, differently from what observed in other parts of the Mediterranean. Analyses carried out from 2007 to 2008, through ROV surveys and samplings of entire colonies, highlight that the populations show dimensions (> 80% with maximum height > 6 cm) able to ensure the reproductive potential needed for their survival. Finally, strong genetic heterogeneity was measured between Sardinian samples and corals from other western Mediterranean localities (e.g. Corsica and Sicily). High level of genetic differentiation was found even among Sardinian samples, over different spatial scales from hundreds to less than 1 km. In conclusion, the strong genetic structuring found, confirms the need for management plans and conservation programs to be locally defined. Moreover, all historical, population structure and genetic data coherently indicate that the harvesting effort should not be increased, and the actual Sardinian management plan, enacted by the regional administration, seems to be effective in protecting the resource from overexploitation. However, the strict respect of this regulation is binding to ensure an optimal balance between harvesting and reproductive rate and hence allow the long term persistence of the species.

Introduction

Corallium rubrum (L. 1758) is one of the components of the Mediterranean coralligenous community (Sarà 1973). Because of their high economic value, the red coral has long been heavily exploited in the Mediterranean Sea since ancient times (Morel et al. 2000; Santangelo et al. 1993; Santangelo and Abbiati 2001). Harvesting on an industrial scale began as early as in the Neolithic age (Grigg 1977). During the industrialization period the stocks declined and the catches dropped dramatically in 1976–1984 (FAO 1984, 1988). Nonetheless, this resource is still present in great quantity in the Northwestern Mediterranean basin (Torrents et al. 2005), where it is still successfully harvested today (FAO 1988).

Sardinia (Central Western Mediterranean) has always been very rich in red coral banks and the main of these are – and were – located mainly in the Western part of the island, almost with no interruption from North to South. A documentation of these banks, most of which are still exploited at present, can be seen in the maps of an old paper of Parona (1883). Unofficial information let us know that Sardinian red corals were already exploited in the 13th century by Provençal fishermen (Doneddu and Fiori 2003). The first official document on red coral fishing dates back to the early 14th century (Zanetti 1946). It is reported that the Maritime Republic of Pisa exploited the Southern part of Sardinia, while Maritime Republic of Genoa the Northern one. In this times, Alghero, in the Northern part, is the leading town, due to its very rich and high quality coral banks. In 1354, Alghero was conquered by Catalans who exploited its coral banks. Later on, in the 16th century, Sardinian banks started to be exploited by people form Campania (Torre del Greco) who became later on the main harvester.

A lot has changed with time in harvesting red coral. First of all the catch methods: while in previous centuries the gear used was the "ingegno," a gear generally made by a wooden cross with some weight or rake and some net, at present the harvesting of the coral is made by professional coral fishermen who dive to find the coral banks and pick it, generally helped by a ROV. These are two very different way of catch coral which determine a very different effort on the resource. Only the latter can select the colonies to be harvested thus leaving smaller ones alive. The change of the catch method has been driven by management advice: since 1979, in Sardinia the harvest is regulated by a detailed regional law, redacted with the strict collaboration of technician, local administrators and fisherman (Regional law n. 59, 5 July 1979). Today, the harvesting, practiced only manually, is regulated annually by the imposition of a period of harvesting (generally from May to September/October), by the issue of a limited number of licenses and by the definition of size and weight limits (basal diameter < 10 mm with a tolerance of 20%; maximum harvesting of 2.5 kg per dive/day) (Regional law N.16/V, 22 May 2006). Since 2008, the fishery above 80 m depth is also forbidden (Regional law N.1409/Dec A/49, 11 June 2008).

Generally, it is stressed that strategies to foster conservation and management need to be based on a sound knowledge of population demographic features and life history traits (Bramanti et al. 2007). Some studies on demography (Santangelo and Abbiati 2001; Garrabou and Harmelin 2002), reproduction patterns (Vighi 1972; Santangelo et al. 2003; Torrents et al. 2005, Tsounis et al. 2006a), recruitment, settlement and mortality (Garrabou and Harmelin 2002; Bramanti et al 2003, 2005, 2007), growth (Marschal et al. 2004; Bramanti et al. 2005), distribution and space competition (Giannini et al. 2003), feeding ecology (Tsounis et al. 2006c; Picciano and Ferrier-Pages 2007) have contributed to know the ecology of the species essentially situated in shallow waters. Little is known on its distribution and population structure below 50 m depth (Tsounis et al. 2007), because of the logistical difficulty of working at greater depths (Genin et al. 1992). The understanding and knowledge of the distribution and population structure along its complete depth range, the magnitude and direction of the exchange of individuals among geographically separated populations are fundamental to understand population dynamics, to forecast how corals are likely to recover from disturbance events both of natural and anthropogenic origin and hence to plan a realistic management for a species such as *Corallium rubrum* (Rossi et al. 2008).

An indirect measure of reproductive population connectivity can be obtained following a genetic approach. The results of early genetic studies on red coral populations, based on allozymes, indicate that Mediterranean *C. rubrum* populations are genetically heterogeneous, and provide evidence of some breeding isolation and population sub-structuring among samples (Abbiati et al. 1993). More recently, microsatellite data indicate that effective larval dispersal in red coral in the Northwestern Mediterranean Sea is highly restricted (Costantini et al. 2007a, 2007b).

The totality of the over-mentioned genetic studies examined shallow waters colonies (mainly up to 30 m of depth). Only a very recent paper provide the genetic characterization of 12 fragments from live red coral colonies collected at the exceptional depths of ca. 600–800 m: these were found to be slightly different, suggesting the possible occurrence of genetic isolation among shallow and deep-water populations (Costantini et al. 2009). However, given the exiguity of colonies analyzed further samplings of red coral deep colonies are needed to confirm these results.

In this paper we reported data gathered from several fields in order to give an historical and actual picture of the status of the red coral resource in a part of Central western Mediterranean, Sardinian seas. A review of historical data (from early 1700 until now) is provided and the first picture of spatial distribution and genetic structure of red coral populations in deep waters of Sardinian seas (below 80 meters) are illustrated.

Materials and Methods

Historical Data

To assess the evolution of the red coral resource in Sardinia from 1978 to 2005, yearly landings data (kg) from FAO fisheries statistics and CPUE (Catches per Unit of Effort, kg) were analyzed. The CPUE here was obtained as the kg of the harvested coral divided by the number of boats (referred to the years in which the "ingegno" was towed) or the number of divers (referred to the years after 1989 when only divers could harvest red coral in Sardinia). CPUE then represents the yearly mean of the red coral fished for unit of effort.

Statistical trends were evaluated with the Spearman rank test (Zar 1999).

Extensive Survey

The Extensive ROV survey was carried out between 2007 and 2008 at depths below 80 meters by professional divers to identify locations of *Corallium rubrum* colonies in the Sardinian Sea and to identify the size structure of colonies. The main objective of this survey was in fact to compile an extensive set of data without causing any destruction whatsoever to the colonies themselves.

This part of the study consisted of an exploration made by a 'Velociraptor' type ROV (Remotely Operated Vehicles). This is a scuba vehicle run by cave, equipped with an autonomous propulsion system and a Sony HDV colour camcorder, which lets vehicle machinist to stay outside while the ROV works suspended in mid-water. The vehicle can develop a maximum of 3-4 knot speed and is composed of an exterior control unit and an umbilical cave 250 m long made in 'Kevlar' fibre that carries current and control signals.

During the monitoring, images, gotten by ROV, were obtained in analogical format, were passed on VHS support by a video recorder, and then converted into digital format by the auxiliary of a DVD recorder. Video transect positioning and distance covered by ROV were relieved by a Global Positioning System (GPS). An echo-sounder, put on the boat, provided bathymetric data.

A total of 33 transects were performed and 19307 colonies were examined (Table 1). In each colony the height was measured, using a rod of 2 cm as the reference size, from a point two centimeters from the base of the stem to the furthest tips of the longest branches (Tsounis et al. 2006a), with the image analysis program, tpsdDig 2 (Rohlf 2005). Finally all colonies were grouped in six classes according to height with five centimeters of difference between one group and the next (I, 0-5 cm; II, 5-10 cm; III, 10-15 cm; IV, 15-20 cm; V, 20-25 cm; VI, > 25 cm). The data have been analyzed according to the coasts from near to which samples were taken (Fig. 1). These coasts are: the Northern coast in the areas of Santa Teresa and Castelsardo, where samples come from depths of between 84 and 93 meters; the Northwestern coast in the areas of Bosa and Alghero, where samples come from depths of from 80 to a 122 meters; the Central-Western coast in the area of Oristano, samples here come from one 113 to one 115 meters down; and the Southwestern coast in the area of Carloforte, harvested colonies from this site were brought up from depths of between 85 and 107 meters. The data relative to each zone are compared by the G method (Zar 1999).

Genetic Analyses

Samples were gathered from the three main islands of the Western Mediterranean basin: Sicily, Corse, and Sardinia. Most of the samples (n=7) were collected off Sardinian coasts in fall 2008 and summer 2009 from deep waters (from 84 up to 121 m of depth). Sardinian samples were harvested in three main areas: the Northern coast (Santa Teresa di Gallura and Castelsardo), the Central Western coast (Bosa and Oristano) and the Southwestern coast (Carloforte) (Fig. 1). Two further samples were collected: one off Corse and the other one in Sicilian waters. At each location, branch fragments from a min of 20 to a max of 40 individual colonies were picked by professional scuba divers; corals were then preserved in 90% ethanol. Total genomic DNA was extracted from polyps using the NucleoSpin® Tissue (Macherey-Nagel). Five microsatellite loci (COR9, COR15, COR46, COR48, and COR58m) were amplified following the PCR conditions described in Costantini and Abbiati (2006). Allele sizing was scored using the software Genemarker v1.75 (Softgenetics).

Allelic diversity was measured through estimates of the Number of alleles (Na), the Allelic richness (Ra), the mean observed heterozygosity (Ho), and the unbiased expected heterozygosity (UHe) using the software GenAlEx v.6.2 (Smouse et al. 2008), Genepop v.4.0 (Rousset 2007) and Fstat 2.9.3. Genepop was also used to test genotypic deviations from Hardy–Weinberg Equilibrium (HWE) measured as heterozygosity deficiency, both for each locus and globally (Markov chain 1000 dememorization steps, 100 batches and 1000 iterations per batch). Significance levels were adjusted with sequential Bonferroni corrections for multiple tests using the program SGoF (Carvajal-Rodriguez et al. 2009). To determine whether null alleles were present, the FreeNa package (Chapuis and Estoup 2007) was used: a maximum-likelihood estimate was calculated for the frequency of null alleles according to Dempster et al. (1977). Differentiation of allele frequencies within and among samples was estimated by an AMOVA analysis and the calculation of a Fixation index (FST) with Arlequin version 3.1 (Excoffier et al. 2005). The significance of FST values were tested using a nonparametric Monte Carlo approach (100000 permutations). Significance levels for pairwise FST were adjusted with sequential Bonferroni corrections. The software Genetix (Belkir et al. 1996) was used to construct a factorial component analysis (FCA) to visualize the genetic distance between all genotypes.

To estimate the effects of isolation-by-distance, we calculated the correlation between pairwise genetic differentiation (FST) and geographic distance, measured as the direct sea path between sampling locations, using a Mantel-test implemented in the software Isolation by Distance Web Service (IBDWS) http://ibdws.sdsu.edu/~ibdws/aboutibdws.html (Jensen et al. 2005).

Results

Historical Data

The analysis of FAO data show that from 1978 a marked decline in red coral landings can be observed (Fig. 2). This reduction resulted to be statistically significant (Spearman rank test: P-value < 0.01). However it doesn't necessarily reflect a decrease in the production: it can be often referable to the decrease in the number of boats and, as well, to the market demand.

The CPUE was then analyzed (Fig. 3). The greater values of CPUE are recorded in the period 1989–1994 (with a peak in 1992: 335.7 kg by diver). On the whole, these data are more regular and show the clear absence of a decreasing trend (Fig. 3). The absence of a statistical trend is highlighted by the Spearman test (P-value = 0.784).

Extensive Survey

The population structures of *Corallium rubrum* appeared statistically different (G = 449 d.f = 15 P < 0.005) among all four investigated areas.

On the Northern coast, from the 10 ROV transects carried out in Santa Teresa at depths of between 84 and 93 meters, populations that in the past were exposed to considerable human impact were identified. In this area there is in fact a near absolute dominance of small colonies, with 90% of the colonies falling into either one or the other of the smallest of the two height classes (I and II) (Tables 2-3). In particular, 49% of the colonies are in the height class of up to 5 cm, and 41% in the height class of from 5 to 10 cm. Our ROV survey has not revealed any colonies within this sector having heights in the classes of over 15 cm. In contrast, *Corallium rubrum* resources on the Northwestern coast are not just in a different state but in a better and healthier one. From the 18 transects carried out in the Bosa area in 2007, the highest values are observed for the medium-size colonies comprised in the two classes of from 10 to 15 cm in height and 15 to 20 cm in height, with percentages of over 30%. Only 5% of registered colonies pertain to smaller-height categories (Class I) (Tables 2-3). On the Central Western coast the structure of *C. rubrum* populations is seen to be similar to those on the Northwestern coast. Finally, an intermediate structure between that of the Northern and the Northwestern coasts has been found in the Carloforte area on the Southwestern coast. The 11 ROV transects carried out in 2007 and 2008 at depths of between 85 and 107 meters show that the colonies prevalently found here do not exceed 10 cm in height. Only 17% of all colonies in this sector belong to the height class of between 10 and 15 cm.

Genetic Analyses

A total of 185 individuals were successfully genotyped, and the 5 microsatellite loci were polymorphic across all samples. Estimators of genetic diversity varied through loci and populations, with variable levels of polymorphism in number of alleles (Na), allelic richness (Ra), observed heterozygosity (Ho), and unbiased expected heterozygosity (UHe) (Table 4). In all samples, the inbreeding coefficient FIS resulted to be significantly > 0, indicating that breeding among close relatives seems to occur, but with different levels of consanguinity in the different samples (Table 4). Significant heterozygosity deficiency was detected for almost all populations in the HWE tests (Table 4). Different frequencies of null alleles were computed in the five loci (Table 4).

Analysis of molecular variance (AMOVA) revealed that populations were genetically differentiated (Table 5). The AMOVA assigned 8.28% (FST = 0.083, P-value = 0) of the genetic variation to among-site variation, suggesting that recruitment is highly localized. This is supported by the indices of pairwise FST, ranging from 0.015 to 0.16, values statistically significantly > 0 (data not shown), and providing evidence of a genetic subdivision between almost all populations even when the allele frequencies corrected with FreeNa for technical artefacts (null alleles) were used.

When all Sardinian samples were gathered in one group and compared with the other samples, Corse and Sicily, placed in two other distinct groups, these 3 groups were significantly differentiated (Table 5). When Sardinian samples were split in three groups (north, central, and south groups) according to their geographical origin, the 5 groups (3 Sardinian groups + Sicily + Corse) were still significantly different (Table 5).

The FCA plot (Fig. 4) show three well defined and separated clouds: Sardinian corals, Corsican and Sicilian samples. Moreover, focusing on the Sardinian samples, three clusters, corresponding to colonies from the Northern, Central Western, and Southwestern coast are distinguishable. The genetic structuring found on geographical basis with the previous analysis is further confirmed by the Mantel test (r = 0.6087, p = 0.0060, Fig. 5) showing a significant correlation for the deep colonies between genetic and geographical distance.

Discussion and Conclusions

This study employs a multidisciplinary approach to define the status of red coral populations off the Sardinian coasts, an area that harbors the majority of the commercial banks still existent in the Mediterranean Sea. In fact, according to the FAO data, for the last 20 years Sardinia results to be the main producer of red coral in Mediterranean Sea; the annual yield jumped from 35% in 1983 to more than 95% of the total Italian yield in 1991. Since 2000, the Sardinian production reached about the 99% of the overall Italian yield of *C. rubrum*.

Historical landings data, population structure analysis, and genetic surveys were performed in order to gather useful information for a sustainable management of this precious resource.

As concerns the historical data, the analysis of both landings data and CPUE (Catches per Unit of Effort, kg) was performed. In fact, the use of landings data alone is neither adequate nor correct to assess a resource like red coral, strongly dependent on market demand. Variation in landings, in fact, cannot be referred only to a decrease in the population amount but also to a number of events not directly related to the increase in fishing effort. This can be the case when a crash in the market determines a reduction in the red coral demand.

This is an important statement, since landings data variation does not always reflect a decrease in the population amount. The CPUE is a better approach to study the red coral resource. It in fact gives an average of the amount of the red coral caught by single boats or diver, independently from how many boats were used to fish it and so also independently from how intense is the marked demand.

In particular, in Sardinia no statistical decrease of CPUE was observed in the analyzed years and the values obtained from 1978 to present are comparable. This should indicate that the resource has not been depleted and that, the regional laws, enacted from 1978, seem to work very well for a sustainable exploitation of the red coral.

Concerning the population structure analysis, the results indicate that, in general, *C. rubrum* resources present a "good ecological condition" in the Sardinian Sea. Only the North coast resources seem to have been more affected by human impact. It is for this very reason that the area has been closed to harvesting since 2007 (Regional law N. 16/V, 22 May 2006). In all the other areas we have investigated, the colonies show a mean height higher than 6 cm, a size defined by Tsounis et al. (2006a) as the measure at which the colonies reached the 100% of fertility and therefore able to ensure the reproductive potential needed for the survival of the populations. Even in the Northwestern coast the considerable density of adult colonies does not allow the settlement of new larvae so much that a higher harvesting pressure of commercial colonies could be permitted. Whereas size structure of *C. rubrum* resources is the key to the detecting of the species' response to environmental and anthropogenic factors and forms the basis for management decisions, from the gathered data we can definitely confirm that harvesting pressure has not to be increased in the Sardinian Sea. The actual regional law, which is based on three main measures —time of harvesting number of licenses and a harvest per dive/day — could in fact ensure sustainable management. Although, its strict respect should be binding to ensure an optimal balance between capacity of recovery and the harvesting.

Finally, this study utilized high resolution genetic markers, microsatellites loci, to indirectly measure reproductive population connectivity among populations of Mediterranean red coral *Corallium rubrum*. Extensive data on the genetic variability of the Mediterranean red coral deep colonies are presented here for the first time, contributing to fill a crucial knowledge gap.

The first finding of this study is that heterozygote deficits recorded in all populations; this situation was already reported for *C. rubrum* populations in other Mediterranean areas (Costantini et al. 2007a, 2007b) and it is commonly found in several other species of brooding and broadcasting hard corals and in marine species in general (Underwood et al. 2007, and reference therein).

Non-random mating within sites, a product of restricted dispersal of larvae, could be invoked as an explanation and may have contributed to the heterozygote deficiencies observed here. In fact, positive and significant FIS values were measured, indicating that breeding among close relatives seems to occur in red corals, but at different levels in the different locations, that is samples are characterized by different levels of consanguinity.

Furthermore, a limited mixing among all populations is evident as pairwise Fst values were significant, even for sites separated by less than a kilometer (e.g. Oristano113 and Oristano115 are separated by < 100 meters). Consequently, the interpretation is that dispersal over the scale of kilometers to tens of kilometers is sparse among deep coral populations.

AMOVA analyses confirmed a high genetic heterogeneity among red corals across the Western Mediterranean basin. When Sardinian samples are split in three groups (Northern, Central Western and Southwestern groups), these are genetically differentiated and all are different from Corse and Sicily samples (Table 5); the Mantel test confirms that the more distant are the samples the more divergent they are (Fig. 5).

All of these results together permit to gather useful information for management and conservation of this important resource. This study highlight the substantial genetic differentiation of red coral populations on the basis of their geographical, with limited connectivity and gene flow among the different areas and it gives strong support for locally defined management units and conservation plans strategies.

Table 1. Number of transects and examined colonies for each investigated area.

Investigated Area	n° transects	n° examined colonies
Nothern coast	9	11795
Northwestern coast	10	1423
Central Western coast	3	1496
Southwestern coast	11	4593
Total	**33**	**19307**

Table 2. Initial and final coordinates and relative main depth of ROV transect conducted in each zone.

Zone	Initial position of the transect	Final position of the transect	Depth (m)
Northern coast			
001COR07	41°17.182’ 009°01.448’	41°17.253’ 009°01.465’	90
002COR07	41°17.059’ 009°02.143’	41°17.170’ 009°02.130’	84
003COR07	41°14.225’ 009°05.105’	41°14.100’ 009°03.182’	90
004COR07	41°14.206’ 009°05.105’	41°14.312’ 009°05.196’	89
005COR07	41°13.547’ 008°57.173’	41°13.637’ 008°57.003’	90
006COR07	41°13.158’ 009°07.481’	41°13.236’ 009°07.371’	90
007COR07	41°11.240’ 008°55.181’	41°11.128’ 008°55.096’	93
008COR07	41°10.429’ 008°57.006’	41°10.530’ 008°56.935’	90
010COR07	41°10.048’ 008°55.106’	41°09.955’ 008°55.212’	89
Northwestern coast			
001COR07	40°24.117’ 008°15.302’	40°24.235’ 008°17.420’	121
002COR07	40°23.151’ 008°14.395’	40°23.299’ 008°14.235’	102
003COR07	40°22.424’ 008°14.523’	40°22.330’ 008°14.490’	85
007COR07	40°22.175’ 008°12.205’	40°22.098’ 008°12.312’	113
008COR07	40°21.185’ 008°13.445’	40°21.101’ 008°13.568’	109
009COR07	40°20.565’ 008°14.535’	40°20.472’ 008°14.612’	114
010COR07	40°20.335’ 008°13.295’	40°20.240’ 008°13.365’	80
013COR07	40°20.315’ 008°13.395’	40°20.431’ 008°13.256’	119
014COR07	40°19.581’ 008°15.488’	40°19.421’ 008°15.370’	90
018COR07	40°19.275’ 008°15.268’	40°19.169’ 008°15.180’	113
Central Western coast			
01COR08A	40°05.553’ 008°15.000’	40°05.467’ 008°14.921’	94
01COR08B	40°05.325’ 008°14.365’	40°05.241’ 008°14.451’	97
02COR08	40°05.286’ 008°14.524’	40°05.374’ 008°14.676’	106
Southwestern coast			
015COR07	39°18.224’ 008°19.220’	39°18.136’ 008°19.105’	104
016COR07	39°07.592’ 008°10.030’	39°07.431’ 008°09.899’	87
03SAN08	39°07.432’ 008°10.181’	39°07.345’ 008°10.274’	89
04SAN08	39°03.257’ 008°12.255’	39°03.364’ 008°12.331’	92
05SAN08B	39°09.323’ 008°07.979’	39°09.213’ 008°08.087’	107
05SAN08A	38°57.374’ 008°15.851’	38°57.487’ 008°15.943’	106
06-07SAN08	38°58.292’ 008°18.243’	38°58.383’ 008°18.141’	113
08SAN08	38°56.084’ 008°16.415’	38°56.172’ 008°16.326’	105
09SAN08	38°54.270’ 008°18.040’	38°54.369’ 008°18.129’	105
10SAN08	38°51.074’ 008°22.077’	38°51.164’ 008°22.163’	90
11SAN08	38°50.569’ 008°22.044’	38°50.456’ 008°22.157’	85

Table 3. Percentage (%) of the high classes of colonies harvested in each investigated coast.

	Height Classes					
Northern coast	**0_5**	**5_10**	**10_15**	**15_20**	**20_25**	**> 25**
001COR07	54	46	0	0	0	0
002COR07	66	24	7	0	3	0
003COR07	25	50	25	0	0	0
004COR07	48	36	16	0	0	0
005COR07	69	26	4	0	0	0
006COR07	29	71	0	0	0	0
007COR07	44	33	22	0	0	0
008COR07	35	53	12	0	0	0
010COR07	71	29	0	0	0	0
mean value	**49%**	**41%**	**10%**	**0%**	**0%**	**0%**
Northwestern coast	**0_5**	**5_10**	**10_15**	**15_20**	**20_25**	**> 25**
001COR07	10	24	29	28	8	0
002COR07	3	16	22	35	23	0
003COR07	4	19	42	32	3	0
007COR07	0	9	36	40	15	0
008COR07	1	9	52	34	3	0
009COR07	0	10	54	29	6	0
010COR07	1	16	28	41	13	1
013COR07	13	22	31	25	8	0
014COR07	7	35	29	21	7	0
018COR07	9	29	39	18	5	0
mean value	**5%**	**19%**	**36%**	**31%**	**9%**	**0%**
Central Western coast	**0_5**	**5_10**	**10_15**	**15_20**	**20_25**	**> 25**
01COR08A	4	14	41	39	2	0
01COR08B	1	14	44	40	1	0
02COR08	4	11	47	37	1	0
mean value	**3%**	**13%**	**44%**	**39%**	**1%**	**0%**
Southwestern coast	**0_5**	**5_10**	**10_15**	**15_20**	**20_25**	**> 25**
015COR07	13	33	37	15	2	0
016COR07	18	36	33	11	1	0
03SAN08	65	26	10	0	0	0
04SAN08	58	34	8	0	0	0
05SAN08B	39	42	16	2	0	0
05SAN08A	40	42	16	2	0	0
06-07SAN08	46	38	14	2	0	0
08SAN08	48	41	11	0	0	0
09SAN08	44	35	19	2	0	0
10SAN08	73	15	12	0	0	0
11SAN08	40	37	7	12	5	0
mean value	**44%**	**34%**	**17%**	**4%**	**1%**	**0%**

Table 4. Genetic population statistics.

Population	*Carloforte*	*Oristano113*	*Oristano115*	*Bosa90*	*Bosa120*	*Castelsardo*	*SantaTeresa*	*Corse Calvì*	*Sicily BancoTerribile*
Depth	85	113	115	90	121	84	93	90	90
N	18	20	14	20	20	30	33	14	16
Na	7.2	9.4	6.8	7.2	8	11.4	11	6.6	7.4
Ra	6.13	7.60	6.08	6.11	6.34	7.78	7.40	5.97	6.63
UHe	0.75	0.82	0.74	0.75	0.76	0.79	0.79	0.73	0.80
Ho	0.49	0.42	0.47	0.57	0.58	0.44	0.53	0.59	0.42
Fis	0.36*	0.31*	0.22*	0.45*	0.39*	0.45*	0.34*	0.2*	0.49*
Nu	0.15	0.15	0.12	0.21	0.20	0.21	0.17	0.12	0.20

n = number of samples; Na = number of alleles; Ra = allelic richness; UHe = unbiased expected heterozygosity; Ho = observed heterozygosity; Fis = Weir and Cockerham inbreeding coefficient; Nu = frequency of null alleles, according to Dempster et al. (1977). * indicates deviations from HWE, P < 0.001.

Table 5. Results from the AMOVA showing the partitioning of genetic variation among and within groups and individuals.

	Percentage of variation	**Fixation Indices**	**P-value**
1 group (all populations)			
Among populations	8.28%	Fst 0.083	0.00+0.00
3 Groups (Sardinia/Sicily/Corse)			
Among groups	6.78%	Fct 0.068	0.024+0.0015
Among populations within groups	5.70%	Fsc 0.061	0.00+0.00
Within populations	87.52%	Fst 0.12	0.00+0.00
5 Groups (Sardinia N/Sardinia CW/Sardinia SW/Sicily/Corse)			
Among groups	4.21%	Fct 0.042	0.0097±0.00098
Among populations within groups	4.85%	Fsc 0.05	0.00±0.00
Within populations	90.94%	Fst 0.0905	0.00±0.00

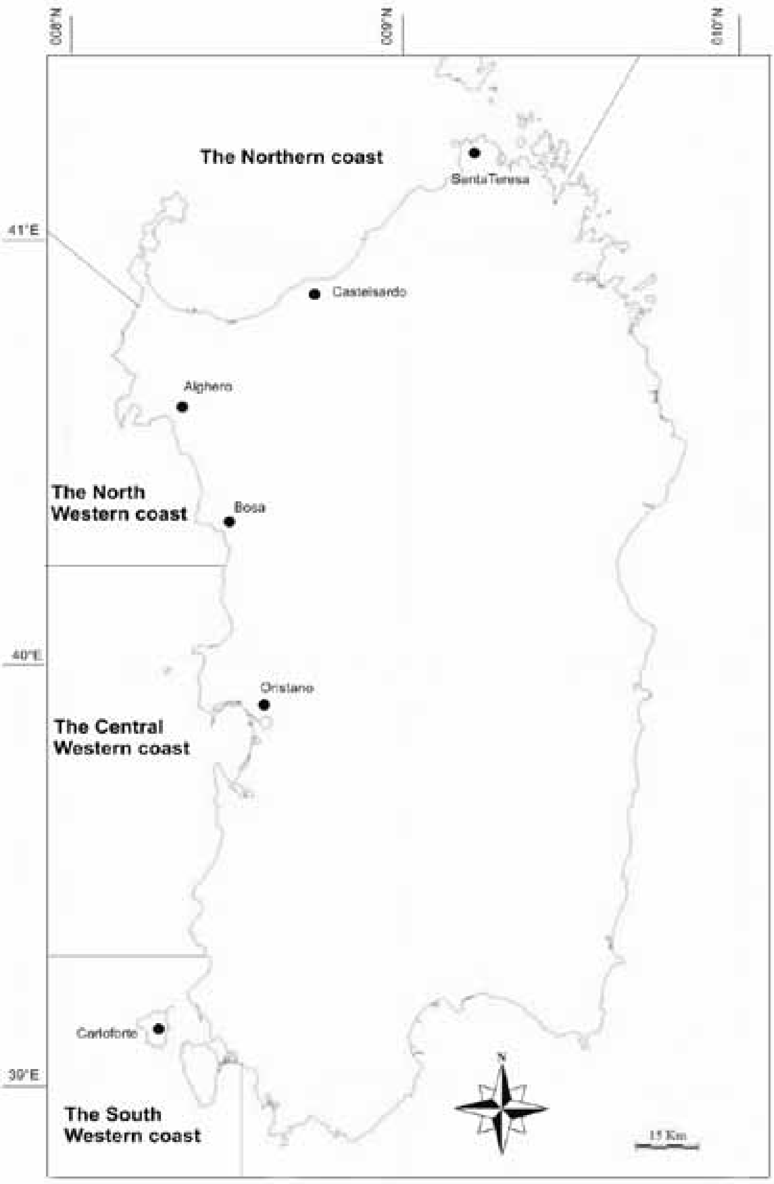

Fig. 1. Map of the investigated areas in Sardinian seas during the extensive ROV survey and genetic analyses.

Fig. 2. Sardinian landings data for the red coral, *Corallium rubrum,* from 1978 to 2005 (FAO sources).

Fig. 3. Catch per Unit of Effort data for the whole of Sardinia (1978-2005).

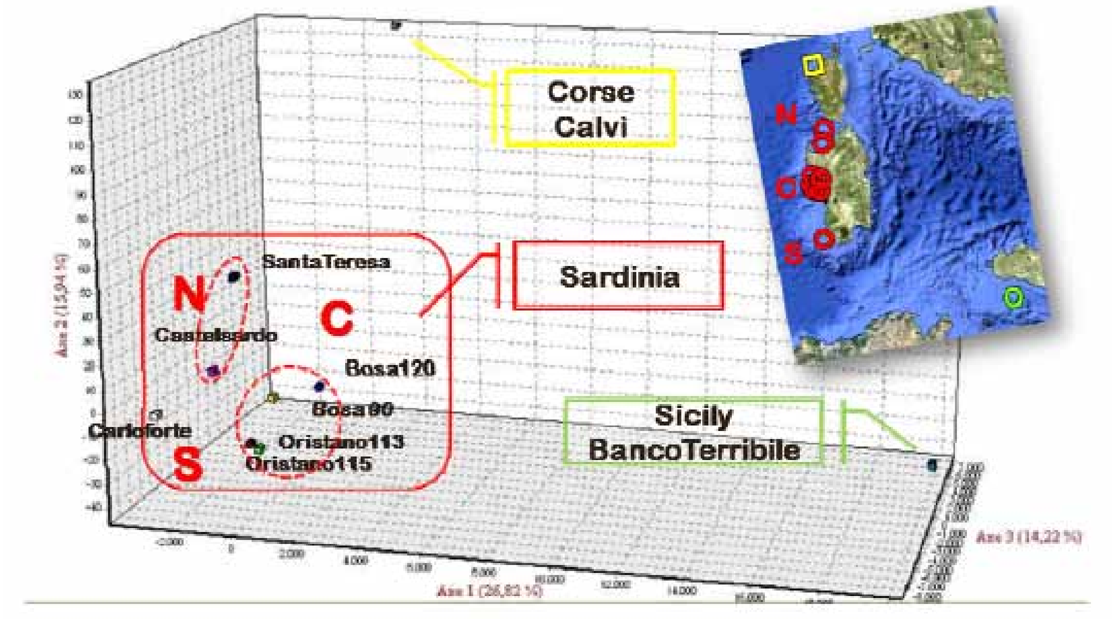

Fig. 4. FCA plot displaying the genetic distance between the deep colonies depicted as the centre of gravity of all sampled colonies within a sampled site.

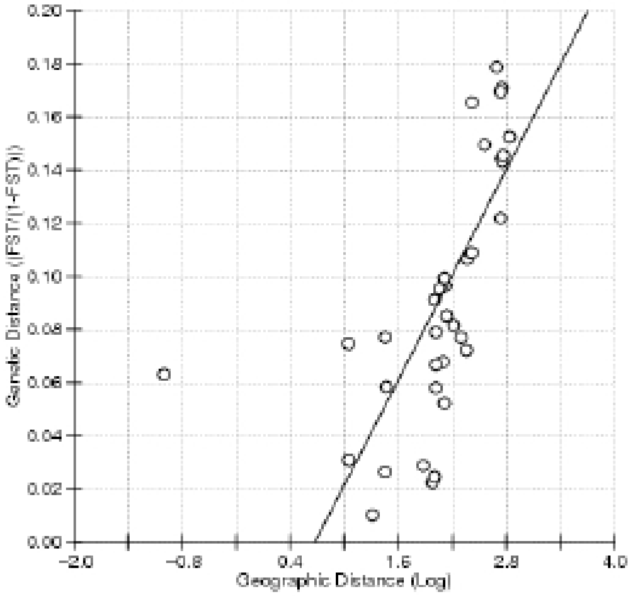

Fig. 5. Genetic differentiation [computed as FST/(1 - FST)] versus the logarithm of the geographic distance (in km) for deep colonies of *C. rubrum.*

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ASSESSING DECLINE IN CORALLIUM POPULATIONS: DO EXISTING DATA MEET THE CRITERIA FOR A CITES APPENDIX II LISTING?

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Abstract

In June 2007, the U.S. proposed *Corallium* (pink and red corals) for listing on Appendix-II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The proposal was adopted and later overturned due to perceived difficulties in implementing and enforcing a CITES listing and uncertainties on population status. An expert review (FAO 2007) questioned whether populations had declined to 20-30% of a historic baseline, the level required for a CITES Appendix-II listing. Although landings declined by over 80% during the 1990s as compared to quantities reported from 1965-1989, this review concluded that this was not a measure of resource decline, but rather declines in the wholesale value of *Corallium* which rendered fishing uneconomical. The review also used colony abundance and density as surrogates of decline, which may be high (200-1300 colonies/m^2) in the Mediterranean. Assessments of decline in sessile, colonial organisms should consider reductions in size, since reproductive output and survival increase exponentially as colonies get larger. Colonies of *C. rubrum* historically achieved heights of 50 cm, developing complex first, second, and third order branching patterns. Today, over 90% of colonies in fished areas are 3-5 cm tall, more than half are sexually immature and most have only rudimentary branches. Few population data are available for Pacific *Corallium* spp.; however, landings over the last 15 years have dropped precipitously from 100-400 metric tons (t) to < 5 t/year. Recovery of populations to their natural state may require up to a century or possibly longer, as colonies protected from fishing for 20-30 years are still less than half their historic size. Minimum allowable size for harvest should be increased because traditionally-determined growth rates appear to underestimate colony age, and corals are being removed long before achieving adequate levels of reproductive output and maximum sustainable yield (MSY). “Boom to bust” cycles of *Corallium* fisheries and dramatic, long-lasting shifts in population demography highlight the need for improved management and trade regulations.

Introduction

Precious corals have been highly valued since ancient times for use in the fabrication of jewelry, amulets, and art objects (Tescione 1973). Precious coral refers to a group of taxonomically distinct corals that includes gold corals (*Gerardia* spp.) in the order Zoanthidae, black corals in the order Antipatharia, and two groups in the order Gorgonacea, bamboo corals (*Acanella* and *Lepidisi*s spp.), and pink and red corals (C*orallium* and *Paracorallium* spp., family Coralliidae, referred to as “*Corallium*”). Pink and red corals are the most valuable precious corals in commerce and among the rarest (Grigg 1989). Because of their high value, these resources have been intensely fished in both the Pacific and Mediterranean, with a well established pattern of discovery, exploitation and depletion (Grigg 1989). International trade, consisting of millions of items and thousands of kg of raw and processed specimens each year, has contributed to serial depletions of most known populations of *Corallium*, and new stocks have been rapidly exhausted shortly after their discovery. In addition to localized depletions, the use of coral dredges has damaged *Corallium* habitats (Chessa and Cudoni 1988). Throughout most of the Mediterranean, the complex, three-dimensional "forest-like" structure has been transformed to low-relief "grass plain-like" habitats (García-Rodríguez and Massò 1986; Rossi et al. 2008), reducing their role as important habitat for other species.

Because of concerns of overfishing and habitat damage associated with the use of non-selective coral dredges, a non-governmental organization petitioned the United States (U.S.) in 2006 to propose *Corallium* for listing on the Appendices of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). After a detailed review and consultation with *Corallium* range states, the U.S. submitted a proposal to list all species of *Corallium* on Appendix-II of CITES at the 14th meeting of the Conference of the Parties. This proposal identified seven species as under considerable threat from harvest and international trade *(C. rubrum, C. secundum, C. lauuense (C. regale), P. japonicum, C. elatius, C. konojoi,* and *C.* sp. nov.) with other species recommended for listing because of their similarity in appearance (Wijnstekers 1988; Bruckner 2009). The listing proposal was adopted in committee and overturned on the final day of the conference, largely due to perceived challenges in implementing and enforcing this CITES listing, and the conclusion that existing data did not demonstrate declines to the level required to justify an Appendix-II listing (Morell 2007). In 2009, the U.S. was petitioned once again to propose *Corallium* for listing in CITES. An evaluation of new data was undertaken to determine whether the listing was warranted, and in October 2009 the U.S. and the European Union jointly sponsored a CITES Appendix-II listing proposal (Anonymous 2009).

The main purpose of this paper was to evaluate existing landings data and biological information for the family Coralliidae to determine if the species in commercial trade meet the biological criteria of decline needed to support a CITES listing. In order for a species to qualify for a CITES listing, there are a number of criteria that need to be met. First, there has to be evidence that the species is in international trade, the trade at existing levels is threatening the sustainability of the species and its role in the ecosystem, and regulation of trade is necessary to ensure that harvest does not reduce wild populations to levels at which survival is threatened by continued harvest or other factors. Second, to qualify for Appendix-II there must be evidence that demonstrates a historical extent of decline and recent rates of decline that have resulted in losses of 70-95% of the virgin population, depending on the productivity of a species. For a medium productivity species, the species should have declined to 10-15% of some baseline while a low productivity species would need to have declined to 15-30% of its historic abundance. In addition to information on the life history traits, which are used to determine whether it is low, medium, or high productivity, relevant information is needed on the size of the population and its distribution, and how the species biology may affect the recovery potential of populations. Proposals must also include a quantitative assessment of the status and trends of populations and an estimate of the level of decline, along with an explanation of uncertainties associated with available data (FAO 2007).

Productivity of *Corallium*

In a review of the 2007 CITES Appendix-II listing proposal for *Corallium* (FAO 2007), four parameters were identified that can be used to infer productivity. Because of extremely low rates of natural mortality, a long lifespan, and delayed age of reproduction, most species in the family

Coralliidae were considered low productivity. *Corallium rubrum* also exhibits a long lifespan and low rates of natural mortality (Grigg 1976); however, colonies can reproduce at a small size, which has been equated to a young age (3-7 years) in previous studies (Santangelo et al. 2003), suggesting it is a medium productivity species. Nevertheless, this needs to be reevaluated based on new information. Recent aging studies have shown the corals to be 2.6-4.5X older than previous estimates determined by counting growth rings (Garrabou and Harmelin 2002; Marschal et al. 2004; Roark et al. 2006), and small colonies do not exhibit 100% reproductive maturity until colonies achieve a minimum height of approximately 6 cm, which may equate to an age of 10 years or more (Tsounis 2005; Marschal et al. 2004). Several other unique reproductive traits further support the conclusion that *C. rubrum* is a low productivity species including: 1) a relatively small number of larvae produced per colony per reproductive event as compared to other corals, and 2) a single discrete annual reproductive period. This is very different from other corals that exhibit a brooding life history strategy, which tend to reproduce monthly on a lunar cycle (Richmond and Jokiel 1984; Szmant 1986). Recruitment in *C. rubrum* also occurs in pulses with no successful settlement in some years; mortality of up to 95% of the larvae occurs before settlement (Tsounis 2005), and 66-70% of the new recruits die over the first four years of life (Bramanti et al. 2005). These data suggest all species in the family Coralliidae are low productivity species.

Distribution of *Corallium*

The family Coralliidae is widely distributed throughout tropical, subtropical, and temperate oceans, but individual species are generally found at very low abundances within their distributional range. Populations that contain economically valuable species, in abundances large enough to support commercial fisheries, have been identified only in three locations north of 19 degrees latitude. This included certain locations in the western Mediterranean, Pacific populations off the Philippines, Japan and Taiwan, and Hawaii and the adjacent Emperor Seamounts, most of which are now overexploited. Individual species are also generally restricted to relatively small areas of suitable habitat within their distributional range, where they form discrete, genetically distinct populations that are separated from other populations by large expanses of unsuitable soft bottom habitat (Santangelo and Abbiati 2001; Santangelo et al. 2004; Baco and Shank 2005). For instance, two commercially valuable species have been identified in U.S. waters around Hawaii in 16 different locations (Baco and Shank 2005). Of these, only three populations are considered large enough to support commercial harvest, and the total size, number of colonies, and estimated MSY for two of these beds is very low (Grigg 2002). The largest of these, Makapuu Bed off Oahu, Hawaii occupies an area of 4.3 km^2; this bed supports *C. secundum* at a density of 0.3 colonies/m^2 with a total population size estimated at 120,000 colonies in 2001. The total number of colonies in all other characterized beds in the U.S. are also low including an estimated 2500 legal-sized colonies of *C. regale* at Cross Seamount and up to 7000 legal-sized at Keahole Point Bed. Available data suggest individual species have small effective population sizes and a restricted distribution within a larger geographic range.

Evidence of Decline

There are five main sources of data available for the family Coralliidae that provide an indication of the dramatic declines in population abundance and structure over the last several decades. The typical "boom to bust" cycles of *Corallium* fisheries has been highlighted in numerous publications for both Pacific and Mediterranean locations dating back to at least the 1800s; these reports highlight the discovery of new beds, rapid increases in the number of fishing vessels and fishery workers, and abrupt termination of fisheries in these areas once the quality and quantity of *Corallium* resources declined (Tescione 1973; Cicogna and Cattaneo-Vietti 1993). Landings data have been compiled since the early 1960s for Pacific reported by Japanese and Taiwanese fishermen, and for twelve countries in the Mediterranean (FAO 2008; Fujioka 2008). Detailed quantitative biological data on the density, abundance, and size structure of colonies are available for populations of *C. rubrum* off Spain, France, and Italy, including 1) recent data from shallow fished populations, 2) historical information from similar locations, 3) depth related differences, and 4) data from inside and outside of MPAs (Garcia-Rodriguez and Massò 1986; Tsounis 2005; Rossi et al. 2008). Additional anecdotal reports are also available from other locations in the Mediterranean. In the Pacific, one population has been studied in detail off Hawaii, and more recently surveys have been undertaken off the Emperor Seamounts in international waters, and off Japan (Fisheries Agency of Japan 2008). There is also information describing the effects of a decline in size on the degree of branching and the total number of individuals (polyps) per coral, and how this affects population viability (Bruckner 2009).

Pacific Landings Data

Available landings data for Pacific *Corallium* fisheries from the last 40 years (1965-2007) illustrate the characteristic boom to bust cycle of Coralliidae fisheries, where both effort and landings increase dramatically after discovery of a new precious coral bed, followed by sharp declines a few years later (FAO 2008; Fujioka 2008). Pacific *Corallium* fisheries emerged in international waters in 1965, following the discovery of a large bed of *C. konojoi* on Koko Seamount at 300-500 m depth. Over the next 25 years, most *Corallium* from the Pacific came from Koko Seamount and other areas in the Emperor Seamount chain, with five major peaks in landings reported by Japan and China (Taiwan); this was followed by rapid decline and minimal landings in international waters since 1989 (Fig. 2). Landings reported by Japan exceeded 375 tons in 1966, sharply declined to 100 tons by 1968, and reached a second peak of 225 tons in 1969 before declining once more to less than 50 tons in 1972 (Fujioka 2008). Annual yield from Japan was the greatest from 1965-1969 and 1979-1984 (57-91 t/yr), with 70-90% of the harvest in later years consisting of Midway deep-sea coral. Japan's reported landings declined to 2.6 t in 1987 and have remained at < 5 t/yr over the last 20 years, consisting mostly of *C. elatius* (mean = 1.9 t/yr) and *C. japonicum* (1.2 t/yr), and minimal amounts of *C. konojoi* and *Corallium* sp. nov. (0.22 t/yr). With exception of the early years of the fishery, landings reported by Taiwan were 2-3 times greater than that reported by Japan, with peaks in landings of *C. kokojoi* in 1969 (112 t), 1976 (102 t), 1981 (270 t) and 1984 (226 t), and even higher amounts of *Corallium* sp. nov. from 1983-1986 (564 t), most of which was harvested off Midway Island. Landings by Taiwan remained at low levels (< 5 t) over the next 20 years with exception of two periods, 1996 (12 t) and 2002-2004 (35 t); these landings consisted of *C. elatius* harvested from 300-500m between Taiwan and the Philippines.

Landings data for the Pacific illustrate a typical trend that has repeated itself throughout the history of the fishery worldwide, although no new large commercially viable beds have been discovered in the Pacific since 1990 and landings have remained at levels that are 10-20% of that reported in the late 1980s (Carleton and Philipson 1987; Grigg 1989; FAO 2008). Changes in landings have been attributed to a decline in the resource as well as a decline in the wholesale value of the product, both which could render fisheries uneconomical. There are two periods when the wholesale value of *C. konojoi* is reported to have declined to levels that made fishing uneconomical (1967 and 1971-

1972), yet fishing resumed a few years later and landings subsequently increased (Fujioka 2008). By 1988, *C. konojoi* beds were reported to be overexploited (Fujioka 2008), which is supported by landings data, and remained at less than 3 tons per year over the last two decades (FAO 2008). Markets were also reported to be flooded with low quality Midway deep-sea coral in 1981-1982, which caused the price of *Corallium* to decline to less than US$100/kg (Grigg 2002). According to Kosuge (2007) Japan and Taiwan abandoned fisheries in the central Pacific due to high costs of harvesting coral in deep water and increased landings of low quality coral, but presumably not due to a strong decline in abundance or biomass. Interestingly, landings data of Midway deep sea coral does not show this trend, as this species was not reported in FAO data until 1982; instead *C. konojoi* showed a decline during this period, and subsequently both landings of *C. konojoi* and Midway deep sea coral dramatically increased between 1983-1987. Furthermore, wholesale prices of *Corallium* rapidly increased to unprecedented highs in the late 1980s and 1990s, yet landings since 1989 have remained at historic low levels. If abundant coral resources still remained off the Emperor Seamount Chain, landings should contain living, large old growth colonies, rather than only low quality coral as reported by Kosuge (2007); declines in the density and abundance of the coral would also trigger increases in the amount of effort needed to harvest the same amount of coral, also driving fisheries costs up. Even though the two taxa known only from the Emperor Seamounts still show up in FAO data, and Taiwanese coral draggers have been observed fishing for coral in this location (Fishery Agency of Japan 2008), production over the last two decades is less than 1% of the yield in the 1980s (FAO 2008).

While landings data alone do not provide information on effort, numerous reports are available that highlight the increase in fishing effort (number of vessels) following discovery, and declines in effort once beds were overexploited. By combining landings data with these fishery reports, conclusions can be made on how the distribution of fishing effort has changed over time. *Corallium konojoi* and midway deep coral were both landed around the Emperor Seamounts and they made up the majority of the landings from the mid 1960s to the end of the 1980s. In contrast, two Pacific species, *C. japonicum* and *C. elatius,* are harvested only off the islands of Taiwan and Japan and are not known to occur around Emperor Seamounts. These two species make up the bulk of landings from Pacific waters today. Submersible surveys conducted by Japan in 2008 on Emperor Seamounts included areas that were targeted by coral draggers in the 1960s-1980s. In several of these they identified isolated live colonies and dead and broken colonies, but they failed to identify a single large patch of *Corallium* that could support a coral fishery, which further demonstrates that the resource was overexploited beyond limits of recovery in the 1980s and 20 years of greatly reduced fishing pressure has been inadequate to rebuild populations (Fisheries Agency of Japan 2008). All of these factors clearly demonstrate a dramatic and long term collapse of populations located in international waters around the Emperor Seamounts, with little recovery after 20 years.

Mediterranean Landings Data

In the Mediterranean, 12 countries report landings data to FAO (Fig. 4). These data show a sharp decline in landings over 20 years, from a maximum of 98 tons in 1978 to 20 tons in 1998, primarily due to a reduction of landings from European waters. This can be partially attributed to a phase-out of the use of non selective dredges, a reduction overall in effort, and a change in management schemes. However, these changes are not the only reason for the decline. SCUBA fisheries were first introduced in the 1950s, while the use of the coral dredge was not banned until 1989 (Sardinia only) or 1994 (throughout the rest of European waters). Landings were already less than 50% of

1978 levels (42 tons) in 1984, and they remained at these low levels (32-48 tons) for the next five years, which was prior to the ban on the use of ingegno. Even in Italy, where the coral dredge was banned five years earlier than in other locations, landings had already declined from a peak of over 72 tons in 1978 to 40 tons in 1980 and 19.3 tons in 1985, with < 10 tons landed each year up to 1988. Even though landings in Italy following the ban were about half the amount prior to the ban, this reduction is minimal when compared to changes observed during years when the ingegno was still legally used (Fig. 4b). Landings reported by individual countries have continued to show sharp peaks and declines since inception of SCUBA fishing, which are suggestive of the discovery of large aggregations of coral in a particular area, followed by rapid overexploitation of these populations.

The Italian coral fishery, especially around the Sardinia region, was the first to begin to phase out the use of the coral dredge, while SCUBA fishing progressively increased. SCUBA fishing was originally concentrated in shallow water (to about 50 m), extracting corals from areas that were largely inaccessible to dredges. Over the last two decades, SCUBA fishing has been progressively moving into deeper areas, in response to a depletion of corals in shallow water, as shallow areas today contain mostly small corals below the legal minimum size. Individual peaks in landings during a single year may also reflect the pulse fishing mode associated with SCUBA harvest, where individual beds are selectively cleared of large colonies, then a new area is targeted. This trend is not restricted to a single location, as shallow water populations are considered overexploited throughout the Mediterranean today.

Biological Data

There are numerous gaps in our understanding of the biology of *Corallium*, their population status, and levels of sustainable harvest. Even though industrial scale fisheries are reported to have undergone periods of intensive harvest followed by years with little harvest since at least the early 1800s, there is no information on what populations looked like prior to the inception of the coral dredge, and there are no known beds of *Corallium* that were never fished with detailed population assessments. With exception of a single location off Hawaii, comprehensive deep water surveys (below SCUBA depths) have been undertaken only in the last several years. Field data are available from Spain and France both show differences in size between fished areas and areas that have been protected from fishing for 15-20 years in shallow water locations, and these provide strong evidence that population dynamics have been altered from their original state largely due to the removal of the largest colonies first, followed by sequential elimination of medium and small corals. Even in Makapuu Bed off Hawaii, where the fishery has operated intermittently for a few years, the largest size classes were still underrepresented after several decades without fishing (Grigg 2001). In addition, the first surveys in this location were undertaken after a short period of fishing, so it is unclear what the virgin population looked like. The observation that corals can achieve a larger size in absence of fishing in shallow water, and the documented presence of larger colonies at depths accessible to SCUBA in the 1960s, demonstrates that the corals can achieve a large size in shallow water, and the current size observed above 50 m depth throughout the region is unnatural, except perhaps in some very shallow marginal habitats such as that reported from Liverno, Italy, and around cave entrances where there is not enough space for the colonies to grow to a larger size. Furthermore, there is one quantitative study from Spain in 2008 (Rossi et al. 2008) and recent work off Sardinia in deep water (e.g. 80-130 m or deeper) that identified colonies of a much larger size.

There are reported differences in growth rates, possibly due to different environmental conditions and other factors, and there are also differences in the density of corals reported from different areas. This includes a notable higher density of corals in shallow areas around caves, overhangs and in crevices, while corals are more widely spaced and larger in deep water. Some of the differences in density may be due to differences in sampling approach. For example, many of the high density estimates reported in the literature may reflect individual patches of *Corallium* that are small and are widely dispersed over a much larger amount of available habitat at that depth. Furthermore, the high density estimates are often based on the total number of colonies in a patch, including new recruits, juveniles, and adults determined by scraping all colonies in a patch or through the use of macro photography, while many of the small colonies may not be recorded using other approaches. While higher densities would be expected in areas with small corals, because they often lack complex branching patterns, whereas fewer large, highly branched colonies could occupy the same area. For these reasons, density is an inappropriate measure of decline, and in fact, high density populations dominated by small corals are likely to represent an altered state due to fishing pressure, or in shallow areas, a marginal environment where there is a rapid turnover of populations.

Size Structure

The most appropriate measure of decline for long-lived colonial animals with a branching morphology is a shift in size towards smaller corals, because larger corals contain more reproductive polyps, they contribute more to future generations, and they are less vulnerable to total colony mortality from natural causes (but more vulnerable to fishing pressure). Significant differences in the size of *Corallium rubrum* colonies are reported between locations and depths, and most areas exhibited a general trend of declining size structure over the last four decades. Colonies collected in the 1950s and 1960s were frequently up to 50 cm height and 2 cm diameter. A 1962 collection off Costa Brava, Spain, consisted of colonies with basal diameter of 10-45 mm (mean = 16 mm) and height of 10-50 cm (mean = 11.5 cm), with the largest corals estimated at 50-80 years in age (Garrabou and Harmelin 2002; Tsounis 2005). Colonies sampled off Costa Brava were still substantially larger in 1986 than that observed today, with 85% of the colonies having a basal diameter > 5 mm. Shallow populations from Costa Brava (10-25 m depth) are now skewed towards small corals (mean height = 3.1 cm, max = 20 cm; mean diameter = 4-5 mm), most of which are young (< 8 years old), and only 35% have basal diameters > 5 mm. Colony height increases with depth to 4 cm height at 25-50 m and 6 cm at 50-90 m; the largest colonies (13-16 cm height) are found in non-harvested areas below 50 m depth. Colonies in an adjacent protected area (Medas Island, Spain), closed to fishing for 15 years, were 20-50% larger (mean = 4 cm height, max = 20 cm) than colonies at similar depths in fished areas off Costa Brava (Tsounis 2005, 2006 a,b, 2007; Rossi et al. 2008). Populations examined in 1998 in fished areas off France (Riou archipelago) were larger (mean height = 6 cm; range = 4-13 cm) than that reported for Spain (although small colonies were not examined in this study). These colonies were also only about half the size of a similar habitat in France protected from fishing since 1983 (mean = 11.8 cm, range = 8-17 cm) (Garrabou and Harmelin 2002; Torrents et al. 2005).

In terms of decline, the shift in maximum size observed in areas targeted by fishermen from up to 50 cm height to colonies that are no more than 15-20 cm, and a shift in mean size from about 10 cm to 3 cm represents a 60-80% decline in size. The effect of these size reductions on the total number of polyps per colony, which is a direct measure of the numbers of reproductive modules, represents an even greater loss because this reduction is also associated with a loss of branches. Although a large colony has fewer polyps at the base as it gets older, the presence of many more branches still equates to a much larger number of polyps. For instance, a 3 cm tall coral with 3 branches may have up to about 100 polyps, of which only a portion are reproductively mature, while a 30 cm tall colony could have 10,000 polyps, all of which may be reproductively mature. Smaller colonies also expend more energy on growth, while larger corals may produce more offspring per polyp because they need to expend less energy on growth and maintenance.

Conclusion

Most articles published on *Corallium* over the last two decades contain statements that the resource is overexploited, including papers published over 20 years ago. Numerous recommendations for improved management have also been proposed, many of which have never been adopted (e.g. increased minimum size of harvest). These corals have been proposed for listing in CITES on several occasions, but these proposals have not been supported in part due to 1) the limited availability of population data to confirm the depleted status of the species, 2) the conclusion that landings data cannot be used as a surrogate of decline, and 3) an incorrect assessment of population structure using density and abundance rather than changes in size structure.

There have been relatively few quantitative population studies undertaken on different species of *Corallium*, but the combination of all available data on the biology, population dynamics, and landings, as well as historical reports on the fishery, illustrate the dire status of these species as a result of unsustainable fishing. It is unlikely that these species will go extinct, but extirpations of individual populations are very likely unless more sustainable management approaches are adopted and enforced. Furthermore, an Appendix-II listing is not intended to protect species threatened with extinction, but rather to regulate trade so that the species does not become threatened in the future due to unsustainable trade.

Landings data must be examined with caution, as they do not directly provide an indication of effort, and they are indicative of decline in some, but not all cases. There are several factors that can render fisheries uneconomical, including the glut of *Corallium* reported during the 1980s. Nevertheless, the sustained reduction of landings once market prices recovered and exceeded previous values, without a concurrent increase in landings, provides a strong indication of decline. Furthermore, the presence of an increasing amount of dead and bioeroded colonies in landings from deep water using coral dredges are indicative of a collapse of the resource.

Available population data for *C. rubrum* illustrate changes in size associated with fishing and the long time required for recovery. The original population structure throughout the Mediterranean has been altered by fishing pressure, with declines in both the reported landings and in population structure that exceeds the level required for an Appendix-II listing. In shallow fished areas, population dynamics have been altered from low density populations that cover large areas and are structured primarily by larger highly branched colonies (10-15 cm up to 30-50 cm), to small, dense patches with colonies that are substantially smaller (3-5 cm, rarely over 10 cm) and have few branches (Garrabou and Harmelin 2002; Tsounis et al. 2006 a,b, 2007; Santangelo et al. 2003, 2007). All known shallow water (< 50 m depth) populations that are accessible to conventional (air) SCUBA exhibit these trends; this includes certain shallow environments that exhibit high rates of turnover due to unstable environmental conditions, high levels of biotic disturbances (overgrowth by sponges), and lack of suitable habitat where they could grow larger, but these may never have supported commercial fisheries (Garrabou et al. 2001; Santangelo et al. 2003). There is evidence that colonies in shallow areas targeted by SCUBA fisheries can grow larger if they are left undisturbed (e.g. in MPAs), but recovery to pre 1980s levels takes many decades. In addition to their smaller size, a large proportion are immature and reproductively mature colonies only contain tens to hundreds of reproductive modules (polyps) versus tens of thousands of polyps in larger colonies that formerly dominated these habitats (Garrabou and Harmelin 2002; Torrents et al. 2005; Tsounis 2005, Tsounis et al. 2006, 2007 a,b). These shallow populations are more likely to collapse under continued fishing pressure when compounded by other disturbances because of the low numbers of larvae produced by individual corals (GFCM 1984, 1988; Santangelo et al. 1993,2003; Galasso 2000; Linares et al. 2003; Tsounis 2005).

Pacific populations appear to be in even worse shape. The low reported landings from international waters around Emperor Seamounts today (e.g. < 1% of landings in the 1960s-1980s) and a failure to identify large, viable beds during recent surveys off Emperor Seamounts suggest the populations have been overexploited and recovery has not occurred after 20 years of greatly reduced fishing pressure. Recent studies from Japan identified densities that are 10-100 times less (0.05-0.005 colonies/m^2) than reported in an unfished population off Hawaii (0.5-1 colony/m^2). Landings by Taiwanese fishermen consist of 80% or more dead colonies, which is indicative of areas previously damaged and over-exploited by trawling that contain few remaining live colonies.

All of the factors presented here are indicative of population declines that exceed the 70-90% required for an Appendix-II listing.

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Fig. 1. Pooled landings for all species of *Corallium* between 1965-2007. Landings data for the Pacific are shown in blue and Mediterranean *C. rubrum* landings are shown in red.

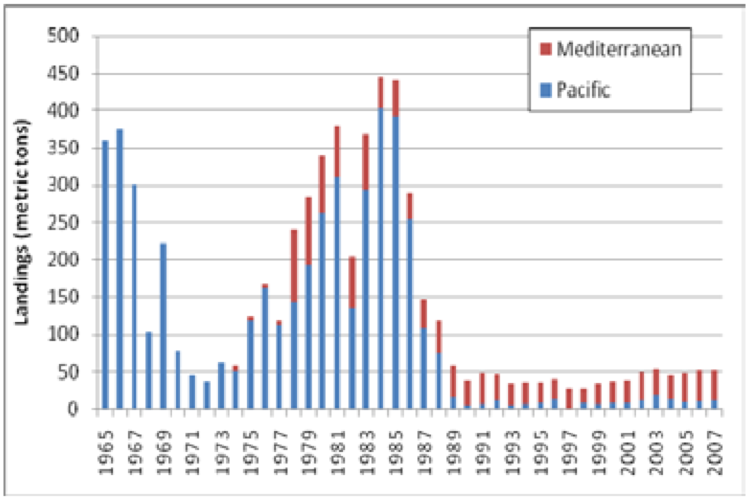


Fig. 2. Landings data presented by species between 1965-2007.

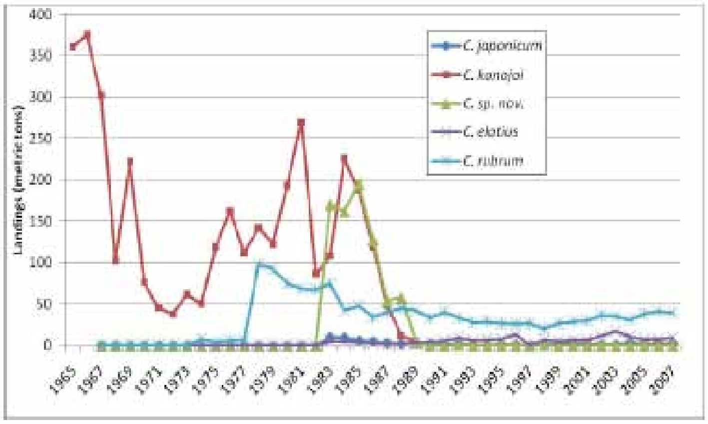
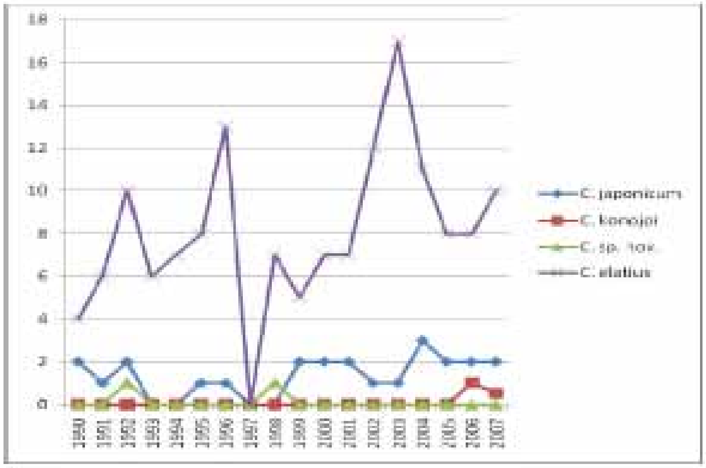


Fig. 3. Landings data for Pacific species of *Corallium* from 1990-2007. The data are the same as in Fig. 2, although a different scale is used to illustrate variations in landings over this period.



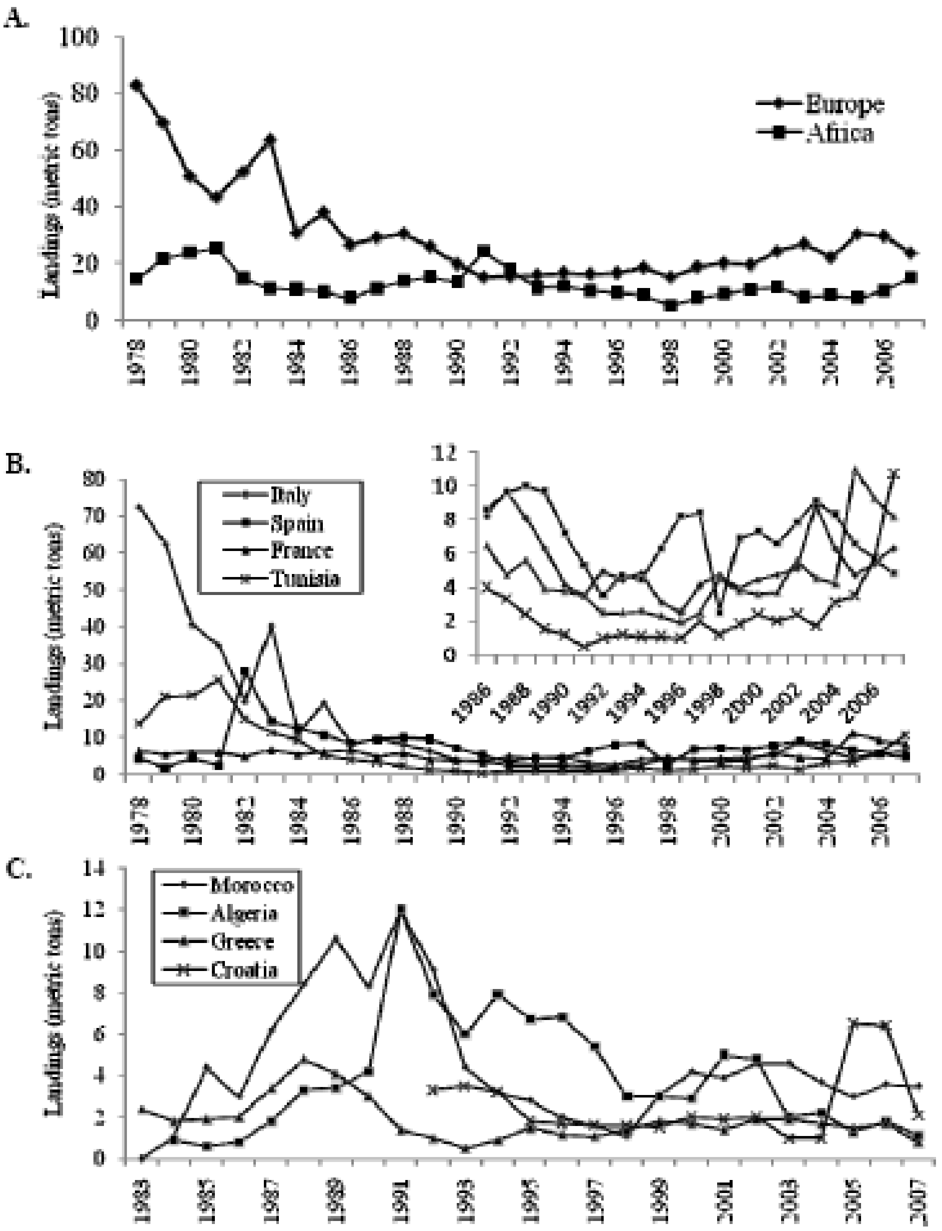


Fig. 4 Landings data for *C. rubrum* between 1978-2007. **A.** Total landings pooled for all countries in Europe (diamonds) and Africa (squares). **B.** Landings for Italy, Spain, France, and Tunisia. The inset shows the same countries over the period 1986-2007 using a different scale to illustrate the variation between years. **C.** Landings for Morocco, Algeria, Greece, and Croatia between 1983-2007.

MANAGEMENT OF PRECIOUS CORALS: LOCAL SCIENCE AND ENFORCEMENT VERSUS A LISTING BY CITES

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Introduction and History of Precious Coral Fisheries

Precious corals have been treasured by man since the dawn of recorded history. Today, many species of precious coral exist and have been harvested in a variety of countries using a variety of fishing methods. The main fisheries have targeted red, pink, and white species of the Gorgonian Genus *Corallium*, black corals in the Genera *Antipathes* and *Cirrhipathes,* and gold corals in two distinct Anthozoan Families and Genera, *Gerardia* and *Primnoa*.

Historically, the most important species is *Corallium rubrum*, the famous Red Coral of Commerce, found throughout the Mediterranean Sea and nearby sites in the Atlantic Ocean. The first record of human use of red coral was the discovery of polished and perforated beads of *C. rubrum* recovered from grave sites in Germany that date back to Paleolithic Time 25,000 years ago (Tescione 1965). Back then, red coral appeared to have had value for trade, perhaps even as an early form of money, but it also seemed to have a great cultural significance. Man's early fascination with red coral is exemplified in Greek Mythology. The myth of the Greek God Perseus and the Gorgon Medusa is famous even today in art, culture, and religion. Perseus was claimed to have slain the hideous dragon and cast her head into the sea, whereupon its petrifying stare turned soft algae to stone and stained it red – giving birth to red coral. At once, red coral became a symbol of rebirth, immortality, and protection perhaps from the Evil Eye and misfortune in general. Red coral became a panacea, an amulet, a symbol of life's vitality. What is even more remarkable, red coral and some other precious corals have held this sacred fascination in the mind of man (and women) for literally 1000s of years even up to modern time.

The cultural history of man's love affair with red coral is important, and so are the histories of various precious coral fisheries, but the man focus of this paper is the question of optimum management. Many management strategies are available and many have been used but unfortunately almost all have been unsuccessful in producing a sustainable yield of the resource. Even so, it must be said that precious corals are biologically renewable resources. They are not minerals and achieving a sustainable yield is simply a matter of utilizing a management strategy that works. But before discussing this problem, it is first important to examine the natural history of various species of precious coral. It is also important to briefly describe the history of major precious coral fisheries in the world that have seriously depleted the stocks versus those that have not. Finally, the potential impacts of listing *Corallium* spp. on Appendix-II of CITES is considered.

Natural History of Precious Corals

In general, many precious corals share a number of similarities in life history phenomena (see papers by Lacaze-Duthiers 1864; Kishinouye 1904; Hickson 1924; Vighi 1970; Grigg 1976,1984, 2002; Bruckner 2008; Tsounis et al., in press). To begin with, precious corals are primarily deep water corals living below the euphotic zone (zone of photosynthesis). All species of precious coral are ahermatypic, lacking symbiotic algae and none form reefs. Universally, precious corals form solitary colonies. Almost all are slow growing and probably have deterministic growth slowing down as they get older. Also, most precious corals have low fecundity and low rates of recruitment (except *C. rubrum*) and natural mortality, and consequently most are relatively long lived, living up to several centuries or more (Roark et al. 2006).

What little is known about their reproductive biology suggests that most are gonochoric (separate sexes, also dioecious) and most spawn annually usually during warm summer months. Reproductive maturity may require many years depending on the longevity of a given species. Precious coral larvae tend to be negatively phototaxic and positively geotaxic, and most are lecithotrophic and have short-lived dispersal capabilities. This may account for another characteristic of precious corals and that is their ubiquitous patchy distribution, although this is also related to narrow habitat preferences. For example, almost all precious corals are found in areas of strong bottom current. Most precious corals are filter feeders or suspension feeders and thereby rely on strong bottom currents for their food supply (particulate organic matter or microplankton). Many precious corals in fact have a planar branching pattern and are oriented at right angles to the prevailing currents. Strong current is also important in maintaining substrata free of sediments which is another ecological requirement of precious corals; a firm or solid bottom texture on which to settle. Because precious corals are moderately long lived, this means that habitats in which they proliferate must be free of sediment (sand, mud, ash, etc.) for long periods of time. These kinds of habitats are often found in channels or off points or capes of land where bottom currents may be intensified due to Bernoulli effects.

Because the distribution of precious corals is patchy and many form large solitary colonies, precious coral beds are often considered keystone species that provide habitat diversity (shelter or an epifaunal substratum) to many other species and for this reason they have been described as biodiversity hot spots. When all of the life history traits described above are considered collectively, it is clear that harvesting strategies must be very conservative. Harvesting rates, or the percent of the standing stock taken annually, must be very low (generally lower than the mortality rate) in order to have any chance of being sustainable. This is particularly important because virtually all species of commercially valuable precious corals are vulnerable to over-exploitation in unmanaged fisheries. This is because many year classes are exposed to harvesting at the same time. It is possible that many decades of accumulated standing stock is exposed to harvest during short intensive periods of fishing. Unfortunately, this pattern of pulse fishing has been employed by the Mediterranean fishermen especially when it was legal to use the Ingegno (also known as St. Andrews Cross) , as well as Japanese and Taiwanese coral draggers who use destructive tangle net gear. These practices have repeatedly led to a pattern of discovery, heavy exploitation followed by significant depletion.

History of Precious Coral Fisheries in the Mediterranean and the Western Pacific

Red coral is found in the Mediterranean Sea at depths of 10-500 m; therefore early man may have collected it by way of shallow water divers or possibly from storm deposits on Mediterranean beaches. Starting about 5000 years ago, Greek sponge divers began to selectively harvest large colonies of red coral while collecting other organisms. Sometime thereafter, Greek fisherman learned to dislodge colonies from deeper water with the use of iron hooks (Buckner 2008). Several 1000 years later, the Arabs invented a wooden cross with attached netting, to drag and entangle red coral from all depths. This device, known as the Ingegno (also known as the Cross of Saint Andrew), was used in Mediterranean Seas up until the 20th century. During the late 1800s, anywhere from several 100 to more than 1000 coral fishing vessels were engaged in red coral dredging operations in the shallows seas off Italy and Northern Africa. The large variability in fishing effort was the result of a boom and bust nature of the fishery. Production depended on the discovery of new coral beds but was always followed by excessive exploitation and rapid depletion. As a result, the use of coral dredges was banned outright by the European Union in 1989. Beginning in about 1960, the commercial harvest of red coral was carried out more and more by divers equipped with SCUBA equipment (Tescione 1965). The modern catch record for about the last 50 years for *C. rubrum* has been compiled by FAO and recently published by A. Bruckner and again the cycle of boom or bust production is evident in the data (Fig. 1). These records demonstrate that virtually all known red coral beds in the Mediterranean have been depleted. Annual production today is about 25% of what it was in the early 1960s.

Precious corals were not discovered in the Pacific Ocean until 1803 in waters off Japan where beautiful red (*Corallium japonicum*) and pink (*C. elatius*) corals were found at depths ranging between 100-300 m. A fishery off Japan, however, did not develop until after the Meiji Reform in 1868. Before then, corals harvested by fishermen were confiscated by the Shoguns. After 1868, fishermen were allowed to sell their catch on the open market. In the late 1880s about 100 small boats were engaged in harvesting precious corals from coastal waters of Japan and although catch records are not available, the methods used were tangle nets (coral mops) and the known grounds were gradually exhausted (Grigg 1971). New grounds were discovered sporadically but they too underwent depletion. Over the years, this same cycle of discovery, exploitation and depletion continued into the 20th century being interrupted only by World Wars I and II.

In mid 1960s, Japanese coral draggers made two large discoveries, the first on the Oza Banks 160 km south of Okinawa and the second, on the Milwaukee Banks in the Emperor Seamounts 800 km northwest of Midway Island at depths near 400 m (Grigg 1971). In 1969, Taiwanese boats discovered even more, new and rich precious coral banks on other Emperor Seamounts. During the 1960s almost 230 tons of red and pink coral worth over $4 million were harvested collectively from these areas (Grigg 1971). Unfortunately, all of these areas were gradually depleted in the following years.

In about 1979 more beds were discovered in the 400 m depth zone east of the Emperor Seamounts on the Mellish Seamounts leading to another coral rush, but again these beds were soon depleted. A final discovery in the Emperor Seamounts was made in the early 1980s when a new and very abundant species was found at depths between 1000-1500 m. Sometime known as scotch coral, or deep sea Midway coral, this species of *Corallium sp. nov.* is characterized by a blotchy pink coral skeleton. Unfortunately, this species was also depleted over the ensuing several years.

FAO has been compiling the landings of *Corallium* species beginning in 1963 to the present and these cycles of boom and bust are evident in the data (Bruckner 2008) (Fig. 1 a,b). During several of the peak years in the Pacific, total annual yields exceeded 200-300 metric tons. These records also demonstrate that all the major fisheries for *Corallium* in the Pacific and the Mediterranean Sea are now economically depleted, although none are close to biological extinction. It should therefore be clear that coral dredges (tangle nets and the *Ingegno*) do not produce sustainable yields and should be universally discontinued for the commercial harvest of precious coral.

History of Sustainable Precious Coral Fisheries in Hawaii

Over the past 50 years, two separate and distinct precious coral fisheries have thrived in Hawaii. The first fishery consists of two species of black coral, *Antipathes griggi* and *A. grandis*. Although both live within SCUBA diving depths, from 35-110 m, both are ahermatypic, non-reef building solitary corals, lacking zooaxanthellae. The second precious coral fishery is located in deeper water between 350-500 m and consists of two species of *Corallium, C. secundum and C. regale*, and one species of gold coral (*Gerardia* sp.). Except for *Gerardia* sp., for which a moratorium on fishing exists, all other species of precious coral that have harvested in Hawaii have been sustainable (Tables 1, 2). Yields have been relatively stable and have never exceeded estimates of Maximum Sustained Yield (MSY). Also the age frequency distributions and recruitment rates of the major species have remained relatively stable (Fig.s 2, 3) (Grigg 2001, 2002).

Commercial beds of black coral in Hawaii were discovered in 1958 by two SCUBA divers in the Au'au Channel off of the island of Maui. The main *Corallium* fishery began in 1966 soon after deeper water species were discovered at 400 m depth about 6 miles off Oahu in the Molokai Channel. Both of these discoveries led to an incipient fishery and both were at first unregulated since very little was known about their ecology (Grigg 1965, 1974).

At the beginning of these fisheries, an information vacuum existed in Hawaii, however, the records of precious coral fisheries in the Mediterranean and the far Western Pacific, left little doubt that the future of the new precious coral fisheries in Hawaii would depend on the development of selective methods of harvest and rigorous guidelines regarding minimum size limits and annual quotas. In response to this need, a long term program to study the ecology of precious corals began at the University of Hawaii in 1970 and continues to this day. The many results of this program can be found in numerous publications but the main findings relative to fisheries management are summarized in a Fishery Management Plan developed by the Western Pacific Fisheries Management Council and the State of Hawaii (Federal Register 1983).

At the outset of the program, it was determined that a model would be needed to produces estimates of MSY, as well as, size limits and annual weight quotas for individual species. Both species of black coral and *Corallium* that are harvested in Hawaii have similar life histories of slow growth, low but steady recruitment, low mortality and moderately great longevity (~ 100 years). The Beverton and Holt cohort production model (Beverton and Holt 1957), turned out to be ideally suited to estimate these parameters. A major assumption of this model is steady state recruitment, a characteristic that can be reasonably ascribed to both species groups (Fig.s 2, 3). The research program was hence designed to analyze recruitment rates, growth rates, mortality rates and ages at first reproduction. Model results for both species of black coral and for *C. secundum* are presented in Fig.s 4 and 5. Specific management guidelines are given in Table 1. Annual harvest data for both fisheries is presented in Tables 2 and 3.

Although the *Corallium* fishery has not been continuous over the years and there is a moderate degree in the variability of annual catch for both fisheries, MSY values for all species have never been exceeded and the fisheries indeed appear to be sustainable (Fig.s 2, 3). Both examples demonstrate that precious corals are renewable resources and can be fished sustainably using selective methods (Fig. 6). Fortunately, both Federal and State agencies in Hawaii have been active in adopting and enforcing the management guidelines. Cooperation of the local industry in not purchasing undersize colonies has also been important. These examples demonstrate that precious coral are renewable resources and can be successfully harvested given the cooperation of science and enforcement working together. Such a plan has worked in Hawaii for over 30 years.

Affects of Listing Black Corals on Appendix-II of CITES

Having reviewed the success of local management of precious corals in Hawaii, it is appropriate to examine the question of whether or not a listing on Appendix-II of CITES would improve the conservation of *Corallium* species. CITES regulations require export, import and re-export permits from countries of origin and destination which help in the monitoring of trade. The regulations also prohibit the issuance of permits from countries where collection is illegal or have been shown to be detrimental to the survival of a given species. The regulations are well intended but do they actually serve to conserve precious coral resources? Do they affect harvesting policies and practices at the local level?

Answers to these questions may not always be the same in every country so it is instructive to examine case histories. In Section 4 of this paper, it has been shown that black coral harvest has been sustainable for about 50 years in Hawaii. A Fishery Management Plan was developed by the WPFMC and the State of Hawaii in 1983 and it has been enforced at the local level in cooperation with local industry. Black corals were added to Appendix-II of CITES in 1981. The main effects of adding CITES regulations have been as follows:

1. Increased costs of procurement of raw and finished black coral products.

2. Increased costs of selling finished black coral products internationally. In the United States, each company is required to obtain a permit for a Master File each year from the U.S. Fish and Wildlife Service. This may take from 4-7 months turnaround time. Once a Master File has been established, single use permits are then required for each black coral product sold. Processing time for these permits is about 1 month. Each single use permit requires about 2 hours of employee time and a $129 processing fee. Repairs require a new shipping permit. As a result of the costs and employee time requirements, some companies no longer sell black coral jewelry outside of the U.S.

3. Domestic sales are also impacted negatively since increased procurement costs are passed on to the consumer thereby reducing demand.

Overall, less black coral is sold and in this sense black coral resources are conserved because less raw material is purchased. Lower demand may or may not lower supply (fishing effort) depending on the global marketplace which is very difficult to quantify.

In conclusion, the principal effects of listing black coral on Appendix-II of CITES on the industry in Hawaii have been 1) to hinder the trade, and 2) to create an excessive administrative burden on the industry. The long-term sustainability of the black coral fishery and the industry owes itself to local fisheries regulations and enforcement programs in the State of Hawaii, not CITES regulations.

General Problems with Listing *Corallium* spp. on Appendix-II of CITES

In addition to producing many of the same problems created by the listing of black coral on Appendix-II of CITES, there are many other problems of a more general nature (Sheikh and Corn 2008), and are as follows:

1. According to Article-II in Appendix-II of the Treaty, only those species that are threatened with extinction (although not necessarily now but may become so) are eligible for inclusion. Although some species of *Corallium* may be near economic extinction in parts of the Mediterranean and the Western Pacific, none are at risk of biological extinction or survival. The quantitative definition of decline in the Treaty is when the standing crop (abundance) of a given species falls below 20% of its unfished stock. By this definition, no species of *Corallium* have been shown to be eligible for inclusion on Appendix-II.

2. The inclusion by China (effective 6-1-08) of four species of *Corallium* (*C. japonicum, C. elatius, C. konojoi, and C. secundum*) on Appendix-III of CITES requires all international traders to obtain one of the following 3 documents: 1) an export permit, for countries of origin, 2) a re-export permit, for other countries, or 3) a certificate of origin, for other countries (CITES Notification to the Parties No. 2008/027).

3. All CITES listings should be species specific in order to identify changes in the biological condition of specific stocks. Only 7 species of *Corallium* are commercially harvested in the world and species identification is very difficult.

4. Some species of *Corallium* and even bamboo corals are dyed or powdered or reconstituted in resin and therefore cannot be correctly identified.

5. Perhaps the biggest problem is that most of the *Corallium* traded in the world today was harvested years ago and is drawn from stockpiles and is therefore exempt from the Treaty (Sheikh and Corn 2008).

6. Many species of *Corallium* have distribution boundaries that extend beyond country boundaries obscuring the location of collection.

7. Another potential problem is that a listing on Appendix-II of CITES may create the appearance that *Corallium* species are under management control thereby defusing efforts at the local level to enact legislation and enforcement programs.

8. The decline in the yield of *C. rubrum* may have been caused by the outlawing of the ingegno in 1989. Annual harvest in the Mediterranean Sea has been relatively stable for the past 20 years (Fig. 1).

9. The decline in the harvest of Pacific species of *Corallium* may in part be a result of reduced fishing effort caused by the coral glut produced in the 1980s and the consequential fall in price of the raw material.

10. In the U.S., a CITES Appendix-II listing would duplicate restrictions on the trade already required by the Lacey Act.

11. The primary focus of CITES is on trade rather than conservation; few criteria for management exist.

12. The permitting process of CITES has created an administrative and costly burden worldwide for the trade of listed species of precious coral and has done little to improve their conservation.

Summary and Conclusions

Precious corals have been treasured by man since antiquity and represent one of the oldest fisheries in recorded history. Most precious corals are k-selected being characterized by slow growth, low recruitment and mortality and relatively great longevity. The famous Red Coral of Commerce, *C. rubrum*, found primarily in the Mediterranean Sea, is an exception, being highly fecund, sometimes exceeding abundance levels of 1000 colonies/m^2, and having withstood centuries of fishing effort. Unfortunately, most *Corallium* fisheries in the world are in decline or have been depleted. In large part, this has been due to the use of destructive methods of harvest utilizing various dredging methods and the lack of appropriate management. These practices have repeatedly led to a pattern of discovery, exploitation and depletion.

In contrast to depleted *Corallium* fisheries elsewhere in the world, two precious coral fisheries in Hawaii have been sustainably fished for many decades using methods of selective harvest and management guidelines that are enforced at the local level. One of these fisheries, that targets black coral has also been affected by CITES Appendix-II regulations. Unfortunately, this added level of regulation has not served to help conserve the resource, but on the contrary, has hindered trade and has been a costly administrative burden on the local industry in Hawaii.

The proposal to add *Corallium* spp. on Appendix-II of CITES is plagued by a number of serious problems ranging from difficulties in identification, to stock exemptions, to potentially defusing local management, to lack of enforcement, to failure to conserve the resource and to hindering trade and creating administrative burdens on the industry. The history of precious coral fisheries in Hawaii has shown that the best management practice for the conservation of the resource has been the application of management guidelines produced locally combined with local enforcement by government agencies and industry.

At the international level, there is no question that precious coral resources are in need of much stronger management practices. The use of destructive fishing methods (dredging) need to be discontinued and replaced by methods of selective harvest. Species specific guidelines need to be developed and enforced at the local level. A myriad of possible management options exist including size limits, annual quotas, limited entry (licenses), seasonal limits, rotation of fishing effort and the creation of Marine Protected Areas (MPAs). All of these approaches are best accomplished at the local level through cooperation of science and enforcement, not CITES.

Table 1. Management guidelines of precious corals in Hawaii (Grigg 1976).

Species	Growth cm/yr	Mortality annual cf.	Yield/ recruit gms	Age/MSY yrs	MSY Kg	OY Kg	Size inches
Black corals (*A. griggi and A. grandis*)							
Maui Bed	6.42	0.07	1050 gm	28	6174	5000	48
Kauai Bed					1543	1250	48
Pink coral (*C. secundum*)							
Makapuu Bed	0.9	0.066	203	34	1072	1000	10

- The MSY size limit of 12” for *C. secundum* was lowered to 10” (optimum yield (OY)) due to economic considerations.

The Preliminary Management Plan for precious corals was completed in 1977 (EIS/PMP for precious coral, 1977). It is recommended that coral dredging be discontinued for commercial harvest of all species due to it destructive nature.

Table 2. Annual harvest of pink, red, and gold coral in Hawaii (kg).

Year	Gear	*C. secundum*	*Gerardia sp.*	*C. regale*
1966-69	Dredge[1.]	1800	0	0
1970-72	No harvest	0	0	0
1973	Submersible[2.]	538	0	0
1974	“	2209	734	0
1975	“	1385	621	0
1976	“	400	363	0
1977	“	1421	329	0
1978	“	474	50	0
1979-1987	No harvest	0	0	0
1988	Dredge[3.]	500	0	0
1989-99	No harvest	0	0	0
1999-2001	Submersible[4.]	1216	150	61
2002-2008	No harvest	0	0	0

1. United Fishing
2. Maui Divers of Hawaii
3. Vessel Aukai
4. American Divers

Table 3. Annual harvest of black coral* in Hawaii (kg/yr), except as noted.

Year	Maui Bed	Kauai Bed
1958-1968[1.]	3,000	0
1968-1972[2.]	4,000	2,000
1972-1980[3.]	8,000	4,000
1981 [4.]	72	0
1982 [4]	430	0
1983 [4]	867	0
1984 [4]	1,422	0
1985 [4]	140	0
1986 [4]	425	0
1987 [4]	1,978	0
1988 [4]	234	0
1989 [4]	464	0
1990 [4]	395	0
1991 [4]	1,048	0
1992 [4]	1,090	0
1993 [4]	393	0
1994 [4]	1,979	0
1995 [4]	2,735	0
1996 [4]	2,211	0
1997 [4.]	689	0
1999-2005 [5.]	3,182	0

* *Antipathes griggi* and *A. grandis*

1-3. Annual harvest based on interviews with divers
4. Annual harvest as reported to the State of Hawaii, Div. of Aquatic Resources, 1981-1997
5. Parrish, 2006

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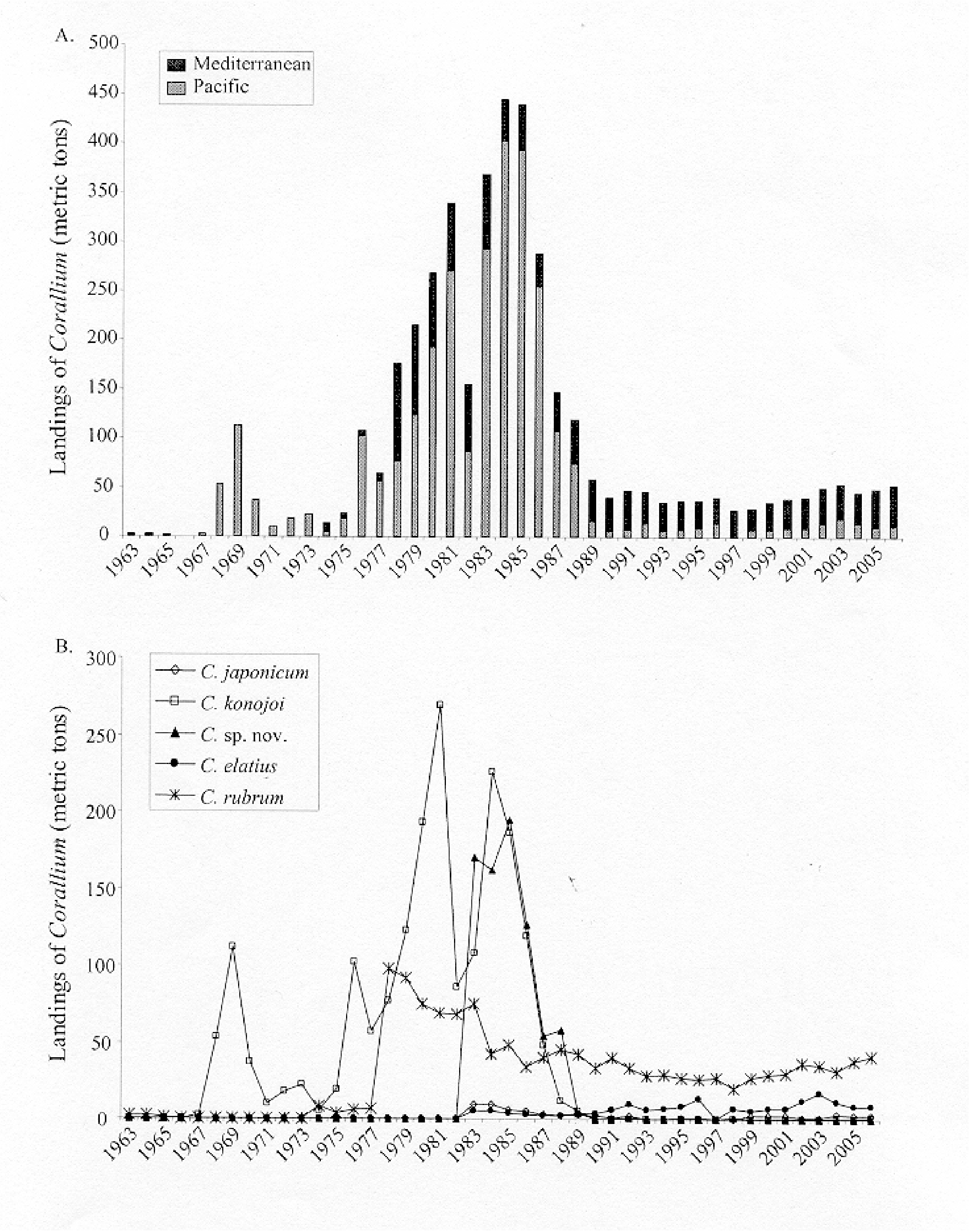

Fig. 1. Landings in metric tons of *Corallium* populations in (A) the Mediterranean Sea and the Pacific Ocean between 1963 and 2005, and (B) Landings of individual species. Note stability of *C. rubrum* landings over the past 20 years (Bruckner 2008).

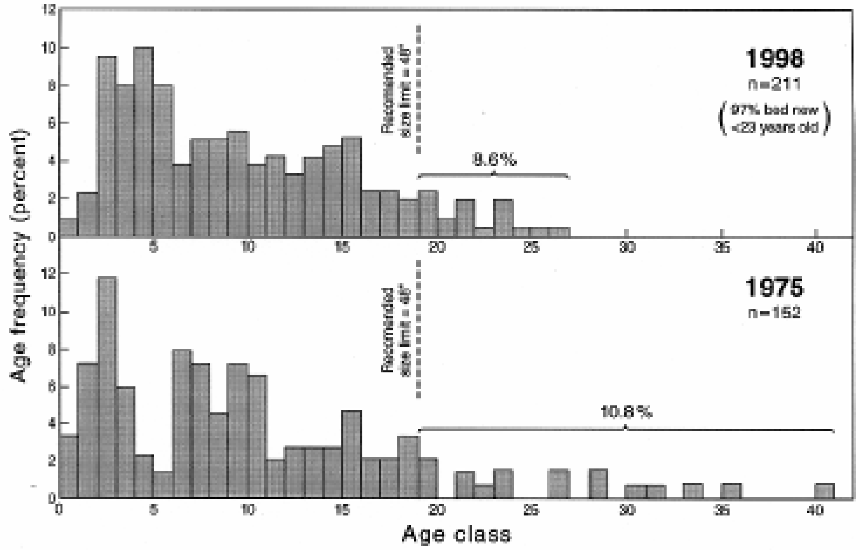

Fig. 2. Age frequency distributions of black coral (*A.griggi)* in the Maui bed in 1975 and 1998 (Grigg 2001). Note that 97% of the bed in 1998 is entirely due to recruitment since 1975. In other words, recruitment has been sustainable over the entire time period of 23 years between 1975 and 1998.

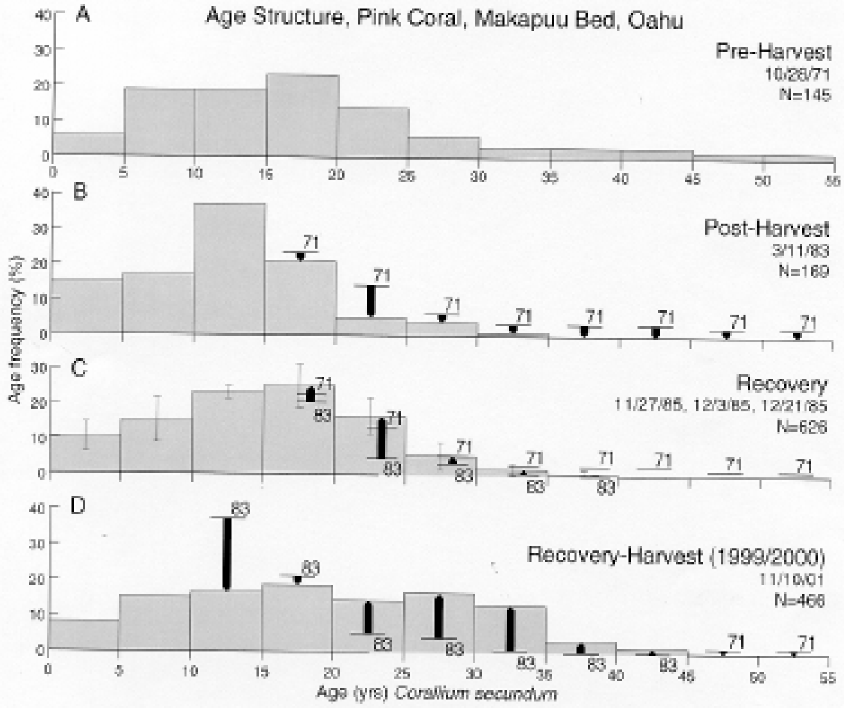

Fig. 3. Age structure (frequency distribution) of pink coral (*C. secundum*) in the Makapuu Bed, Oahu, in 1971, 1983, 1985 and 2001. Arrow bars indicate relative decrease or increase in age frequency since reference year.

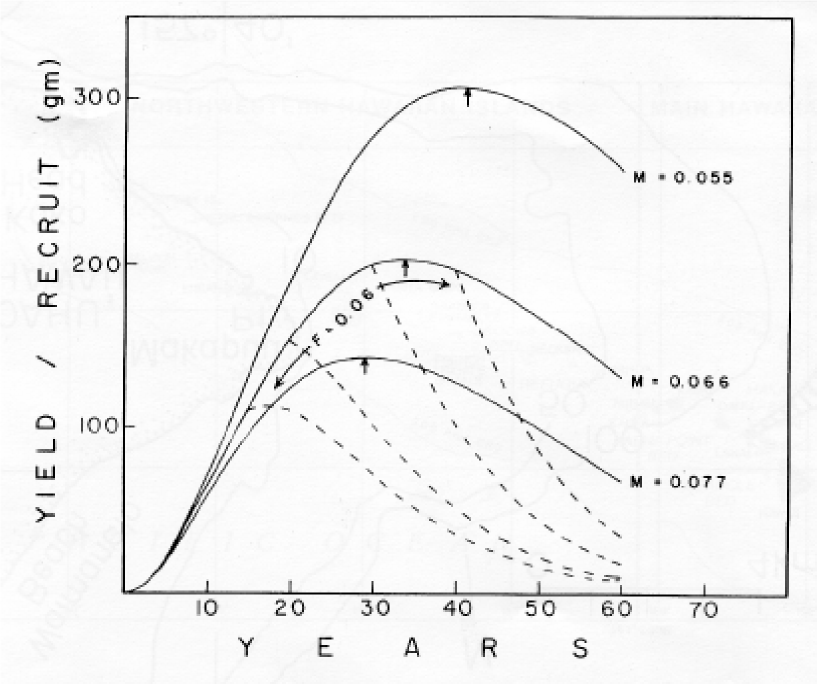

Fig. 4. Yield-per-recruit of pink coral (*C. secundum*) in the Makapuu Bed, Oahu based on the Beverton and Holt yield-per-recruit Model at three different values of natural mortality. Dashed lines indicate yield produced by applying a fishing mortality of 0.06 at four different ages.

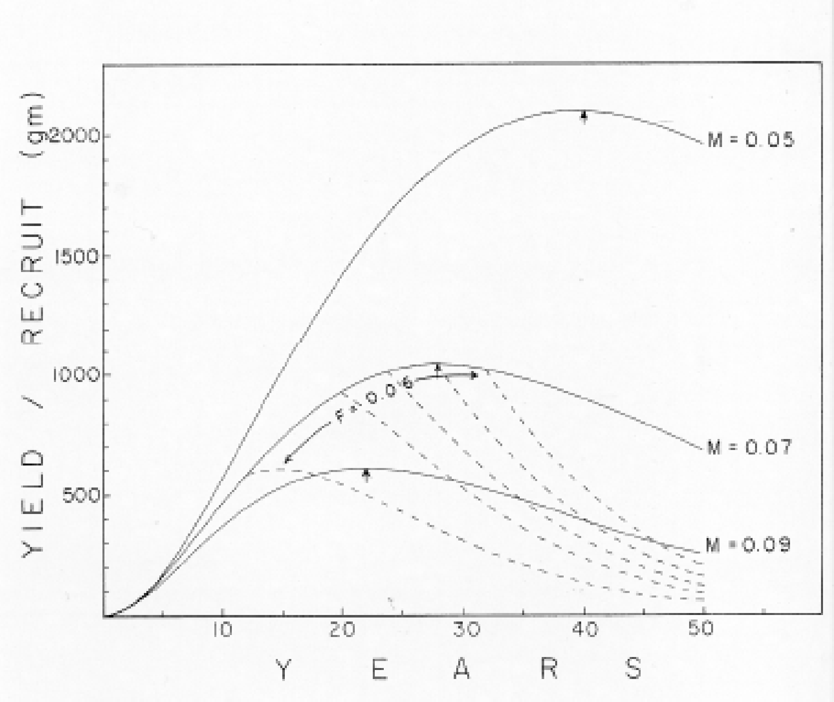

Fig. 5. Yield-per-recruit of black coral (*A. griggi*) in the Au'au Channel Bed, Maui, based on the Beverton and Holt yield-per-recruit Model at three different values of natural mortality. Dashed lines indicate yield produced by applying a fishing mortality of 0.06 at four different ages.

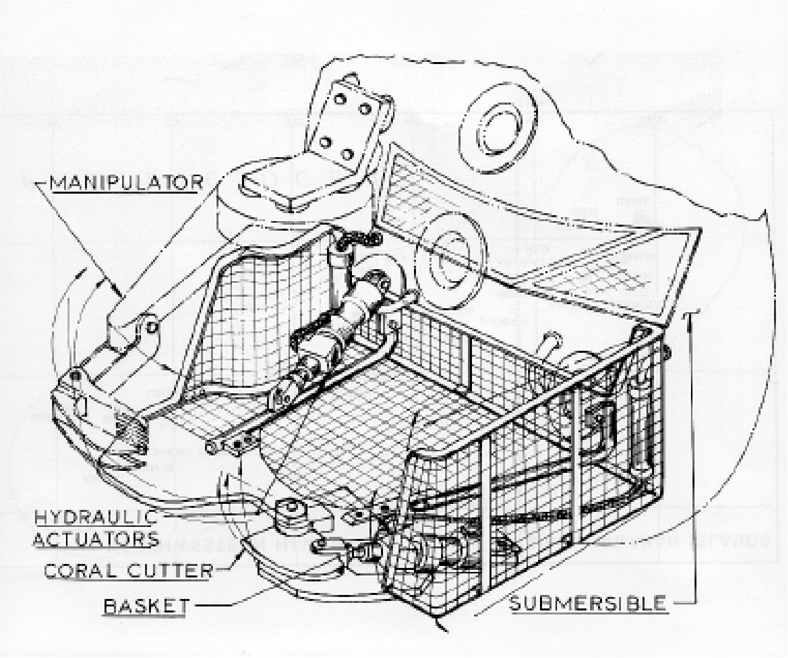

Fig. 6. In 1976, Maui Divers of Hawaii designed and used a basket and coral cutter assembly to selectively harvest precious corals. The basket assembly was attached to the Star II Submersible and operated by the pilot from inside the submersible.

THE DEEPEST KNOWN OCCURRENCE OF THE PRECIOUS RED CORAL *CORALLIUM RUBRUM* (L. 1758) IN THE MEDITERRANEAN SEA

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Introduction

An initiative for the worldwide conservation of gorgonian corals of the family Coralliidae (Anthozoa, Gorgonacea) was attempted at the 14th Meeting of the Conference of the Parties of CITES at The Hague (CoP14) through a proposal to place members of this family on Appendix-II of the Convention (Anonymous 2007; Pala 2007; WWF 2007). Ultimately the proposal was defeated in a secret ballot, although the decision was taken to organize topical workshops devoted to upgrading knowledge of precious corals, which are all grouped in the two extant genera *Corallium* and *Paracorallium.* This call resulted in two workshops focusing on Pacific and Mediterranean precious corals, held in 2009 in Hong Kong and Naples, respectively (IAPPCS 2009; Anonymous 2009). In the meantime the request for inclusion of the Coralliidae in Appendix-II of CITES is in all likelihood going to be proposed for consideration at the forthcoming CoP15 in Qatar, scheduled for the year 2010.

Corallium rubrum colonizes a variety of sublittoral habitats generally between a few meters depth down to 120 m in the Mediterranean Sea and Eastern Atlantic Ocean (e.g. Bayer 1964; Carpine and Grasshof 1975; Zibrowius et al. 1984; Chintiroglou et al. 1989; Cattaneo-Vietti and Cicogna 1993; Abbiati et al. 1993; Garrabou and Harmelin 2002; Torrens et al. 2008; Rossi et al. 2008; Tsounis et al. 2006). The bright red calcitic axis of this species has been prized in the jewelry trade from antiquity to the present day (Cattaneo-Vietti and Cicogna 1993; Tsounis et al. 2007). Although far from being close to extinction, a decline in shallow-water populations of this widespread taxon has nevertheless been observed, giving rise to some concerns about its management (Santangelo and Abbiati 2001; Santangelo et al. 2003; Tsounis et al. 2007).

The present paper is a contribution on novel aspects of the ecology, biology and biogeography of *Corallium rubrum* based on the recent discovery of previously uncharted deep-water populations in the bathyal zone of the Mediterranean Sea (Fig. 1).

Distribution of *Corallium rubrum* at Bathyal Depths

Living red coral colonies were observed in 2006 during the Marum-Quest 4000 ROV survey of the R/V Meteor in the Strait of Sicily in water depths down to at least 684 m (Freiwald et al. 2009: Fig. 4). Before this discovery, the deepest confirmed lower bathymetric limit of this species was 230 m at Cap Creus in the Western Mediterranean (Rossi et al. 2008). In the Strait of Sicily deep water, *Corallium rubrum* is now documented to occur at three disjunct sites, namely (1) Linosa Island, dive 673; (2) Nameless-Urania Bank, dive 677; (3) South of Malta, dive 657 (see Freiwald et al. 2009 for details of the ROV dive stations). The first two sites refer to submarine volcanic edifices where the species fringes overhangs and 'caves' often in close association with living colonial and solitary scleractinians (e.g. Lophelia pertusa, Madrepora oculata, and Desmophyllum dianthus), antipatharians and gorgonians (Fig. 2). The site South of Malta site refers to a sedimentary escarpment and is located in the South Malta Deep-Water Coral Province first described by Schembri et al. (2007). Here *Corallium rubrum* is also found in intimate association with white stony corals, primarily Madrepora and Lophelia. In addition, red coral branches, some possibly still alive, were also spotted in recent coral taluses accumulated at the foot of coral-covered walls, again in association with 'white corals' (Fig. 2).

Colonies of red coral were collected alive for the first time from such deep-sea sites off Linosa and South of Malta in 2007 during the scientific cruise MARCOS of R/V Urania (Fig. 3). Some of these samples were provided to investigators for genetic characterization to investigate the genetic connectivity between geographically and/or bathymetrically disjunct coral sites (Costantini et al. in press). Samples have been used for the geochemically-based evaluation of climatic signals incorporated into the calcitic skeleton (Montagna et al. 2008, in progress).

Conclusions and Recommendations

The discovery of deep-sea populations of *C. rubrum* is important for the overall characterization of its ecological requirements (substratum and physicochemical factors), connectivity (interrelationship between disjunct coral populations), and sustainable management. It is also relevant for the evaluation of the present status of this species in the Mediterranean Sea and the adjacent Atlantic Ocean.

The existence of previously uncharted deep-water populations is opening new perspectives in characterizing the distribution and the role that this habitat forming species plays in ecosystem processes of the deep Mediterranean Sea. This discovery increases significantly the known depth range of this cnidarian, suggesting its potential presence at many other still-uncharted deep-water sites in the Mediterranean basin.

The *in situ* observation of its intimate association with other ecologically valuable sessile organisms (white corals, antipatharians etc.) is a strong argument against any commercial exploitation of these deep-water colonies, and no exploitation whatsoever should ever be considered. On the contrary, such fragile red coral bearing deep-water habitats are in strong need of proper management to ensure their protection. The relative inaccessibility of such remote habitats at present serves to protect them; however, the continuous implementation of wide scale operations in the deep ocean (including industry) could in principle put in jeopardy some unique systems. Action should therefore be taken to ensure the inclusion of known deep-sea *Corallium* habitats within marine protected areas.

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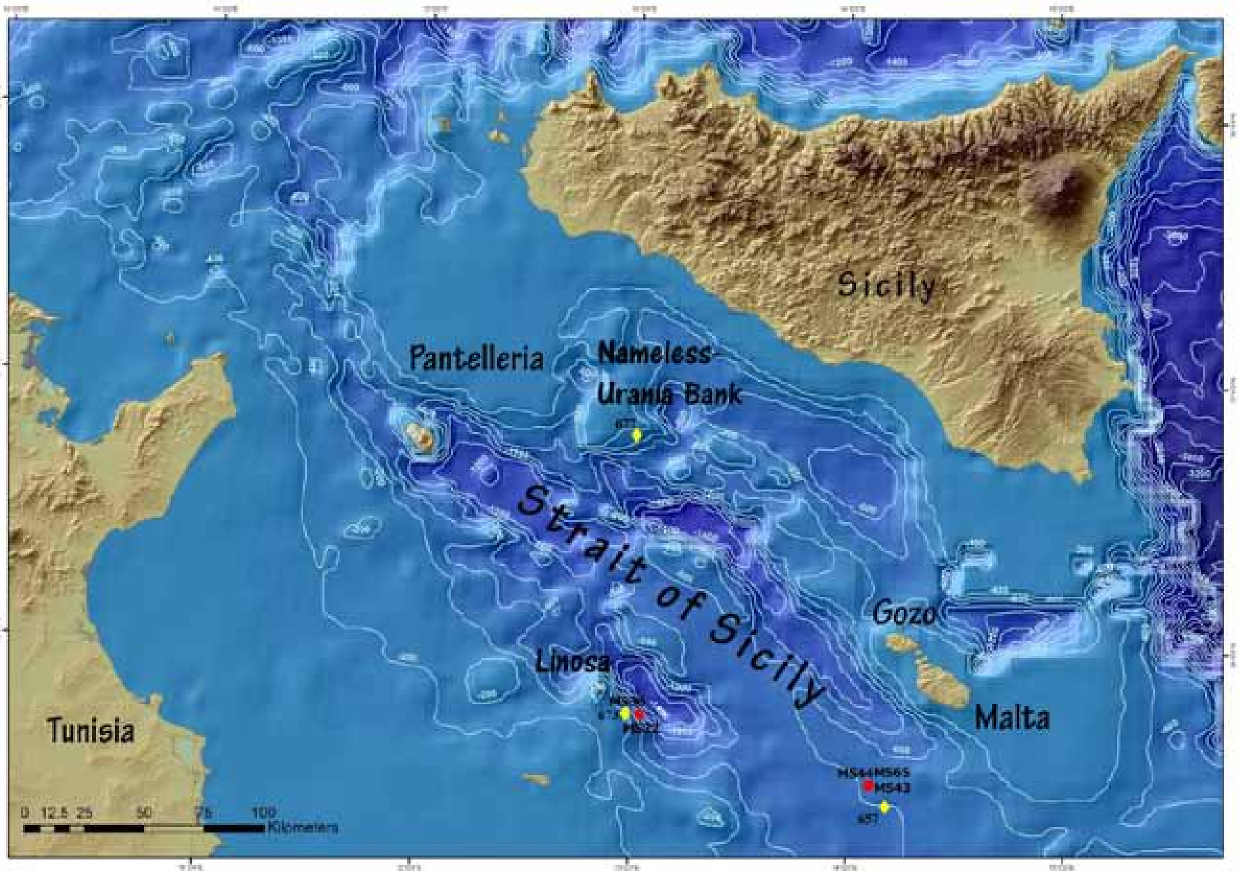

Fig. 1. Map of the Strait of Sicily showing the location of the MARCOS stations that provided live *C. rubrum* from bathyal depths. Red dots are samples from MARCOS Cruise; yellow diamonds are ROV dives from Meteor M70/1 Cruise (see Freiwald et al. 2009 for details).

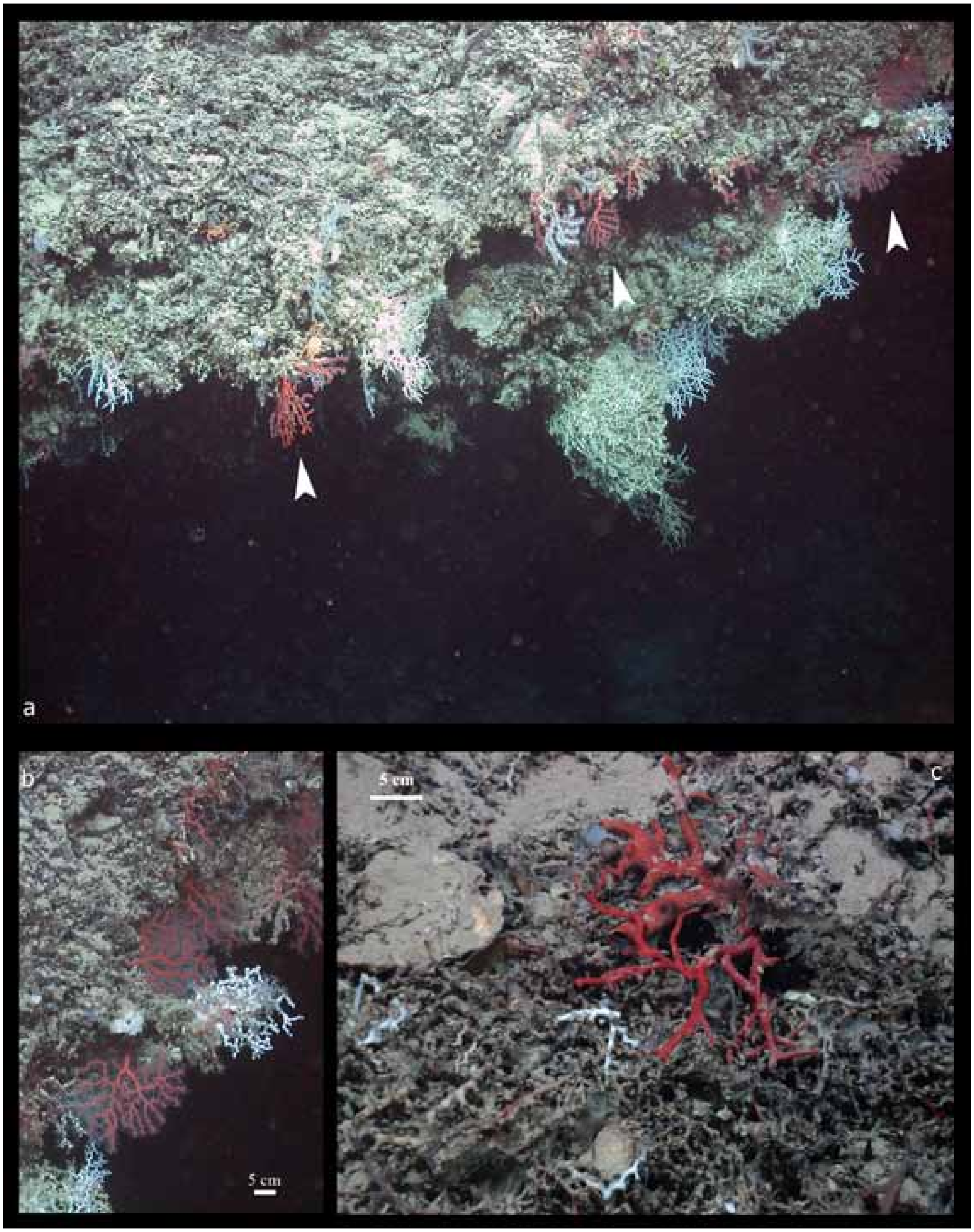

Fig. 2. MARUM ROV 'Quest 4000' *in situ* documentation of *Corallium rubrum* occurrences at Linosa Island site, Dive 673, Linosa Trough: (a) panoramic view of the complex coral-bearing community fringing overhangs at the edge of volcanic caves at 673 m water depth: note clumps of live *C. rubrum* (arrows) intimately associated with other cnidarians, including *Madrepora oculata*; (b) close-up of living *C. rubrum* from the same site showing fully expanded polyps (-673 m); (c) biostromal coral accumulation at the foot of the Linosa volcanic edifice; note fresh-looking *C. rubrum* and *Madrepora* together with degraded and partly silted white and red coral debris (-737 m). All pictures courtesy of MARUM, Bremen University.

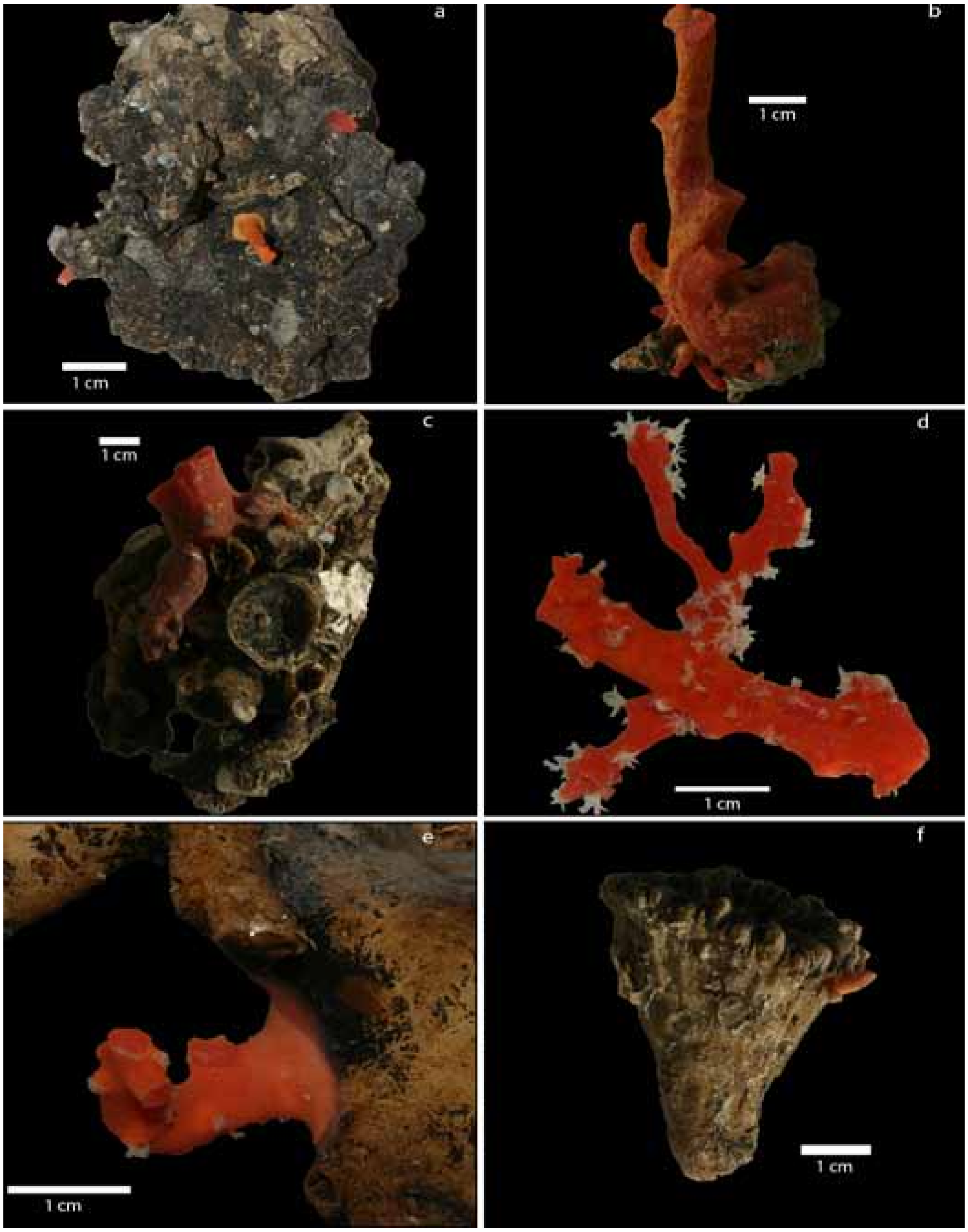

Fig. 3. Examples of deep-water red coral samples from the Strait of Sicily, MARCOS Cruise: (a) Coral-hardground with modern *C. rubrum* colonies St. MS43; (b) Large live *C. rubrum* colony st. MS43, ca. 650 m; (c) Degraded patinated hardground with red coral growth St. MS32; (d) Living colony of *C. rubrum* with expanded polyps, st. MS43; (e) Living colony of *C. rubrum* growing on degraded coral hardground st. MS43; (f) *Desmophullym dianthus* fouled by recent *C. rubrum*.

FOSSIL CORALLIIDAE IN THE MEDITERRANEAN BASIN

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Introduction

Members of the family Coralliidae (Cnidaria, Octocorallia, Gorgonaria, Scleraxonia) are characterized by a massive, continuous, calcitic axis, and loose calcitic sclerites imbedded in the soft polyp and coenenchyme tissues. The axis is easily preserved as a conspicuous fossil whereas the tiny (taxonomically significant) sclerites are dispersed post mortem and are still unknown in the fossil record. Discrimination of species is based on shape and size of sclerites, branching mode of the colonies, and axis ornamentation (e.g. Bayer 1964; Bayer and Cairns 2003). The some twenty species described in the recent fauna world-wide have lately been distributed between the genera *Corallium* (Cuvier 1797) and *Paracorallium* (Bayer and Cairns 2003), the latter being characterized by longitudinally grooved axes and axial pits with beaded margins containing the autozoid polyps.

Part of the deep-water coralliid species world-wide have their branches modified by symbiotic polynoid polychaetes which induce the formation of gall-galleries with series of lateral openings. These galls run along or curl around the branches, providing a shelter for the symbiont (Bayer 1964). Polynoids associated with various deep-water coralliid species from the Atlantic and Indian Oceans have been identified as Polynoe caeciliae Fauvel 1909, by Hartmann-Schröder 1985 (see also Martin and Britayev 1998). Polynoid gall-galleries on Coralliidae are of the same type as skeletal deformations observed in many species of Stylasteridae (Hydrozoa), likewise caused by other species of Polynoidae (Zibrowius 1981; Cairns 1991).

In the present-day Mediterranean Sea, the family Coralliidae is represented by the single species *Corallium rubrum* (Linnaeus 1758), which is eurybathic (from shallow low-light to bathyal aphotic habitats) and widespread in this basin and in the adjacent Atlantic (e.g. Carpine and Grasshoff 1975; Zibrowius et al. 1984; Chintiroglou et al. 1989; Cattaneo-Vietti and Cicogna 1993; Santangelo and Abbiati 2001; Tsounis et al. 2007; Rossi et al. 2008; Freiwald et al. 2009; Taviani et al., this volume, with references therein).

However, as shown here, Mediterranean Coralliidae were more diverse in the past and had been established in this sea since at least the Early Miocene. These preliminary results arise from the critical examination of literature data, museum collections and new paleontological material collected from Cainozoic deposits in northern and southern Italy (Fig. 1).

Fig. 1. Location map of fossil Coralliidae in the Mediterranean area. Only confirmed records are indicated (samples examined and confirmed as Coralliidae). White marks: Miocene from Carboneras (SE Spain) and Turin Hills (N Italy); black marks: Pleistocene from Capo Milazzo, San Martino and Messina (Sicily, S Italy); grey mark: Pleistocene from Augusta and the vicinity of Catania (Sicily, S Italy).

Cainozoic Documentation of Coralliidae in the Mediterranean Basin

The oldest record of *Corallium* in the Mediterranean area (De Angelis 1894) is Oligocene ("Tongriano") but needs to be verified. Records from the Miocene are more reliable, some even duly confirmed and well illustrated. Several examples are thus reported in the literature (e.g. Zuffardi Comerci 1927; Chevalier 1961; Barrier et al. 1992; and references therein). Various fossils have been examined for the present study.

Although the taxonomy of the Miocene coralliids remains problematical (sclerites still unknown) it can be stated already that in the Mediterranean Miocene two types of Coralliidae are represented: (1) axes morphologically indistinguishable from those of the recent *Corallium rubrum*, and (2) others most similar to those of deep-water species known from the present-day Atlantic fauna, their resemblance marked by the presence of polynoid gall-galleries. Records of the latter type include the Lower Miocene (Burdigalian) of the Turin Hills (northern Italy: Zuffardi Comerci 1927; Taviani et al. 2005) and the Upper Miocene of Carboneras (SE Spain: Barrier et al. 1992); Fig. 1.

Depending on the state of preservation, coralliids of the "deep-water"-type are more or less easily distinguished from their *Corallium rubrum*-like counterparts by (1) branching mainly in one plane, (2) having secondary branchlets distributed only along one side of the main branches and/or eventually showing more distinct axial depressions corresponding to autozoids, and (3) bearing polynoid gall-galleries (even if not on all fragments). The galls are fragile structures often preserved only as longitudinal grooves (Fig. 2 a,b).

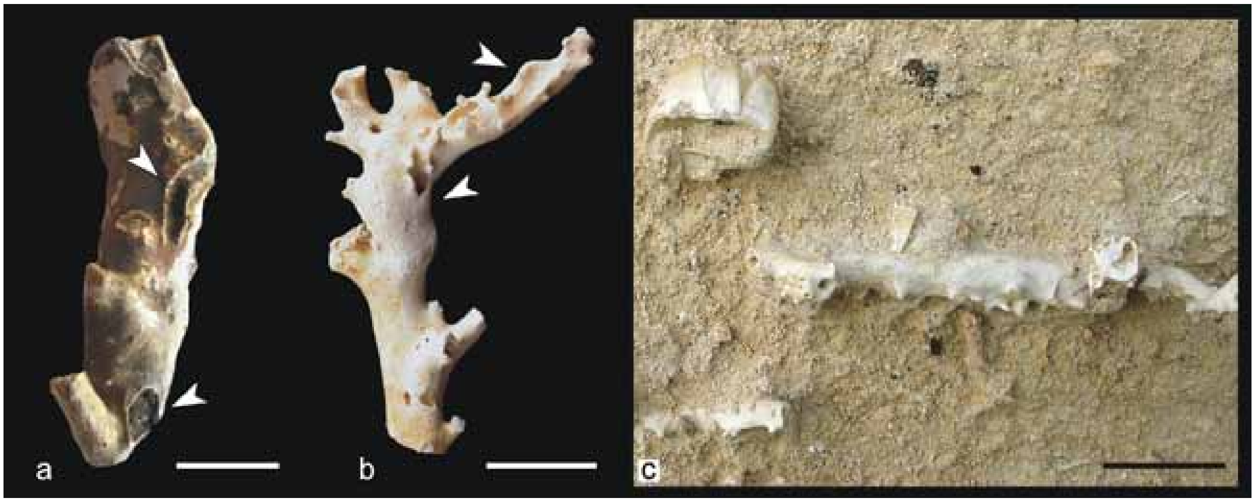

Fig. 2. Fossil *Corallium* fragments showing traces of polynoid gall-galleries (white arrows); a Burdigalian from the Turin Hills (N Italy), scale bar 1 cm; b,c Pleistocene from Capo Milazzo (Sicily, S Italy), scale bars 2 cm.

The larger and better-preserved "deep-water" coralliids with occasionally distinct polynoid gall-galleries were found to be more abundant at some Pleistocene sites of Sicily (Messina, San Martino, and especially Capo Milazzo: Figs. 1, 2 b,c). It can be deduced from their shape that colonies were essentially uniplanar. The axis surface is devoid of deep (autozooid) depressions, shows a fine granulation and a faint longitudinal striation which is more evident on the side not bearing secondary branchlets. As in recent Atlantic bathyal species (e.g. *Corallium johnsoni, C. niobe*), the Pleistocene fossils have polynoid gall-galleries located on the "front" side of the branches where the induced abnormal growth of secondary branchlets contributes to the gall formation by fusing upwards and producing the cage-like structures (Fig. 2 b).

In addition, Pleistocene deposits of southern Italy (Sicily) produced tiny coralliid fragments marked by deep (autozooid) depressions with their margin conspicuously beaded. This is the first record of what, according to Bayer and Cairns 2003, would be a character of the genus *Paracorallium*.

Finally, fossils morphologically indistinguishable from the recent *Corallium rubrum* are known from Pleistocene deposits (mostly circalittoral) at many sites in Sicily (e.g. vicinity of Catania, Augusta). A comprehensive compilation of fossil occurrences of this species is in progress.

Discussion and Conclusions

The data presented here document that Coralliidae morphologically close to, if not identical, with the recent species *Corallium rubrum* were already present in the Mediterranean since Miocene times. The data also indicate that the basin was, at times, inhabited by more than one species of

Coralliidae as this is still the case now in the adjacent Atlantic. Thus the Coralliidae is one more group (in addition to, e.g. scleractinian corals, molluscs and pedunculate crinoids) that testifies of the "more oceanic" character of the ancient Mediterranean deep-water fauna when homothermy of deep waters at a relatively high temperature was not yet established. The new fossil records also include forms that would conform to the genus *Paracorallium*, previously recognized only in the Indo-Pacific (Bayer and Cairns 2003).

It can be assumed that populations of *Corallium rubrum* did occur, without interruption, in the Mediterranean basin at least since the early Pleistocene. Their early presence may explain (1) the variety of partly-disjunct habitats presently occupied basin-wide, from shallow to bathyal depths, and (2) the significant genetic variability displayed by shallow and bathyal populations (e.g.,Abbiati et al. 1993; Costantini et al., in press). This aspect should be taken into account when considering sustainable management of *C. rubrum* throughout its Mediterranean-Atlantic range.

Acknowledgements

We are grateful to V. Bugnano for his assistance in paleontological research on the Miocene of the Turin Hills. A. Logan kindly revised the English text. Research was partially funded by HERMES (GOCE-CT-2005-511234-1) and HERMIONE (contract number 226354) projects of the European Commission and Catania University research programs (PRA: "Programmi di Ricerca di Ateneo"). This is ISMAR-Bologna scientific contribution no. 1652.

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GEOCHEMICAL INVESTIGATION OF *CORALLIUM RUBRUM* FROM SHALLOW AND BATHYAL SETTINGS IN THE MEDITERRANEAN SEA

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Specimens of the calcitic gorgonian coral *Corallium rubrum* collected from shallow and bathyal settings in the Mediterranean Sea have been investigated for trace elements and stable isotopes at high-spatial resolution, using laser ablation ICP-MS and a computer-controlled micro-drill. Our research aims to assess the environmental parameters recorded in the calcitic skeleton of this precious long-lived coral as geochemical signals, considering the possible complications of the biological activity of the organism during the skeletogenetic processes. Laser ablation ICP-MS and stable isotope transects across the solid axial calcareous skeleton of living and fossil specimens from shallow water off Marseille, Corsica and the Medes Islands and deep-water settings off of Linosa show large geochemical variability (25% for Mg/Ca, 57% for B/Ca, 20% for Sr/Ca, 200% for U/Ca, 17% for Ba/Ca, 75% for P/Ca and 80% for Li/Ca). Bathyal environmental conditions are quite stable at around 13.9°C and 38.77 PSU throughout different seasons and the amplitude of the geochemical tracers should be minimal. The highly variable and microstructure-related geochemical concentration across the axis indicates that vital effects might be involved and partly controls the systematics of the trace elements, with most of the elements significantly enriched in the medullar region. The role of the biological activity in obliterating the environmental signals recorded in the geochemical pattern can be best assessed at the bathyal sites and might have also implications for shallow water specimens.

The multi-proxy approach will also help to test the likely annual nature of the thin banding in bathyal specimens and the use of high-resolution micro-analytical techniques will potentially provide monthly records of temperature and other important environmental parameters (e.g. nutrient content).

Section II

Harvest, Manufacturing, and Trade

OVERVIEW OF LAW ENFORCEMENT ISSUES REGARDING THE TRADE IN CORALLIUM

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Wildlife Inspectors at various ports in the U.S. regulate the import and export trade in the various species of coral, including the precious Red Corals, (*Corallium* sp.). Included in the many issues and challenges faced by these inspectors are; a lack of training or experience in identification of the various species of red corals listed on CITES and other similar non-CITES listed corals, and a lack of ready access to experts in this area. Despite such challenges, Wildlife Inspectors remain dedicated to the enforcement of CITES laws and regulations. Data from the Law Enforcement Management Information System (LEMIS) shows the trends of imports and exports of such coral items in the trade.

"THE CORAL ROUTES:" FROM THE MEDITERRANEAN SEA TO THE WORLD-WIDE JEWELRY

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Certainly the fascination that coral has always exercised on the human imaginary originates from its enigmatic nature, between the three kingdoms: not a plant, even if branched, not a mineral, though petrified, not exactly an animal, even if of the color of blood, but in fact we now know that coral is composed almost entirely of calcium carbonate produced by colonies of microorganisms and is therefore of animal origin. Its singular genesis has been a source of myths and beliefs of portentous apotropaic virtues, which have crossed the centuries-old traditions of different and distant cultures from East to West.

The ancient Romans of the first century A.D. already wondered about its origin, and soon joined its warm and vivid color to blood, so that Ovid in his "Metamorphoses" and Pliny the Elder in his "Naturalis Historia" recognized to coral the same mythical genesis: the blood which continued to drip from Medusa's Severed Head, turned into coral. The coral ornaments found in some archaeological sites suggest that it was already known several thousand years ago, and we know for certain that the Greeks appreciated coral and used it also in pharmacology. But it was only a few centuries later, with the ambitious project of Alexander the Great to fuse East and West into a single empire not only through military conquests, but also thanks to a cultural unification favored by trade, that coral opened its way to India. Pliny provides tangible proofs of this, in the aforementioned "Naturalis Historia," stating that: "The Indians prize coral just as the Romans prize pearls, the cost varying according to the importance attributed by each people to the commodity in question."

Coral fishing was practiced throughout the Mediterranean and surely the Greeks, the Phoenicians, and the Etruscans were devoted to it and through this dense network of routes by land, sea, and river, along which in ancient times the Chinese empires and the West used to trade, the coral arrived in the Middle East, Asia Minor, India, China, and became deeply rooted in the customs of those eastern nomadic peoples where it was even used as an ornament for their horses, a protection before battles, seeing it as a formidable talisman. The routes of silk and spices became therefore a huge melting pot in which the most different cultural experiences met and melted giving rise to unique results, real synthesis of the encounter between different traditions. The wonderful ethnic jewels made from coral fished and worked mainly in Mediterranean countries and then assembled according to local customs, are the most eloquent testimony of the exchanges between the precious goods of those eastern countries and coral: the most typical product of the Mediterranean civilizations. This extraordinary jewelry is the tangible evidence of the millennia–old links that have joined East and West, through the renowned silk and spice routes, which became also the routes of coral, since our red gold was often the price paid for the precious eastern goods.

Since ancient times coral and magic have been chasing each other, intertwining, confusing in superstition, or just good-luck rituals, but perhaps what is more amazing is that over the centuries coral has always been recognized as a powerful talisman: from the Mongols to the Indians, from the Chinese to the American Indians, through Yemen, Turkey, Uzbekistan, North Africa, and Europe.

This fascinating and unusual circumstance was due to the fact that the “Silk Route,” which started two thousand years ago from northern China, across the steppes of Central Asia and arrived in the West, and the “spice route,” which connected the deep south of the Arabian Peninsula with Mare Nostrum, had been travelled also in the opposite direction from brave merchants, people who had moved from the Mediterranean to the Far East, using the red coral as a bargaining chip, thereby increasing its perfect assimilation with local habits.

What makes the ethnic jewel so peculiar is its strong symbolic language to which no part is by chance, but always the result of a well-considered choice! Red coral, with its strong apotropaic powers, is chosen for its propitiatory virtues to well-being, fertility, longevity and when it is set in a jewel, all its benefits are reinforced by other features of amulets such as the shape, pattern, text and so on, which vary from one culture to another.

Different tasks assigned to ornament generate diversity in the style of the jewel of East and West. In fact, while in the West, jewels mainly fulfill an aesthetic reason, meant to make a person look nicer and are expression of people’s taste and wealth, in other cultures, a jewel takes on a lager role; not only does it indicate one’s taste and economic status, but it also conveys symbolic messages connected to the history and religion of the culture in which the jewel was conceived. Nothing is left to chance and all symbols, shapes and materials define the person who wears them, ornaments are transformed into “identity cards” whose main function is to protect the wearer through the most delicate phases of life: birth, puberty, marriage. The ornament is then charged with magic powers, becoming an amulet to ward off evil, or a powerful talisman to provide wealth and prosperity.

In India, a country with huge ethnic, linguistic, and religious differences, where a billion people communicate in about twenty officially recognized languages, but in fact they use three hundred different dialects, one constant point of reference amidst the ethnic diversity is the passion for the ornament. Perhaps in no other country like India, jewels have satisfied the desire to adorn the body and the need to define membership in the cultural group, in a perpetuation of forms that have been handed down and repeated by the Indians for millennia.

According to the Indians, each gem has a magical and symbolic value in relation to its color that summarizes the emission of cosmic rays of a corresponding planet, personified in turn by a celestial deity: it is the Navaratna amulet, a precious jewel with nine gems which represent the nine celestial bodies identified with nine deities in which there is a triple association: gem-planet-deity.

Coral is associated to the deity Mangala and to the planet of Mars which is believed to govern the color red, the fundamental life-giving energy, and to determine kinship, strength, and sexual potency; coral as an amulet plays a role of mediator and will balance those aspects of life.

Also in the Tibetan-Mongolian area, coral has impressed the collective imagination so much that it was attributed with extraordinary scaramantic powers.

In fact, on top of the world, in Himalaya, jewels are worn stacked overlapping on clothes: in Tibet, Nepal, Buthan, Ladakh, those jewels are meant to resist the itinerant life of a mainly nomadic population. They are talismans that help protect them from a magnificent but also menacing landscape.

Similarly in Mongolia, a jewel does not only indicate one's taste but it also conveys symbolic messages connected to the history and religion of the culture in which the jewel was conceived and coral has the protagonist role. Maybe for its sanguine red color, its indefinite origin, its durability, and its magic, coral fascinated this nomadic people, accustomed to the monochromy of their steppe, and became the sign of vital energy and for this quality it could propitiate well being, health, and fortune. These powers were enhanced by combining coral with turquoise, symbol of the air.

As for other nomadic populations, the Mongols invest much of their wealth in jewels and other precious objects, in order to be able to carry and eventually convert them into cash, for this reason it is not unusual to see women at work, covered with showy necklaces.

Following the route of silk, we move to Central Asia, where the scarlet gem deeply fascinated the nomadic peoples of the deserts. Although surrounded by mountains, this region didn't close its boundaries to the western world. The route towards Asia, definitely opened by Alexander the Great, became one of the main euroasiatic trading routes, a network of caravan trails along which oases rose, offering a haven to the merchants and travelers on their way to India and China. The "silk route" was also the "route of coral."

It was its color that became decisive in its evaluation and adoption. The blood-red tint, together with its mysterious origins and its durability, captivated these migratory peoples and came to symbolize the force of life. Coral began to be considered as a protective amulet or talisman, in time it became a metaphor for beauty and vitality. In fact, in Uzbekistan, the allegorical description of an ideal woman evoked "…eyebrows like bird's wings, teeth like pearls, ears like sea-shells, lips like coral."

There were also other caravan routes, which bore the precious resins and other Indian and African commodities to the Mediterranean and they all passed through Yemen. On these routes, exotic spices and cloths from India were exchanged for coral, highly priced by the peoples of southern Arabia for its blood red color and other virtues.

When, in 7th century, Islam took over the Arabian peninsula, it enhanced the importance of coral. In Sura 55 of the Koran, we read that the virgins in the garden of paradise "will be like ruby and coral" (LV, 58), this metaphor is very striking and gives us the full measure of coral's importance. In Yemen, the ornament has to fulfill a range of functions. Certainly, it adds luster to the person who wears it, but it also affirms the economic standing and defines the role in society. Different jewels are meant for different people: a baby, a child, a young girl, or a married woman, because any special moment of life requires special protection, which only coral can provide.

The importance of coral in the ethnic costume and ornamentation of the Berber and Maghrebin peoples is just one more instance of how coral has been one of the main vehicles for common symbolism and meanings throughout the Mediterranean. A very fascinating symbolism can be found in the culture – and then in the jewels – of Morocco and Algeria, the countries bordering the Mediterranean that witnessed uncountable cultural mixtures, so the indigenous Berber population assimilated new information from all the civilizations they came into contact with: the Phoenicians, Greeks, Romans, Byzantines, Vandals, Arabs, Turks, Andalusians. Inevitably, the signs of this stratification, have been immortalized in the Maghrebin ethnic jewelry: In the techniques of granulation, for example, we find the imprint of Roman jewelers, the round tabzimt brooch of the Algerians Benni Yenni recalls the models of the jewelry of the Vandals, Visigoths, and Merovingians, then, new symbols (such as the preference for abstract motifs or the "hand of Fatima" amulet), together with new techniques and materials arrived with Islam, starting from the eighth century.

Even in the hearth of Africa the ornaments are not only decorative, but they are the image of a society and mirrors of cultural identity, they convey symbolic messages connected to the history and religion of the culture in which they are conceived.

The ethnic jewelry is an effective and synthetic symbolic message that, thanks to the use of particular forms, colors and materials, can tell the life of the person who stands before us, and reveals the creed, class and position within the community, a real status symbol to flaunt to get the public recognition of his role in society. In Nigeria, for example, coral is very highly valued, becoming sign of dignity and unquestioned power, in fact the quantity of coral worn indicates both the social level and the wealth of the wearer.

From East to West, backward along the routes of coral, we return to the Mediterranean and in particular to Torre del Greco, world famous for coral processing from the beginning of the XIX century. In fact, in 1805, Paolo Bartolomeo Martin, from Marseille, had the idea of founding a coral factory in Torre del Greco, already a thriving fishing centre, and from that point on the history of coral binds strongly to the history of the town in an inseparable combination that still today should aim to the mutual enhancement.

As with other biological resources that exist in nature and are used for commercial purposes, also for coral, there is the issue of sustainable management, in fact since 1994 the European Union has banned fishing with dragging nets. Today, throughout the Mediterranean coral is harvested by skilled and experienced scuba divers in a very selective way, and in quantities far less than before. Moreover, there is the example of the Sardinia Region where, after thirty years of regulation of coral fishing (www.regione.sardegna.it), scientific data have shown that in the island red coral is in good ecological conditions. The island is confirmed as a model in the Mediterranean area for the preservation, management and sustainable use of red coral, a proof that a correct use of coral is possible, without the bureaucratization of its trade.

This demonstrates that a proper management can reconcile the demands of safeguarding the precious resource, with economic requirements of the "corallari" who, among other things, must also ensure future generations the opportunity to pursue a craft that for centuries has contributed significantly to the economy of the Country.

By preserving our traditional crafts, we will not perform a merely economic operation but also and above all a cultural one, since coral workmanship contains our history without which we would lose the sense of belonging and the awareness of our deep roots.

We wish our town to receive again the role it had in the past when it was the centre of the coral economy, giving it credit for creating a generation of expert craftsmen who worked and transformed the raw material with skill and fineness, creating a jewelry that reached a wide international audience and that made the "Made in Italy" world famous.

DISTRIBUTION AND FISHERIES OF THE RED CORAL *CORALLIUM RUBRUM* (LINNAEUS, 1758) IN THE GREEK SEAS: AN OVERVIEW

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Abstract

Information, both on the spatial and vertical distribution of *Corallium rubrum* and its fisheries status in the Greek Seas, is reported in this paper, along with problems related to the conservation and sustainable management of this renewable biological resource. Although fisheries of red coral stocks in Greece have been regulated according to a national rotating harvesting system since 1994, the difficulties experienced by both local and central authorities in confronting the illegal fishing of red corals in closed areas may have resulted in a decrease of the local populations. Available data show that in many areas the shallow water red coral stocks (up to 60 m) are now almost depleted. The observed evidence for the decline of red coral stocks in areas only recently opened up to exploitation is a clear indication that fishing (most probably by using illegal dragging gears) was carried out in these areas throughout the closed period. As an attempt to safeguard stock conservation, it is strongly recommended that an international research programme be set up, aiming at investigating the spatial and vertical distribution as well as the population structure of red coral in the Greek Seas, along with the enforcement of supplementary measures that will improve the effectiveness of the rotating harvesting scheme.

Introduction

The presence of the red coral *Corallium rubrum* (Linnaeus, 1758) in the Greek Seas, from its first record (Forbes 1844), has since then been reported sporadically (Dounas et al. 1989; Chintiroglou et al. 1989, and references therein). For a long period this species was commercially (though unofficially) exploited in the Greek Seas. Since the early seventies, interest in investigation and assessment of its populations throughout the Greek territorial waters as a new and promising financial resource for Greece had already been brought to the attention of the Fisheries Central authorities. This led the Ministry of Agriculture to establish for the first time relevant legislation (Greek Law 1740/1987) imposing a general framework for the exploitation of the red coral stocks. According to this legislation, harvesting, processing, and trade of the red coral were to be allowed only after the purchase of a special license. Five years later, after scientific data confirmed its presence in large populations in certain areas of the Greek Seas and at depths ranging from 50 to 110 m (Chintiroglou et al. 1989), two additional laws were enacted in order to further manage the exploitation of *C. rubrum* (Presidential Decree 174/1994; Ministry Decision 240102/1995).

The present study provides an updated checklist of *C. rubrum* records in the Greek Seas as well as fisheries data from the last two decades, and concludes by suggesting measures for the rational exploitation, conservation and sustainable management of this renewable biological resource in this part of the Eastern Mediterranean Sea.

Materials and Methods

A review of available data concerning the spatial and vertical distribution of *C. rubrum* in the Greek Seas was conducted by retrieving information from publications in scientific journals, conference proceedings, and grey literature (e.g. project technical reports and Ph.D. theses). Moreover, new and previously unpublished records from the island of Crete and the North Aegean Sea, which have been gathered during different research activities of the Hellenic Centre for Marine Research (HCMR) and the Department of Marine Sciences of the University of the Aegean, are included. Information concerning red coral landings during the period of 1995 to 2006 was also provided from General Fisheries Directory of the Greek Ministry of Agriculture.

Results

Spatial and Vertical Distribution, New Records

C. rubrum is distributed in several areas of the Greek Seas (e.g. Aegean, Ionian, Cretan, and Libyan Seas) (Fig. 1, Table 1). As far as bathymetric distribution is concerned, the red coral extends from 40 to more than 120m (Fig. 2, Chintiroglou et al. 1989; Vafidis et al. 1994; Salomidi et al. 2009; unpublished data from the HCMR and Dept. Marine Sciences) and is usually found in caves or under overhangs.

Fig. 1. Geographical distribution of *Corallium rubrum* in the Greek Seas based on scientific data.

Table 1. Population and bathymetric distribution data available for *Corallium rubrum* in the Greek Seas.

Populations	Bathymetric Distribution	Locations	Source
8 colonies of *C. rubrum*	50-110m	N. Aegean Sea (Ierissos Gulf, Chalkidiki Peninsula, N. Evia Island coasts, Island of Crete)	Chintiroglou *et al.* 1989
22 colonies of *C. rubrum*	60-65m	N. Aegean Sea (Siggitikos Gulf -Mount Athos, Alonissos and Lesvos Islands)	Vafidis *et al.* 1994
Living colonies of *C. rubrum*	50-91m	N. Aegean Sea (E. Evia Island)	Salomidi *et al.* 2009
Living colonies of *C. rubrum*	90-125m	Crete Island	HCMR-Crete unpublished data
Living colonies of *C. rubrum*	70-90m	N. Aegean Sea (Agios Efstratios Island)	Dept. Marine Sciences unpublished data

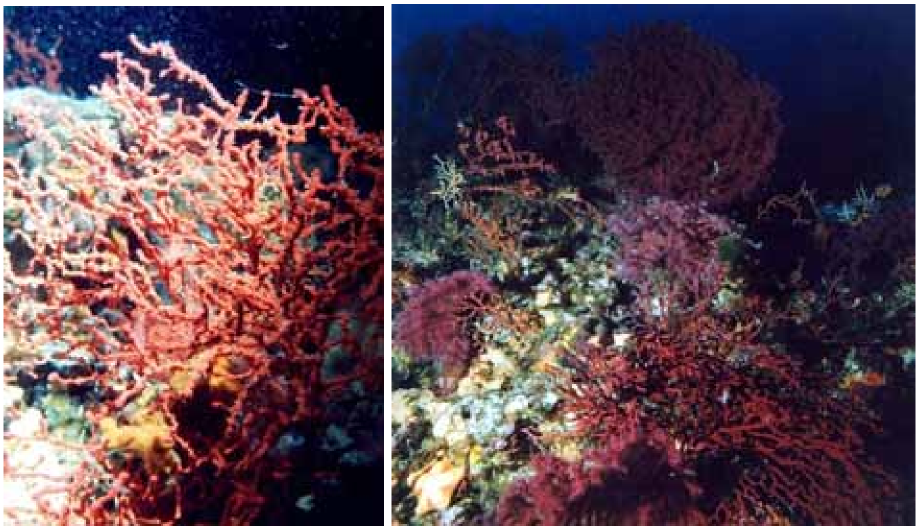

Fig. 2. Colonies of the red coral *C. rubrum* along with the purple gorgonian *Paramuricea clavata* (Risso) in coralligenous beds of Mountain Athos coasts, North Aegean Sea (Photos by C. Christou).

Red Coral Fisheries

A national rotating harvesting system covering five large fishing geographical zones was set up in Greek waters once the legislative framework was in place in 1994 (Fig. 3). According to this scheme, each area may be harvested on a maximum 5-year rotational basis, which is then followed by a 20-year closure period. The harvesting period in each zone can vary depending on the density of coral populations.

Fig. 3. The five large geographical regions in the Greek Seas where the red coral is harvested on a rotational basis.

Overall, a maximum of 10 licenses are given each year, each costing 3000 Euros. The harvesting period in each year lasts from April 1 to December 31. Whenever professional coral harvesters find coralligenous formations, they must immediately inform the local port authorities before any harvesting can be undertaken. According to the national legislation, there were three harvesting methods for the red coral stocks in the Greek Seas. The first was manual harvesting by means of SCUBA diving or hookah diving "nargiles" using a metal serrated pickax which is still in force. The other two methods – now illegal – included the use of a specialized dragging gear equipped with nets of different mesh sizes: a) a metal rod called 'ingegno' (weight of 100-150 kg and maximum length of 3 m) (Fig. 4), and b) an egg-shaped piece of marble called 'Columbus' egg' (weight of 100-150 kg and maximum length of carrying nets of 10 m). The corals are firstly cracked and detached from the seabed and then collected by the nets as the harvesting gear is dragged from the boat with a rope (Figs. 5, 6). Each boat was allowed to carry only one metal rod or egg shaped gear. The use of Saint Andrews' cross was always officially forbidden.

Fig. 4. Harvesting of the red coral in the Greek Seas by means of "ingegno" (Photos by C. Dounas).

Fig. 5. Sorting of nets for the red coral harvesting collected by means of destructive dragging gears (Photos by C. Dounas).

Fig. 6. Colonies of *Corallium rubrum* collected by professional fishermen in the Greek Seas (Photos by C. Dounas).

Until now, only three out of the five geographical zones of the Greek Seas have been harvested (N. Aegean, S. Aegean-Island of Crete, and Ionian Seas). The total official recorded landings of red corals per region harvested over the period 1995-2005 are presented in Fig. 7. Overall, landings of red corals amount to 22.9 tones over this period, while annual landings seem to decrease gradually in each of the zones being harvested. Total landings from the N. Aegean Sea are twice as high as those recorded from the Cretan and Ionian Seas taken together, while landings from the coasts of Crete are the lowest. According to the available fisheries data, there is a significant decrease of the shallow water red coral stocks (up to 60 m) in these zones towards the end of the harvesting period. Depletion of red corals in the shallower areas, where harvesting is allowed, has currently forced professional divers to harvest colonies at greater depths (up to 125 m) by means of advanced mixed gas diving equipment, as today this is the only effective legal fishing method.

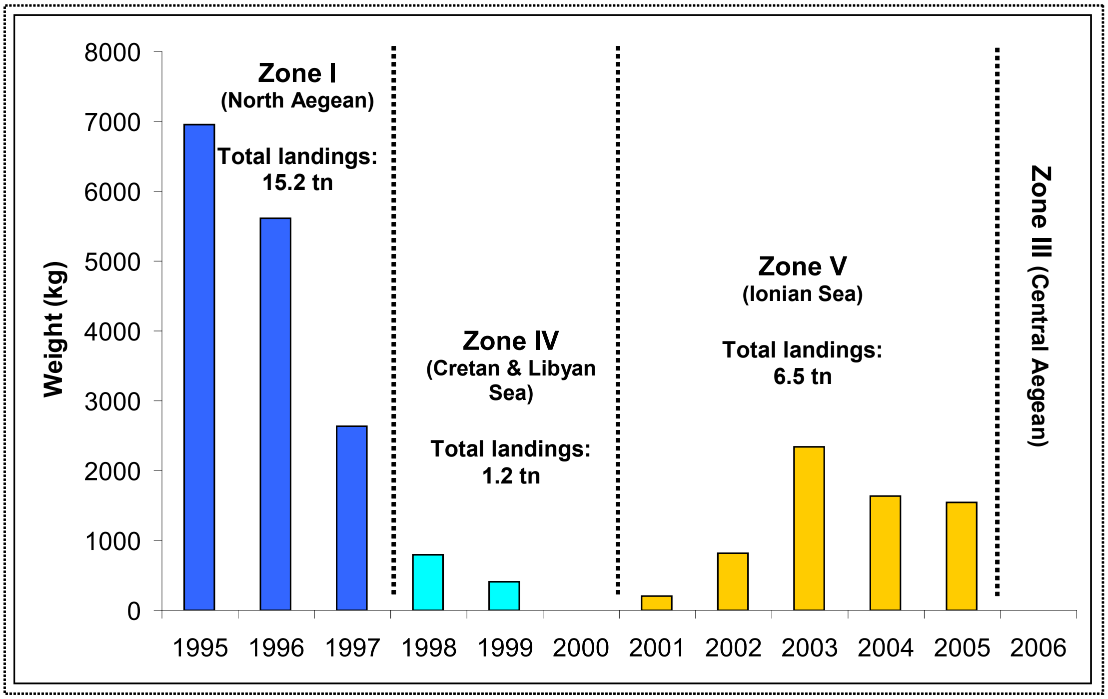

Fig. 7. Red coral landings in the Greek Seas over the period 1995–2006 (source: Greek General Fisheries Directory).

Discussion

According to the available data (both scientific records and official landings) the most abundant populations of *C. rubrum* in the Greek Seas are found in the N. Aegean Sea. This should probably be attributed to the eutrophic conditions of N. Aegean Sea which are quite similar to those of the Ionian Sea and parts of the NW Mediterranean where the species is generally thriving. However, the Cretan Sea, along with the Libyan Sea, is dissimilar and can be grouped with the rather oligotrophic Levantine Sea (e.g. Voultsiadou 2005, 2009; Bianchi 2007). In addition, current research has revealed that the N. Aegean Sea is characterized by rich biodiversity and hosts complex hard substrate communities such as coralligenous formations and bio-concretions as well as a large number of marine caves (Antoniadou et al. 2005; Chintiroglou et al. 2005; Gerovasileiou et al. 2009). The lack of scientific records from the central part of the S. Aegean Sea (e.g. the Cyclades plateau) is worth mentioning, despite the fact that extended deep coralligenous banks have been reported from this area (Laborel 1961; Jacquotte 1962; Georgiadis et al. 2008). However, the opening of this zone for the harvesting of red corals (from the summer of 2009) will probably provide new data on populations *of C. rubrum*. The review of *C. rubrum* records in the Greek Seas showed that knowledge concerning its distribution in these waters is far from being considered as complete. Further research on hard substrate communities, and especially on specific habitats (e.g. deep coralligenous banks and semi-obscure caves), which are either difficult to approach or not even accessible by scientific diving, is expected to reveal new data regarding the distribution and abundance of the species in this part of the Mediterranean Sea. Moreover, the significant increase in recreational diving activities in Greece, which was prohibited in most coastal areas until 2005, could provide additional information from previously unexplored marine areas within the shallower zone for diving.

The official fisheries data on the red coral in the Greek Seas show a decrease in shallow water populations, which seems to be closely related to the fishing effort (there are fewer landings towards the end of the fishing period in each large geographical zone). Another major issue, related to the depletion of red coral stocks in the Greek Seas, is the intrinsic difficulties experienced by both local and central authorities in confronting the illegal fishing of this renewable biological resource. There is growing concern in the red coral fisheries sector that fishing by unauthorized vessels, illegally using destructive dragging gears (e.g. Saint Andrews' cross), has increased considerably. A possible reason for this practice could be the high cost of purchasing and maintaining the legal, though often highly sophisticated and expensive harvesting equipment (e.g. mixed gas apparatus). The observed decline of red coral stocks in areas which were only recently opened up to exploitation is an indication that harvesting was carried out illegally throughout the closure period. It is obvious that new effective measures for the control and monitoring of landings are urgently needed in the Greek Seas for the conservation and sustainable management of this renewable biological resource. It is therefore suggested that certain additional measures should be included in the existing national legislation. For instance, red coral landings should be officially registered and tagged with regard to the harvesting place and time, while corals should be stored in sealed bags and identified by the local authorities. Management measures should also include penalties against the harvesting of small colonies (basal diameter less than 10 mm), as well as penalties for buyers and fishermen who possess even a small quantity of unprocessed corals without the required documentation. Furthermore, the large rotating harvesting zones should be examined separately in detail in order to assess the effectiveness and viability of the present harvesting scheme (e.g. number, size, and borders of the harvesting zones, optimal temporal and spatial orders for the opening of different zones). The optimal rotation period should remain constant instead of fluctuating according to fishermen's pressures and monitoring of landings should define the time of closure.

Apart from management measures based on fisheries landings, it is clear that there is a need for further scientific research in the Greek Seas aiming at a detailed investigation of the size and structure of the red coral populations. This approach should also take into consideration that *C. rubrum,* apart from its highly acknowledged commercial value, also plays an important ecological role. *C. rubrum* along with other gorgonian species distributed in the Mediterranean Sea, comprise ecosystem engineering key-species which provide important three-dimensional complexity to the coralligenous habitats and host high biodiversity (Boudouresque 2004; Ballesteros 2006; Giaccone 2007). For example, colonies of *C. rubrum* from the N. Aegean Sea and the coastal area around the island of Crete have been found to host a large number of epibenthic faunal species, such as the sponges *Geodia conchilega* (Schmidt), *Dysidea fragilis* (Montagu), *Erylus* sp., *Axinella guiteli* Topsent, *Agelas oroides* (Schmidt), *Petrosia ficiformis* (Nardo), *Ircinia dendroides* (Schmidt) and *I. foetida* (Schmidt), the cnidarians *Sarcodictyon roseum* (Philippi) and *Corynactis* sp., the serpulid polychaetes *Vermiliopsis infundibulum* (Philippi), *Placostegus crystallinus* (Zibrowius) and *Janua pagenstecheri* (Quatrefages) and the molluscs *Calliostoma zizyphinum* (Linnaeus), *Pseudosimnia carnea* (Poiret), *Heliacus alleryi* (Seguenza), *Coralliophila brevis* (Blainville), *Mitra zonata* (Marryat), *Lopha stentina* (Payraudeau) and *Ostrea edulis* (Linnaeus) (Chintiroglou et al. 1989; Vafidis et al. 1994; Koutsoubas et al. 1997).

In conclusion further scientific research, detailed mapping and a regular monitoring scheme along with measures for the protection of the coralligenous structures and especially for the *C. rubrum* populations in the Greek Seas are considered to be necessary, in order to safeguard their conservation and avoid extensive loss caused by environmental or anthropogenic pressures.

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THE RED CORAL EXPLOITATION IN MOROCCO

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Introduction

Morocco is endowed with two coastlines, the Atlantic and the Mediterranean, with very important red coral and varied fisheries resources. This typically Mediterranean species of red coral found at both regions an ideal biotope to develop.

In Morocco, red coral harvesting began at the Mediterranean as a special activity at the Mediterranean in the 1970s, by foreign boats. In the 1980s, this activity took an important rise, in particular in the area of Al Hoceima at the Mediterranean side with great red coral abundances with red coral colonies of big sizes and good quality. In 1990, the activity of fishing of the coral was located in Asilah site at the Atlantic zone extending between Cape Spartel and Larache, where was discovered an exploitable red coral stock starting from 40 meters of depths. After 13 years of exploitation, the zone of Asilah was closed for coral exploitation. Since 2004, the zone of Al Hoceima was again opened for red coral harvesting.

Red Coral Exploitation

The first gear used in the exploitation of red coral was the cross of Saint Andrew, which is pulled on sea-bed, breaks the coral colonies and causes consequently a degradation and an exhaustion of the red coral layers on the one hand, and affect the biodiversity and the marine ecosystem as whole on the other hand.

This damaging technique of exploitation presents a production of bad quality product in spite of the great harvested quantities. However, during the 1980s, this technique was prohibited in Morocco and replaced by a new technique based on liquid bottles which is called deep-sea diving. This technique became the single technique practised for red coral harvesting. The tool of divers consists of a net basket and a sharp marteline on board which makes it possible to cut the foot or coral colony.

Operating Fleet

During the period 1984-1987, the number of boats in activity varied from 2 to 17, totally of foreign nationalities. Since the freezing of the investments in 1992, the number of coral boats was set to 10 units.

Harvesting Zones

The exploitation of the red coral was carried for a period varying from 10 to 12 years of exploitation per area. Between 1980 and 1991, two principal fishing zones can be considered in the Mediterranean, as shown in Fig. 1.

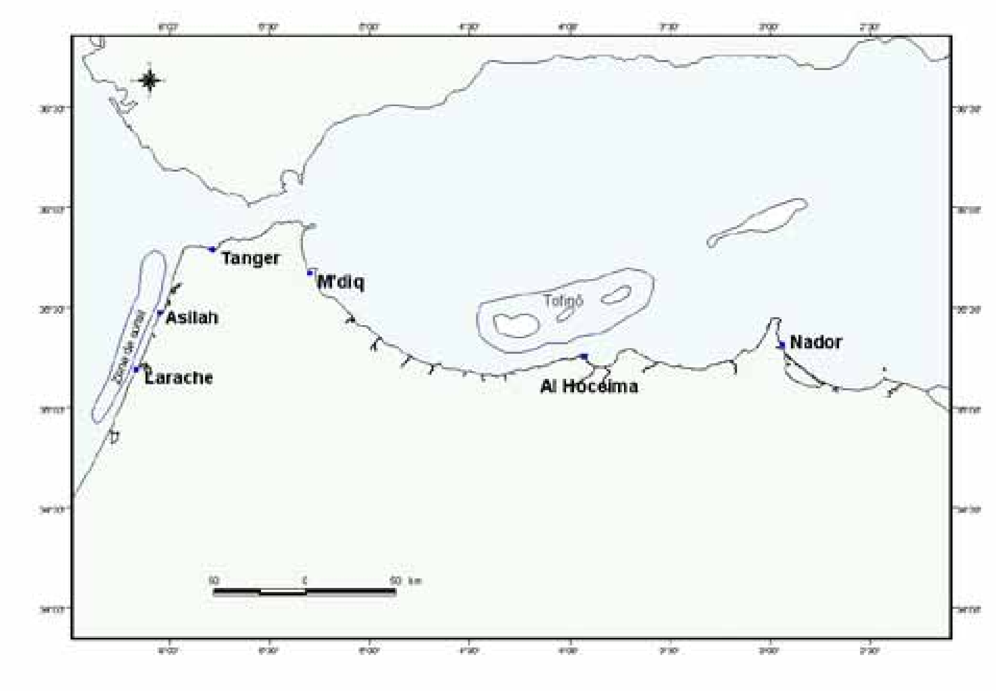

Fig. 1. Red coral stocks in Moroccan coast.

- The zone called TOPOS is a very coastal zone in which the coral resources is very close to the surface (30–60 meters depth). In this zone, the red coral harvesting is only done by diving under compressed air. However, these zones with low depth are subjected to an intense harvesting fishing activity owing to the fact that the diver can remain under water for a long period of time (45 to 60 min), and the operation of diving can be done twice per day without risk.

- The zone known as TOFINOS, moving away from the nautical coast of approximately 24 miles, is a very deep, rocky zone, characterized by very strong currents. The coral is on the sides of rocks beyond 80 meters depth. Contrary to the zones of low depths, in these zones of great depths, the duration of diving is very limited not exceeding a maximum 20 to 25 min because of the mixture of gas (helium and oxygen). The diver must obligatorily follow and respect the instructions of the rules of the diving; if not it can endanger its life.

Since 1992, the Mediterranean area was not interesting any more as the collected colonies were of small sizes and consequently their economic value had fallen; thus, the exploitation of the coral moved towards the Atlantic area on the level of the Asilah region extending from Cape Spartel in Larache. This zone is made up of three red coral layers: (1) a layer at the level of Cap Spartel, (2) another layer at the level of Asilah, and (3) a layer at the level of Larache. The choice was put on the layer of Asilah owing to the fact that the red coral can be observed starting from 35 meters of depth, characterized by good visibility for divers, along with weak marine currents, and thus more favorable exploitation conditions.

Production

The exploitation of coral at the Mediterranean during the 1980s saw a total production in Al Hoceima in 1985 of 8.6 tons. After three years of exploitation, this production recorded a fall of 80% to reach 1.6 tons in 1988. The drastic fall of the production during a tiny time, colonies of small sizes proved that coral layer at the Mediterranean was subjected to an overexploitation.

Year	**Zone**	**Exported Quantities (tons)**
1992	Asilah (100%)	9.6
1993	Asilah (100%)	6.2
1994	Asilah (100%)	6.0
1995	Asilah (100%)	4.3
1996	Asilah (100%)	2.8
1997	Asilah (100%)	2.0
1998	Asilah (100%)	1.9
1999	Asilah (100%)	4.7
2000	Asilah (100%)	7.7
2001	Asilah and Al Hoceima 97% 3%	8.0
2002	Al Hoceima (100%)	22
2003		11
2004	Al Hoceima (100%)	6
2005		2.5
2006	Prospection- Mediter.	1.6
2007		2

Source: Change Office

The analysis of the great variations of the production or of the level of exports from one year to another show that the rise can be due to the exploitation of deeper zones than usual or the addition of quantities already harvested the previous year.

Conclusions

Generally, the exploitation of the red coral in Morocco, whether at the Mediterranean or at the Atlantic, by the means of the production carried out each year shows the same tendency of evolution. The production reaches a maximum after the opening of the zone of activity and starts to fall progressively. This downward trend is due mainly to the discontinuous geographical distribution of the red coral and/or to the manner with which the exploitation is done.

The exploitation of the red coral starts on the level of the layers of low depths where abundance is more or less high, the production can oscillate because of the rarefaction of the species, or to several environmental factors which would prevent the realization of good coral harvest, mainly the terrigenous contributions, turbidity, lack of visibility for divers.

The exploitation continues towards great depths where the coral appears on the exposed faces of the rocks. The exploitation of these depths requires qualified divers.

RED CORAL AND ITS ACTUAL SITUATION IN TURKEY

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Red coral is known as one of the precious coral species by Turkish coral divers and fishermen. This species is caught in the northern Aegean Sea and Turkish Mediterranean Sea until 1990. Accurate data for the amount of catch and prices during the last period, however, is not available. This species was caught below 40 meters depth banks and marine caves mostly between Anamur and Kaş.

Since 1990, according to the Turkish Fishery Law 1380, red and black coral species have been under protection continuously. The reason of this decision was that coral divers destroy other benthic species, such as slipper lobster, European locust lobster, and spiny lobster, as well as some fish, such as dusky grouper and grouper, in deep seas and caves.

Actually, red coral *Corallium rubrum* is imported from some countries as jewelry materials in Turkey. The amount is not known due to its very small quantity.

A global assessment for the Mediterranean Sea is needed for the sustainable resource management. Local people's income and opinion for the management of the coral resource should be also considered.

ANALYSIS OF FAO STATISTICS OF HARVEST OF *CORALLIUM RUBRUM* IN THE MEDITERRANEAN 1978–2007

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FAO Fishery statistics are presented and linked to the introduction of major legislations to regulate harvest of *Corallium rubrum* in the Mediterranean.

It is important to note that the supposed decline is based on an analysis of harvest data produced by FAO.

It is worth noting that in last 10 years period no decline of the harvest has been noted and that, more importantly, change in harvest techniques has greatly reduced the fishing efforts for the species. In fact, after the ban of the "ingegno" or of "Saint Andrews cross" (1994 EU regulation 1626/94), harvest is exclusively done by SCUBA and only by professional divers who harvest the species between 60 and 110 m of depth with clear technical difficulties.

In fact, diving time at such depths is very limited (maximum 20 minutes), and also the quantities that can be harvested are limited. Only a hammer can be used according to the management measures and legislation of many countries.

Spain, France, Morocco, Algeria, Tunisia, and Italy (Sardinia) have enacted specific legislation on the red coral harvesting. In particular, the Sardinia Region has banned the use of non-selective gears since 1989 and intermittently banned their use since 1979 when the first legislation on coral harvesting was enacted.

This explains the decline of the statistical figures.

In fact, of the 100 tons harvested in 1978 that represents the peak of the harvest for the Mediterranean, 72 tons were harvested in Sardinia. The legislation introduced in Sardinia in 1979 and the intermittent ban on non-selective gears, together with high taxes imposed on the fishing vessels, explain the decline of harvest from 1979 to 1989 when the use of non-selective gears was definitively banned in Sardinia, five years before the entry into force of 1994 EC Regulation 1626/94, which banned the use of non-selective gears for the coral harvest in the Member Sates of the European Union.

Therefore, the statistical decrease is linked to the decrease in fishing efforts and not to the decline of the species. In the last 30 years the fishing efforts on *C. rubrum* in the Mediterranean has considerably decreased. This was due to the ban on the use of the "ingegno" and of the Saint Andrews Cross (two different non-selective gears) and to the fact that in many countries fishing is exclusively done by licensed divers that can harvest the species in limited quantities only and only between 60 and 100-110 m of depth. The populations below that depth are completely intact. Moreover, official statistics do not take into account the finding of dead coral banks generated by the detachment of old or sick coral transported by streams.

IL COMPARTO DEL CORALLO DI TORRE DEL GRECO

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Il comparto della lavorazione dei coralli, cammei ed oreficeria di Torre del Greco si caratterizza per alcuni elementi che lo rendono unico nel panorama produttivo nazionale, anche nell’ambito dei distretti analoghi di Valenza Po, Vicenza ed Arezzo.

1 – Ha una tradizione storica che risale alla fine del ‘700, che ancora si riscontra nei caratteri tipicamente artigianali, individualistici e, però, anche artistici della lavorazione. In questo contesto l’innovazione tecnologica e la delocalizzazione potrebbero rappresentare, addirittura, degli elementi di eradicamento dalla storia e dal territorio, piuttosto che dei fattori di sviluppo.

2 – Si basa su di una rete di relazioni interne ed internazionali particolarmente fitta ed articolata: a livello locale molte imprese operano per altre imprese vicine con una divisione complessiva del lavoro che dà spazio alla creatività degli artigiani ed alle capacità di percorrere i mercati internazionali e seguirne le tendenze in maniera proattiva. (Organizzazioni di rete degli approvvigionamenti, delle relazioni interne al comparto e delle vendite internazionali)

3 – É strettamente legato all’immagine turistica complessiva dell’Italia artigiana al punto che prodotti tipici dell’area vengono offerti e ricercati dai turisti stranieri sia nelle aree campane (Sorrento, Pompei, ecc.), che in altre tipiche aree turistiche italiane (Venezia, Firenze, ecc.).

4 – Grazie alle relazioni internazionali (soprattutto con USA, Giappone ed Estremo Oriente) ha ampliato la gamma di prodotti oggetto di attività produttiva e commerciale. È diventato negli anni uno dei principali centri italiani sia per l’oreficeria, che per il commercio internazionale e la lavorazione delle perle.

Pur essendosi verificata anche a Torre del Greco una contrazione delle imprese e, ancor più, degli addetti, proprio i caratteri tradizionali del settore ne hanno guidato il riorientamento nel corso degli ultimi anni.

Attualmente nel comparto torrese operano circa 270 imprese con oltre 2000 addetti ed il mancato riconoscimento delle attività locali come distretto (con la possibilità di attingere ai relativi benefici) è derivato non dalla carenza degli elementi strutturali e dinamici tipici di queste realtà, ma, piuttosto, dal fatto di essere fortemente radicate all’interno di un’area urbana ad alta densità abitativa, il che ancora una volta evidenzia uno dei punti di forza del settore nella forte sinergia, da un lato, tra vita quotidiana e produzione e, dall’altro, tra produzione e territorio.

Prima ancora della crisi attuale, come in altri settori, si è manifestata nell’oreficeria una rilevante dicotomizzazione della domanda tra prodotti di basso prezzo/qualità e prodotti di medio-alto prezzo/qualità. La domanda di prodotti del primo tipo trova soddisfazione maggiore nelle offerte a più basso prezzo basate su produzioni orientali; la domanda di prodotti di livello medio-alto trova riscontro nei caratteri di artigianalità, creatività artistica e peculiarità dei materiali oggetto di lavorazione a Torre del Greco: il corallo e le capacità di lavorazione del corallo; i cammei e le capacità di lavorazione dei cammei rappresentano elementi trainanti di una offerta unica nel panorama mondiale basata su forti elementi di cultura e competenze.

Basta notare che nell'indagine svolta nel 1999 il 53% degli intervistati considerava l'orientamento delle consumatrici tra i fattori considerati nella progettazione e realizzazione dei prodotti, mentre il 93% degli stessi operatori inseriva fra i fattori considerati la qualità della materia ed il 40% la forma.

Nonostante le evoluzioni più recenti, quindi, la produzione rimane fortemente legata ad una specifica materia prima – il corallo –, alle competenze ed alle relazioni che attorno ad essa ed a partire da essa si sono diffuse e consolidate per altri materiali ed aree. Si parte da una esperienza di navigazione, le famose "coralline", e si ritorna ad esperienze di relazioni internazionali che hanno il corallo come matrice originaria ed, ancora oggi, fonte di creazione di competenze di approccio di capacità di gestione responsabile delle materie prime, di lavorazione, di distribuzione e di commercio internazionale applicate ad altre materie ed aree con gli stessi principi di creatività ed arte.

L'eventualità di introdurre elementi di burocratizzazione del commercio che porti a forti riduzioni del corallo fra le materie oggetto di lavorazione non sarebbe, quindi, come togliere gli oggetti in oro bianco dalla gamma di prodotti di un orefice, ma sarebbe come togliergli la fonte e la ragione stesse della formazione delle sue competenze, che nel tempo lo hanno portato ad occuparsi di altri materiali e di nuove aree di sbocco.

CORAL AS PRODUCT: ANALYZING PRODUCTION AND MARKET PERSPECTIVES

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This paper will examine the production of and markets for coral products in the two largest coral sectors in the world – Torre del Greco and Taiwan – using a global commodity chain perspective. In both coral sectors, different products are made for different markets. Very particular destinations and target markets were identified by coral producers in both sectors for specific types of coral products. The coral commodity chain is a complex global chain of value-added commercial production from raw material to final marketed commodity, in which market and end use for the product determine the production processes. Production methods and industry drivers in both sectors will be characterized and compared. Market categories will be identified based on 1) characteristics of the raw materials, 2) characteristics of the finished products, 3) values of coral, and 4) meanings and cultural needs. Examining coral production and products from a commodity chain perspective tracks how the value of a coral object is increased at each stage of its production for specific markets, in a process of production that transcends national boundaries. These perspectives can provide not only a starting point to develop approaches for environmental sustainability of managing coral trade but provide insight to develop targeted approaches for sustainability of production and market sectors in an industry facing the impacts of international trade regulations.

RED CORAL (*CORALLIUM RUBRUM* L., 1758) MANAGEMENT STRATEGIES IN SARDINIAN COASTAL WATERS

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Abstract

Red coral in Sardinia is a historically important resource, coral harvesting being documented since the XIII century. Since 1979, coral fishing in the island has been subject to specific regulation (Regional Laws: 5th July 1979 n. 59 and 30th May 1989, n. 23) that introduced several restrictions in order to improve sustainable exploitation, conservation of coral resources, and protection of marine ecosystems. It provides the main following rules: coral harvesting only be conducted by professional fishermen in possession of a regional permit that is renewed annually, and fishing tools limitation, since 1989 towed gears prohibition and only manual harvesting with hatchet permitted. Furthermore, every year on the basis of scientific evidence harvesting effort (maximum permit numbers, harvesting time, allowed areas, minimum size of coral basal diameter, and daily maximum amounts of coral per fisherman) is established. Daily harvesting data have to be provided by fishermen. Since the 1980s, the Regional Administration has been funding scientific studies in order to collect biological data and obtain periodical coral stock assessment along Sardinian coastal waters. The management strategy adopted in Sardinia is one of the first in the Mediterranean Sea and seems to represent a successful experience, having achieved a good balance between protection and exploitation requirements as confirmed by recent scientific evidences.

Introduction

Red coral (*Corallium rubrum* L., 1758) in Sardinia is an historically important resource from a biological, economical, and cultural point of view, due to the richness and high quality of coral banks mainly distributed along the west coast.

Coral harvesting has been going on for several centuries in the island, being documented since the XIII century (Doneddu and Fiori 2003, reported by Cannas et al., in press).

At present, red coral exploitation involves about 250 people (unofficial data) including fishermen, craftsmen, and tradesmen; it represent a remarkable yielding sector, especially for cultural and historical reasons mainly connected with a well-known processing tradition. The town of Alghero, a little city on the North West cost of the island, is famous in Europe for its coral carving tradition and for the high quality of red coral handmade products.

Today, the estimated number of people involved in coral harvest, processing, and trade include roughly (Fig. 1) 170 between craftsmen and tradesmen, 35 crew assistants, 25 allowed fisherman, and only two wholesales (unofficial data referred to the year 2009) from Torre del Greco – a town located in the Campania Region that today represents the most important coral trade and processing site in Italy.

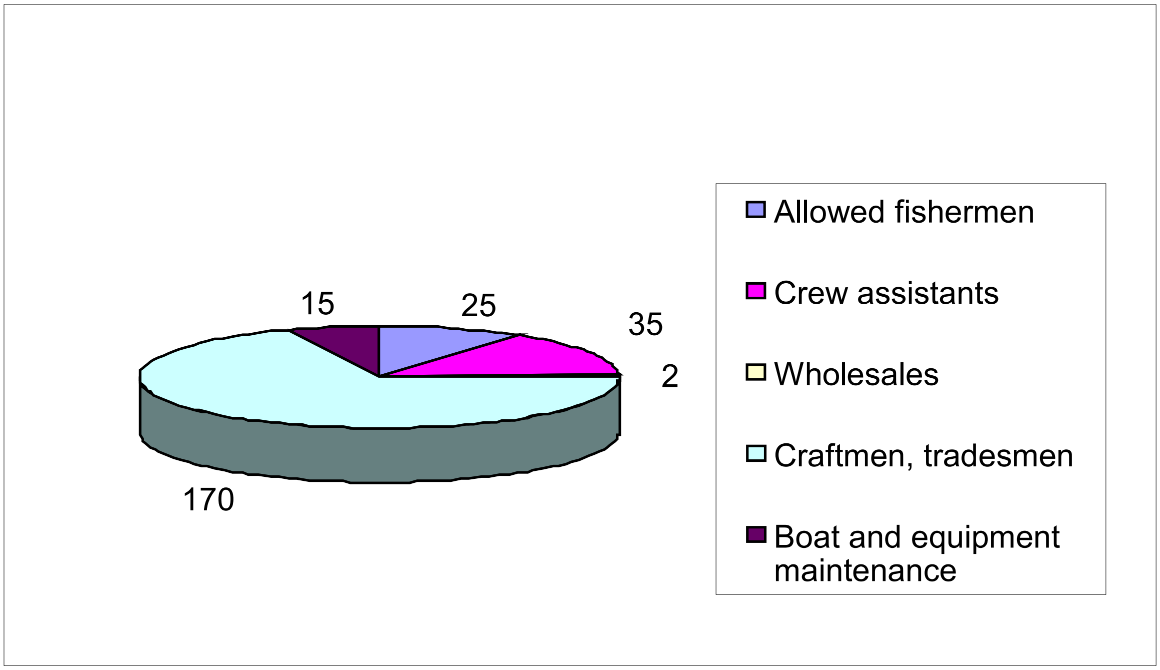

Fig. 1. Estimated number of people involved in Sardinian coral harvest processing and trade in 2009 (unofficial data).

In Italy, since 1965, National Law 14th July 1965, n. 963 "Maritime Fishing Regulation," implemented by President of the Republic's Decree (DPR) 2nd October 1968, n. 1639, established specific regulations for the exploitation of discovered coral banks (Fig. 2).

In particular the above mentioned Law established that fisherman who finds a new coral bank has to declare the discovery to marine authority in order to be allowed to its exploitation for the next two years (Art. 16).

Furthermore, President of the Republic's Decree (DPR) 2nd October 1968, n. 1639, issued for implementation of this Law, specified that discovery declaration of a new bank has to include personal data of the fisherman, day of discovery, position and extension of the bank (Art. 123) and that fishing season lasts all the year (Art. 124).

Since 1948 Sardinia is a self-government region with a Special Statute (Constitutional Law 26th February 1948, n. 3)

Sardinian Administration has primary legislative function on fishery items (D.P.R. 24.11.1965, n. 1627).

So according to the National Law 963/1965, the Regional Administration from 1965 to 1979 had been issuing decrees to allow responsible exploitation of discovered coral banks within the territorial waters.

In 1979, Sardinian Regional Council issued the Regional Law n. 59 – afterward integrated and modified by the Regional Law 23/1989 (Fig. 2) – one of the first experiences of specific regulations in the Mediterranean Sea, that has ruled harvesting effort management on red coral banks, ensuring an effective protection of the resource.

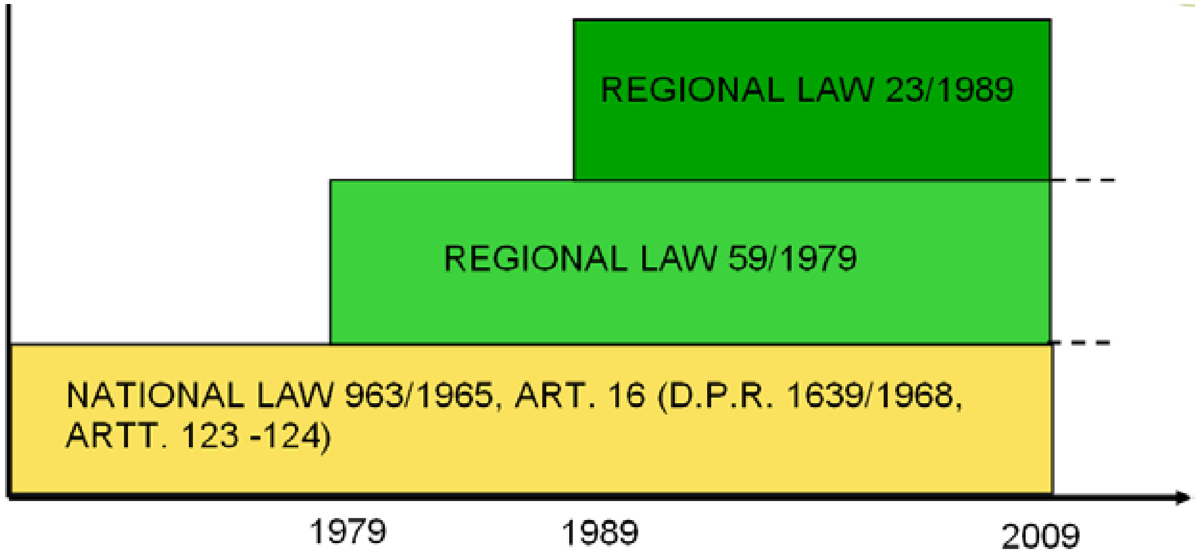

Fig. 2. National and regional regulation.

Materials and Methods

Harvesting data, provided to the Regional Administration by fishermen, were analysed from 1996 to August 2009 in order to evaluate the effect of regional regulation on coral resource and harvesting effort. Total allowed harvesting days were obtained on the basis of the harvesting period fixed by regional decree. The number of harvesting days per fisherman was obtained dividing the total number of effective fishing days (provided by coral divers) by the number of permits effectively used. Daily coral amount was calculated dividing the total annul coral amount by the total number of effective harvesting days (obtained as the sum of annual harvesting days of all coral divers).

Results

Regional Laws

The Regional Law 5th July 1979, n. 59 “Coral Fishing Regulation” introduced several restrictions in order to improve sustainable exploitation, conservation of coral resources, and protection of marine ecosystems. It includes the following regulations:

Art. 1 – In Sardinian coastal water, red coral harvesting can be conducted by professional fishermen in possession of a regional permit, with the exception of the cases read in Article 4.

Art. 2 – Regional permit must be renewed annually and is issued or suspended by means of regional councillor's decree.

Art. 3 – Coral harvesting is allowed only with the following gears:

a) hatchet, used by professional fishermen equipped with scuba-diving devices;
b) Saint Andrew's cross*;
c) Ingegno*, maximum length: 3 m, maximum number per boat: 1
* cross shape towed gears equipped with pieces of net

Catch methods different from those above mentioned are forbidden.

Art. 4 – Annually, within January, in compliance with the Regional Council decision and once the opinion of the Regional Technical Advisory Committee is acquired, the councilor's decree establishes:

a) harvesting time;
b) maximum daily amounts of coral per each harvesting gear;
c) allowed areas;
d) deadline and conditions for requests submission;
e) the fee amount for each harvesting gear;
f) maximum permit numbers for each harvesting gear.

Harvesting permit can be issued in order to allow scientific research.

Art. 5 – For ecological and biological protection, requirements the councilor's decree can forbid coral harvesting in specific areas for a minimum period of 3 years.

Art. 6 – Every year coral fishermen have to provide daily harvesting data (coral amounts, position, and depths of fishing areas) within 30 days from the end of harvesting time.

Art. 7 – The Regional Administration provides for collecting scientific data on red coral banks in order to ensure sustainable exploitation charging:

a) scientific research institutes;
b) specialized private enterprises or local government.

Art. 8 – The councillor's decree, in compliance with the Regional Council decision, can:

a) organize or fund specific professional training classes about coral harvesting with the use of scuba-diving devices;
b) grant funds for young Sardinian people to attend the above mentioned professional training classes.

Art. 9 and Art. 10 – Establish the administrative sanctions in case of violation of the Law.

Afterwards, to ensure a more strict and effective protection of the coral resource and the marine ecosystems the Regional Law 30th May 1989, n. 23 – partly modifying the Regional Law 5th July 1979 n. 59 – introduced the following further restrictions:

Art. 1– Only manual harvesting with hatchet is permitted to professional fishermen equipped with scuba-diving devices. All the other fishing methods are banned.

Art. 2 – Financial aids are provided to sustain transition from destructive dragging methods (Saint Andrew's cross and Ingegno) to allowed gears (hatchet). Contribution until 70% are given to fishermen allowed to non-selective gears in 1988 and 1989 to purchase new fishing equipment.

Regional Management Actions

According to Article 4 of the Law n. 59/79, yearly, on the basis of the scientific evidences, a councilor's decree establishes the value of the harvesting variables and further limitations in order to ensure the protection of the species (Table 1).

Table 1. Regional management actions: main harvesting variables fixed by regional annual decrees.

	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Total allowed harvesting days	199	199	199	199	188	92	0	111	168
Number of permits	31	32	37	41	38	31	0	20	30
Minimum allowed harvesting depth (m)	0	0	0	0	0	0	0	80	80
Maximum red coral amount per day (kg)	4	4	4	3	3	2,5	0	2,5	2,5
Minimum basal diameter (mm)	10	10	10	10	10	10	0	10	10
Tollerance on minimum basal diameter (%)	30	30	30	30	30	20	0	20	20

The minimum basal diameter of 10 mm is fixed with a tolerance of 20% (basal diameter between 8 and 10 mm); furthermore, new-harvested red coral has to be maintained in sea water for a minimum of 30 minutes in the net (size ≥ 5 mm) in order to allow the dispersion of gametic products.

Analysing the main harvesting variables fixed annually by the Regional Decree in the last decade is possible to highlight the trend of the catch effort management established on the basis of the scientific evidence (Table 1).

Generally, the harvesting period has been fixed from spring to autumn, but the number of total allowed harvesting days has changed greatly, especially in the last decade (changing from 0 to 199 days), as shown in Fig. 3 and Table 1.

Since 2006, the Regional Government has chosen to reduce the harvesting period, the number of permits and the daily maximum red coral amount per fisherman (Fig. 3, Table 1).

In 2007, the Regional Government decided to forbid red coral fishing, applying the precaution principle to better preserve the biological resource assessing the need of deepening scientific studies on stocks condition in Sardinian coastal water.

Since 2008, a minimum harvesting depth has been established allowing the harvest only at depth > 80 meters, in order to preserve the shallower colonies.

Furthermore, in 2008, the Regional Government allocated funds for a multi-annual restocking program (Decree 19th December 2008 n. 3189/DecA/7108), at the moment in a start-up phase.

In 2009, the Regional Council, considering the results of scientific researches, assessed that an enlargement of the permits number and a longer harvesting period were sustainable.

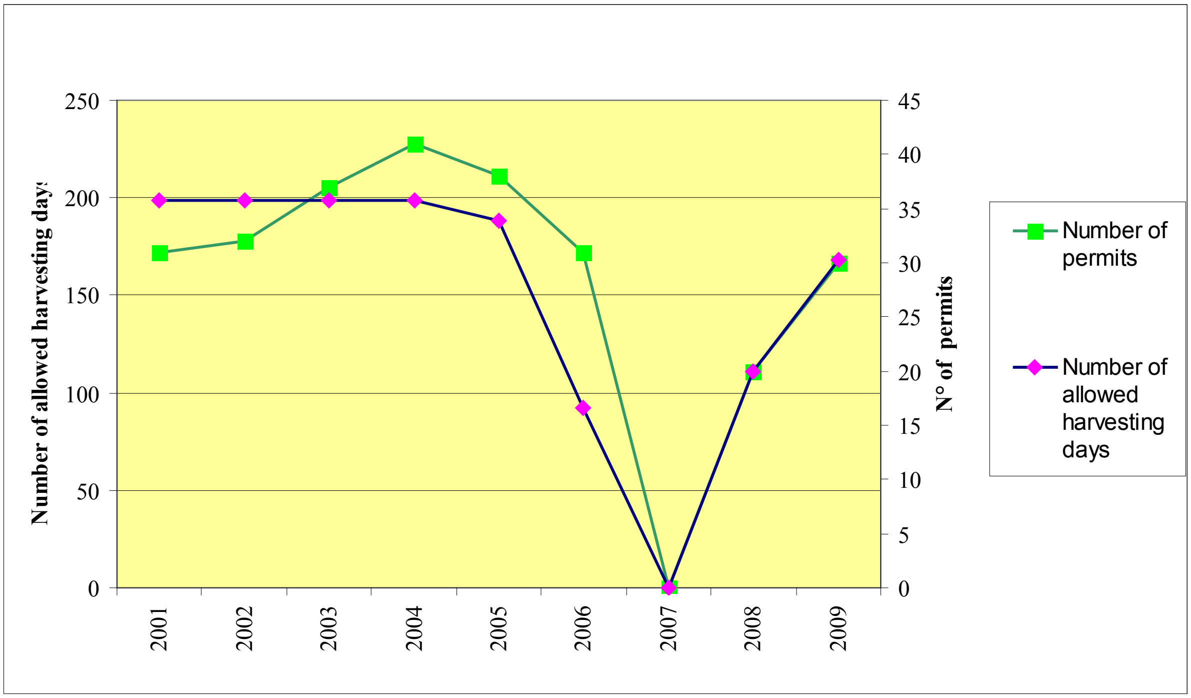

Fig. 3. Trend of Regional Regulation: number of coral licences and allowed harvesting periods.

In 2009, 25 permits were issued, involving about 16 fishing boats (Table 2), coral harvesting were allowed from the 1st of May to the 15th of October.

At present, as well as in the past, the main harvesting areas are located along the Western coast, especially in the Northern part (Fig.s 4, 5, 6). Fig. 4 shows also the position of the areas in which coral harvesting is presently forbidden due to the strong impact of the towed gears used in the past on those ecosystems.

The distribution of the harvested coral amount in different conditions (dead, mixed, spoilt, and red) among the harvesting areas during 2008 is reported in Fig. 7.

Table 2. Recent figures.

	2008	**2009 (until August)**
Number of issued permits	20	30
Number of effective permits	20	25
Number of fishing boats	17	16
Total red coral harvested (Kg)	1120	1457
Range of trade price declared by coral divers (€/kg)	500 - 1000	400 - 800
Current trade price for mixed quality coral declared by coral divers (€/kg)	500	450

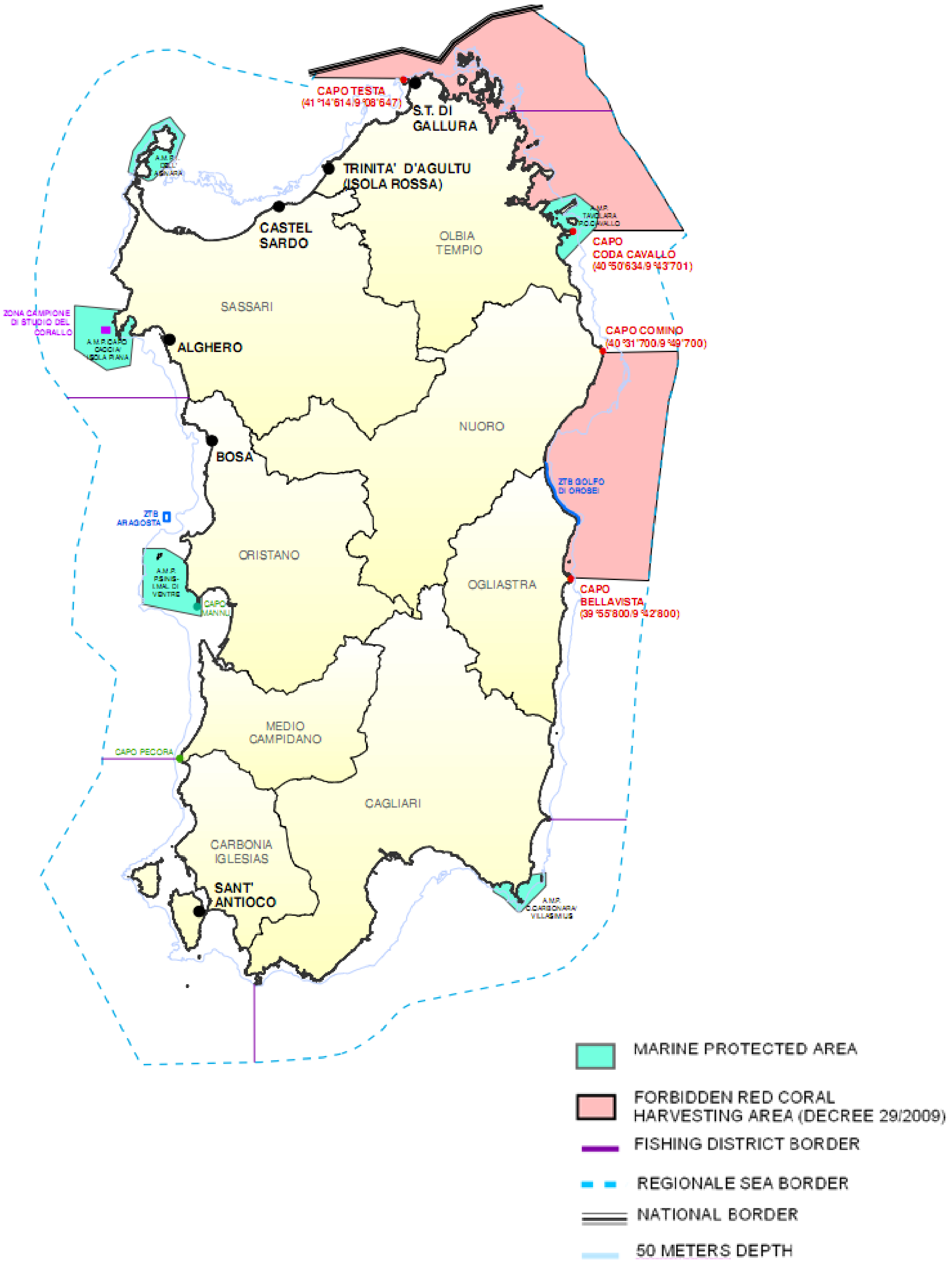

Fig. 4. Coral harvesting areas (map scale 1: 1.150.000).

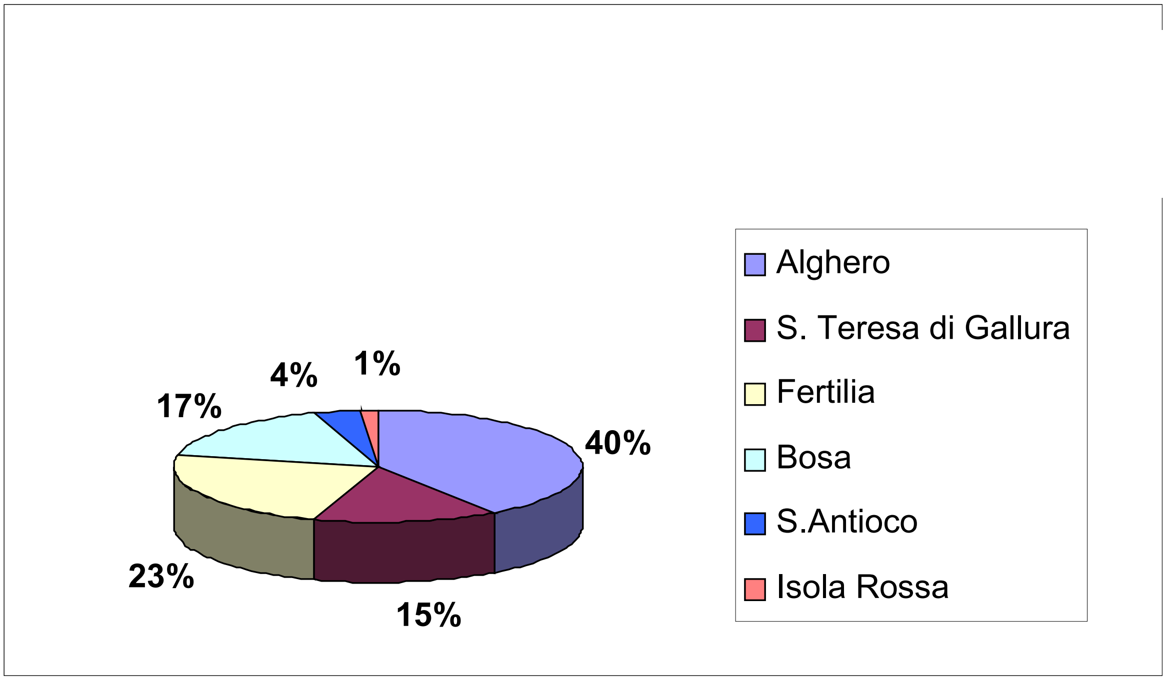

Fig. 5. Geographic distribution of annual red coral amounts in 2008 (total annual harvest 1120 kg).

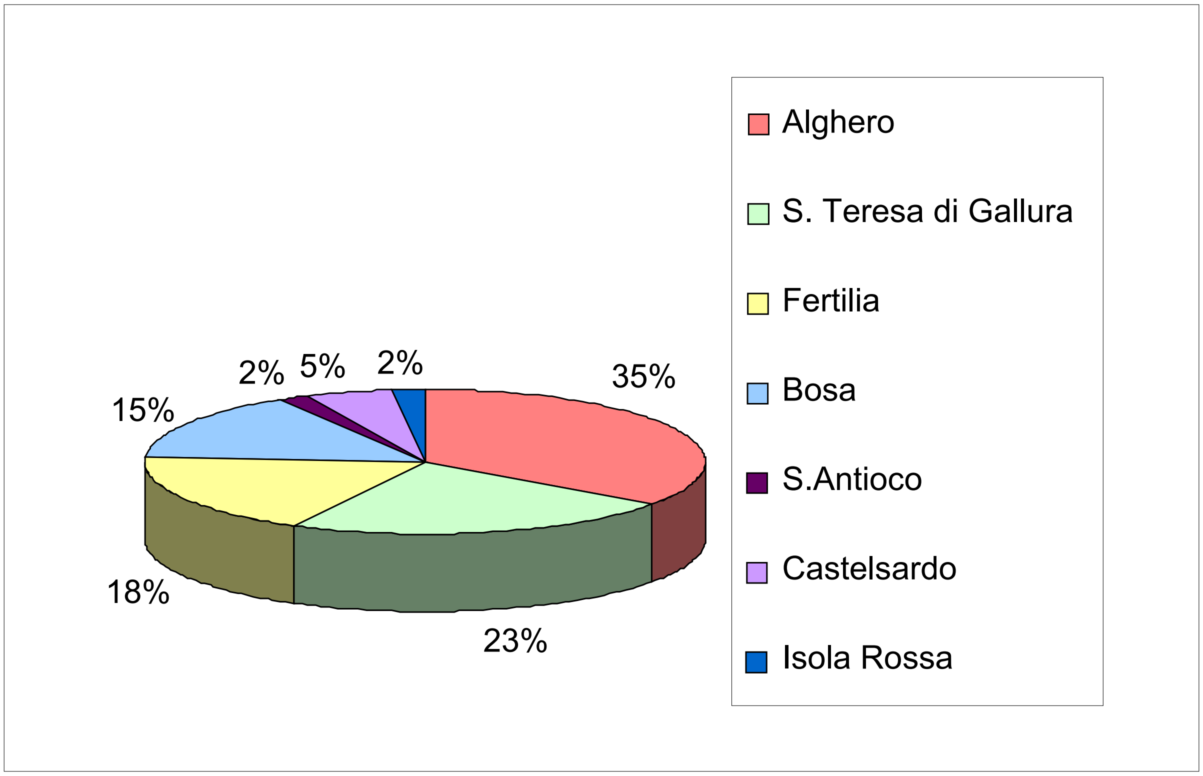

Fig. 6. Geographic distribution of annual red coral amounts in 2009 (until August) (total annual harvest 1435 kg).

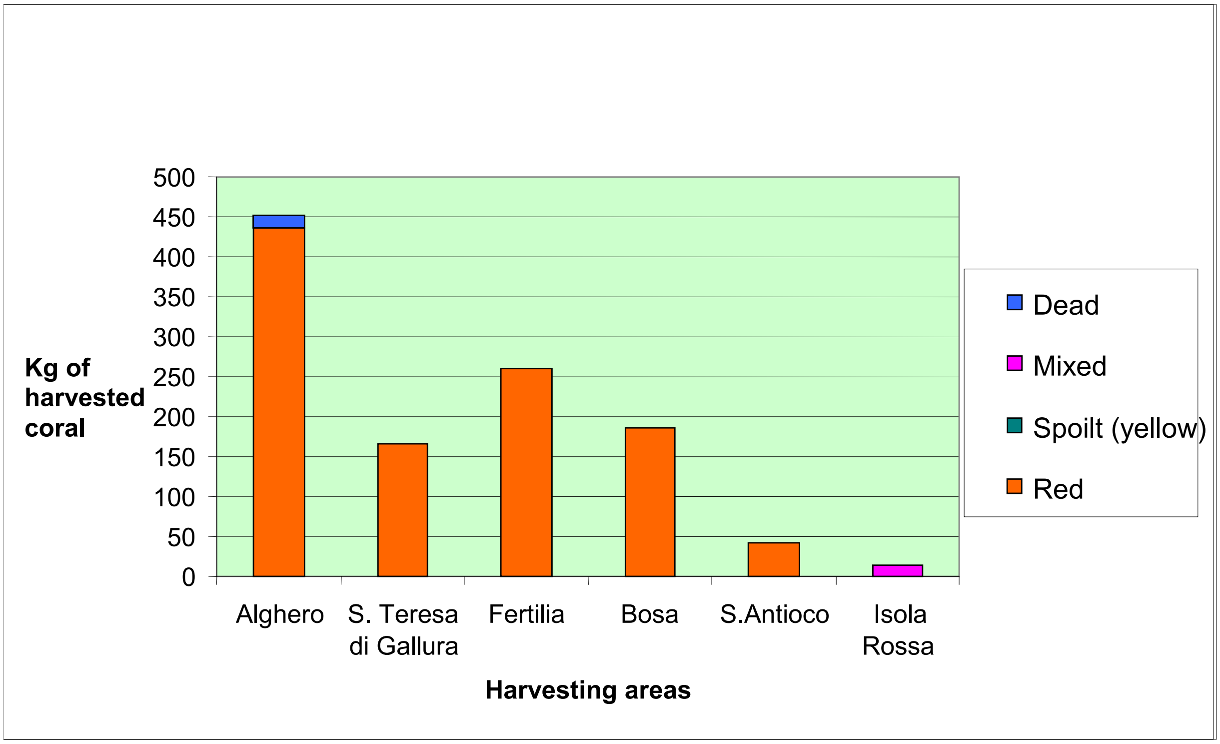

Fig. 7. Distribution of coral harvesting: different coral conditions in Sardinian harvesting areas in 2008 (Kg).

Effects of the Regional Management

Analysis on the main harvesting effort variables related to red coral annual or daily harvested amount were carried out from 1996 to 2009 (until August) in order to evaluate the effects of the regional management strategies on the resource (Fig.s 8, 9, 10).

Fig. 8 shows the trend of the red coral annual amount related to that of the number of permits (effectively used). The two variables seem to be closely related till 2005. In 2006, the strong limitation of the harvesting period (from the 1st of July to the 30th of September), and of the allowed daily coral amount per fisherman, took to the extreme decrease of the coral annual harvest. Similarly, in 2008, the reduction of the annual coral amount was caused by the drastic reduction of permits number and harvesting period (from the 1st of June to the 15th of October).

Fig. 9 highlights the close relation between the annual coral amount per fisherman and the number of annual effective harvesting days per fisherman. The decrease in coral annual amount per fisherman is not due to a reduction of coral resource as confirmed by the positive trend of daily coral amount reported in Fig. 10. The resource seems to be in good balance with the harvesting effort.

The trend of daily coral harvest related to that of the total harvesting days (Fig. 10) shows how the limitation of harvesting period fixed by councillor’s decree from 2006 to 2009 caused a stronger harvesting effort per day (corresponding to a bigger daily coral amount and to worst working conditions in relation to safety of coral divers).

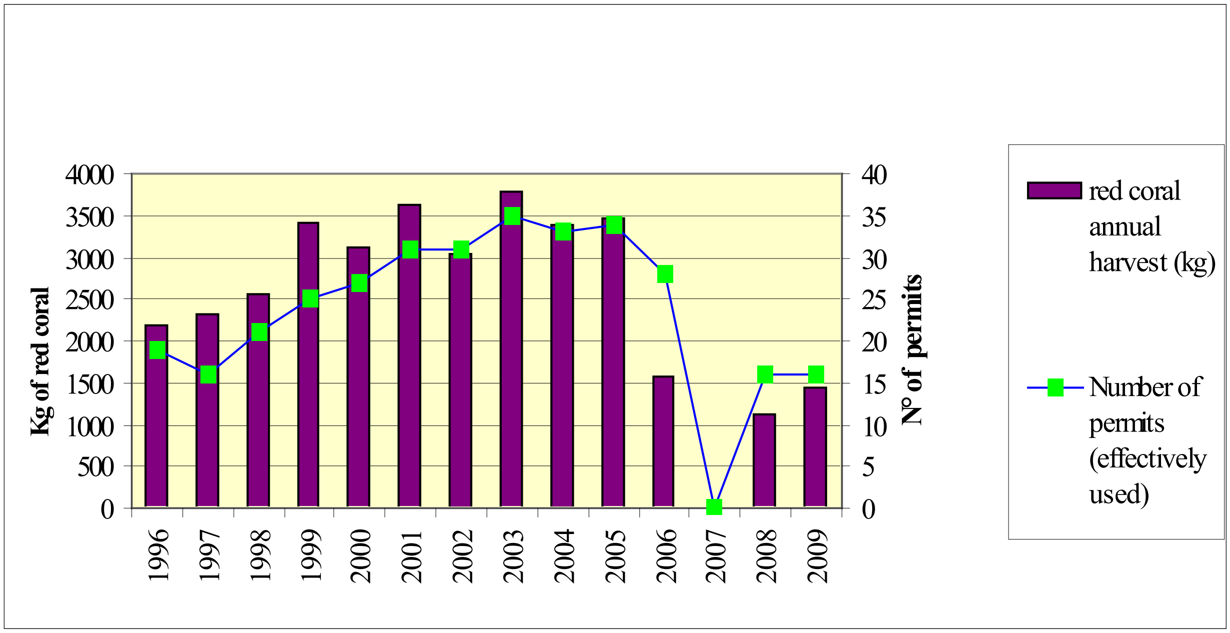

Fig. 8. Red coral annual harvest related to the number of permits effectively used.

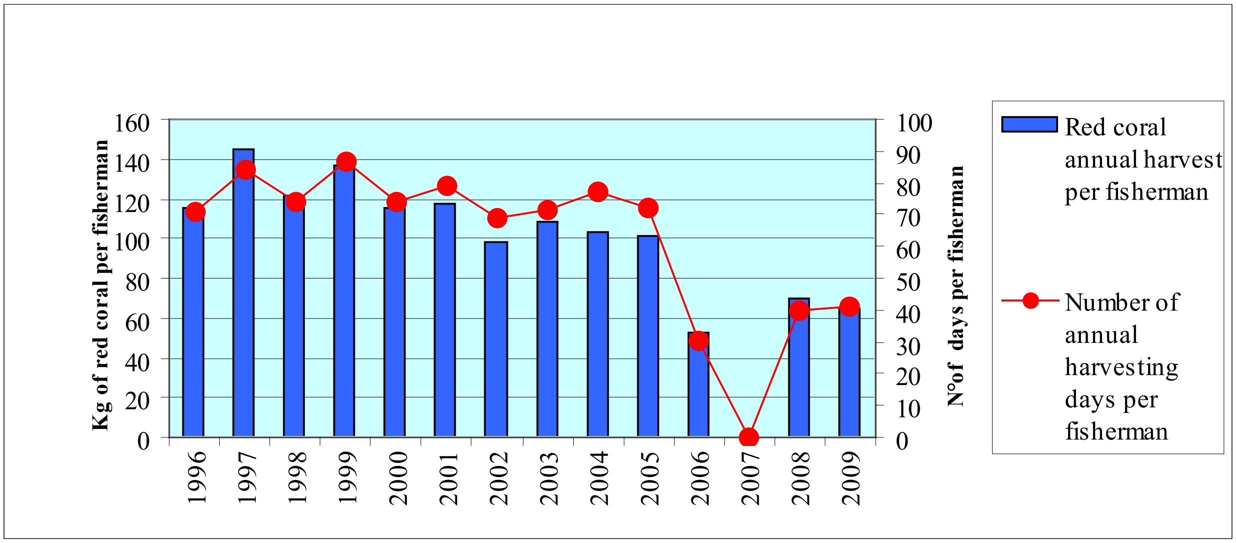

Fig. 9. Red coral annual harvest per fisherman related to the number of annual harvesting days per fisherman.

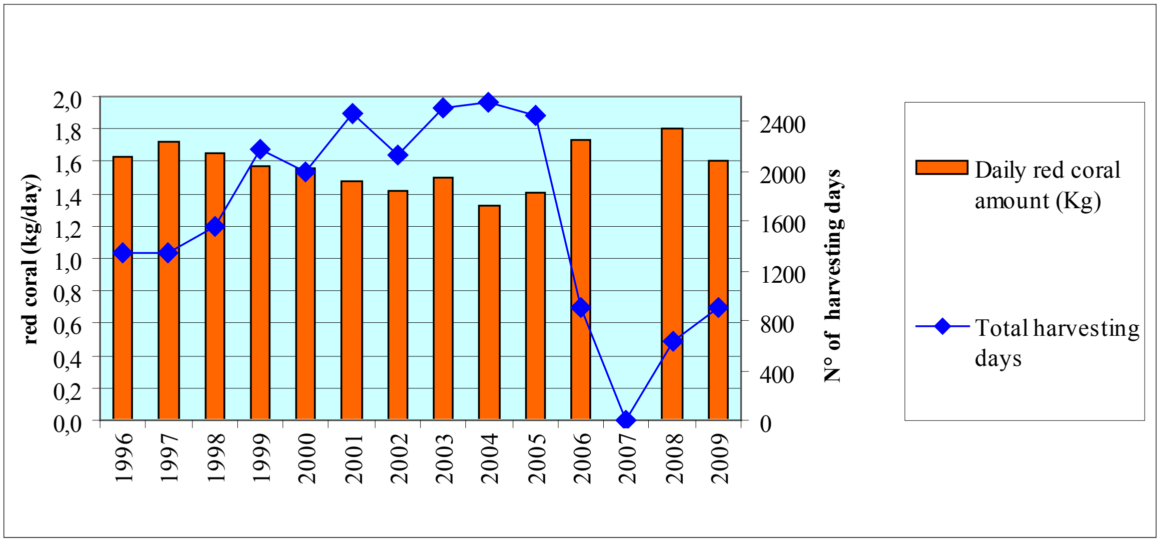

Fig. 10. Daily red coral amounts related to the annual number of harvesting days (total of effective harvesting days of all coral divers).

Discussion and Conclusions

A SWOT analysis was carried out (Table 3). In conclusion, the management strategy adopted in Sardinia seems to reveal that a good balance between protection and exploitation requirements is achievable also thanks to the strong collaboration among fishermen, high profile research institutions and regional administration. Further improvements will take into account new challenges like collection of independent data, independent evaluation, promotion of consortia, benchmarking with other administrations, and development of international pilot projects.

Table 3. SWOT.

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
Settled management system	Lack of training programs for coral divers and officers are continuous	Strengthen economic viability	Climate change (global warming)
Restrictions on destructive fishing methods	Lack of entrepreneurial networking	Branding strategies and distinctive quality management programs	Illegal, unreported and unregulated (IUU) fishing
Specific regulation and management system based on biological features of red coral (low growth rate, short distance larval dispersion, low recruitment rate)	Trade of mixed quality coral	Research development	(illegal fishing during forbidden periods and in forbidden areas)
Multiannual harvesting data collection (quantities, areas, depths)	Poor marketing strategies	International cooperation and benchmarking	Lack of financial resources to guarantee long-term enforcement and widespread control on fishing activities
Annual regulation based on scientific evidence		Active involvement of red coral fishermen against ghost fishing gears retrieval	
Multiannual experience of bilateral cooperation between Regional Administration and Scientific Research Departments		Restocking programs	

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DEVELOPMENT OF A GUIDE TO THE IDENTIFICATION OF PRECIOUS CORALS

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Director Traffic and Wildlife/WWF

Products such as jewelry and objects d'art made from Coralliidae and other coral taxa (including Antipatharia, Gerardia, Heliopora, Isididae, Melithaea, and Scleractinia – collectively referred-to here as precious corals) command high prices and near-global market demand. As a result, the trade in these corals is extensive and profitable and provides ample incentive for their harvest. Unfortunately, most of these taxa have life-history characteristics that make them particularly vulnerable to over-exploitation. In addition, the use of non-selective, destructive harvesting equipment in some areas, for some taxa, impacts not only the targeted coral species but also the invertebrate species dependent on the corals as a substrate.

Management and enforcement of trade regulations and international agreements concerning these taxa is complicated by the lack of resources designed to assist with the identification of precious corals and their products. Currently a comprehensive guide to the identification of precious corals does not exist.

Completion of this project will result in the worldwide distribution of an identification guide to the precious corals that will assist fisheries and wildlife trade management, scientific and (especially) enforcement authorities to better manage and enforce regulations regarding the harvest and trade of these taxa and thereby promote the wise management and sustainable use of coral resources. It will also facilitate the implementation of a CITES listing of *Corallium,* should the genus be so listed at the 15th Meeting of the Conference of CITES Parties in 2010.

Section III

Science: Biology and Ecology of Red Coral

POPULATION GENETIC STRUCTURE OF *CORALLIUM RUBRUM*: IMPLICATIONS FOR MANAGEMENT AND CONSERVATION

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Abstract

Understanding patterns of population genetic structuring has been recognized as one of the priorities for the conservation of biodiversity, including marine species affected by natural threats and human harvesting. The development of refined molecular tools allowed the collection of information on population divergence, gene flow, mixing of gene pools, effective population size, genetic loss, bottlenecks, effect of natural/human selection etc, providing an invaluable contribution for a scientifically sound management and conservation of marine biological resources. Genetic data are particularly informative in sessile taxa with patchy distribution, where spatial patterns of genetic structuring can be clearly assessed. Moreover, in species where is not possible to track spawning and larval movement, genetic data allow inferences about effective larval dispersal and connectivity among populations. Molecular tools allow the identification of "Management Units", thus contributing to the implementation of effective conservation strategies. Most studies on genetic structure of *Corallium* species have been done on Mediterranean *C. rubrum* while only preliminary data are available for some Atlantic species (*C. lauuense* and *C. secundum*). Genetic structure of *Corallium* species has been investigated using molecular markers with different levels of polymorphism (e.g. ITS, microsatellites, mtDNA). *Corallium* species are characterized by significant heterozygote deficiencies and deviations from Hardy–Weinberg expectations. These deviations are likely due to inbreeding and Wahlund effect.

Detailed studies on shallow water (15-50 m depth) *C. rubrum* populations showed the occurrence of chaotic genetic structuring at Mediterranean scale. Moreover, at small spatial scales, a surprisingly strong pattern of genetic divergence has been found. These results suggest that habitat features together with biological processes favor the structuring in "Evolutionarily Significant Units" at local scales. Patterns of genetic structuring are of great importance to infer about resilience of red coral populations. Harvesting strategies and conservation plans of shallow waters banks has to be planned at local scale on single populations. Further studies are needed to confirm occurrence of small scale patterns of genetic structuring in commercial banks (depth range 70-150m). However, a conservative approach would suggest considering each bank as a "Management Unit" requiring individual harvesting plan.

Introduction

In the past decades, human-induced disturbance (e.g. habitat loss and fragmentation, global climate change, overexploitation of commercial species, intensive trawling, pollution, and tourism) has increased in marine coastal areas (Airoldi and Beck 2007). Owing primarily to this disturbance, subtidal biogenic reefs in tropical and temperate habitats have suffered severe degradation, affecting both species and genetic diversities (Pandolfi et al. 2003; Bellwood et al. 2004; Worm et al. 2006). Sustainable exploitation and conservation of marine species are among the priorities of modern bio-resource management (Gray 1997). In this context, estimating connectivity among populations is essential since dispersal is a key element warranting population resilience following disturbance (Palumbi 2003; Bellwood et al. 2004). Population resilience after a disturbance event depends on the supply of new recruits. If populations are self-seeded, relying mainly on recruits produced within the population, disturbance events can have long term consequences due to reduction in larval supply. Moreover, reduction in population size may promote genetic drift, reducing the evolutionary potential of the species and increasing the risk of local extinction. However, connectivity among populations is a process that depends on dispersal of gametes and larvae between patchily distributed populations, and survival of recruits in the new population until they breed and reproduce (Pineda et al. 2007).

Connectivity is also strongly related to the life history and ecological characteristics of the species (reproductive strategies, presence or absence of planktonic larvae, migration habits, etc.). Physical and behavioral mechanisms of larval retention (e.g. marine water circulation, wind-driven circulation) that can affect genetic homogeneity (Leis and Carson-Ewart 2000; Swearer et al. 1999) and occurrence of physical barriers to larval dispersal (hydrodynamism, substrate geomorphology, etc.) are extremely relevant. Recent studies (Gaylord and Gaines 2000) underlined the need to improve knowledge on biotic and abiotic factors influencing larval dispersal in particular for sessile and sedentary benthic species, apparently more vulnerable to habitat fragmentation (Palumbi 2003).

Up to now, knowledge on reproductive strategies and range of larval dispersal in benthic invertebrates are limited due to the difficulties related to direct observation/tracking and experimental field studies (Palumbi and Lessios 2005; Moritz and Lavery 1996). Molecular tools, quantifying genetic divergence among populations and the effective number of migrants among them, allow an indirect estimation of the range of larval dispersal and of connectivity among populations. This information is useful to identify the Management Units (MU) and to plan conservation schemes and effective management strategies of natural populations.

For conservation porpoises, MU has to match the “Evolutionary Significant Units” (ESU). ESUs (or population) require an independent management, because they may differ in productivity, adult mean size, growth rates, and reproduction time. Moreover, characterization and mapping of ESUs allow to identify which units could harvested or conserved, if there are adaptive genetic differences among populations and if populations react differently to disturbances.

The genus *Corallium* comprise 19 species (Bayer and Cairns 2003), including the most valuable precious corals. *Corallium* species dwell on rocky bottom at a depth ranging between 10 and 2000 m, typically aggregating on banks and seamounts, under ledges, and in and around caves. They occur in the Mediterranean Sea, Atlantic Ocean, Indian Ocean, Western and Eastern Pacific Ocean. Out if 19 species only seven are harvested for jewelry purposes (*C. secundum, C. elatius, C. konojoi, C. japonicum* (now classified as *Paracorallium japonicum*), *C. lauuense, Corallium* s.n., and *C. rubrum*). *C. rubrum* is the only Mediterranean species. It is able to colonize caves and overhanging at shallow depths (from about 10 m depth), differing from all other *Corallium* species, which occur at a depth greater than 500 m (Bayer 1964, 1996; Grigg and Bayer 1976; Bayer and Cairns 2003). Recently, live red coral colonies have been observed in the Strait of Sicily down to about 800 m (Costantini et al. 2009; Freiwald et al. 2009). These new records suggested the occurrence of three typologies of *C. rubrum* populations: (i) shallow-water populations in a depth range between 15 and about 60 m, dwelling on vertical cliffs and in caves; (ii) intermediate-water populations, at a depth range of about 60–300 m; (iii) deep-water populations below 300 m depth that are poorly known (Costantini et al. 2009). Nowadays, the commercial harvesting is mainly focused on intermediate-water populations of *C. rubrum*, whereas the main bulk of biological knowledge refers to the more accessible shallow-water populations.

In this work we summarize the existing knowledge on population genetic structuring in *Corallium* species, to identify the recurrent genetic features and to reveal spatial scales of genetic structuring and patterns of larval dispersal capability in Mediterranean *Corallium rubrum* populations. The implications of these findings for harvesting management and conservation strategies of precious red coral are also addressed. We also discuss gaps in genetic data and how to fill these gaps.

Mitochondrial Genetic Markers in *Corallium* Species

The most effective molecular markers to investigate intraspecific level of genetic structuring are sequence polymorphism of mtDNA and microsatellite loci (Fig. 1). Studies on genetic structure of *Corallium* species are limited, and deals mainly with Mediterranean *Corallium rubrum* (Table 1).

In Anthozoa, mitochondrial DNA is highly conserved, providing little information on the genetic structure of the species and failing to detect genetic heterogeneity among samples because of their high degree of conservativeness (Shearer et al. 2002). Studies by Costantini et al. (2003), Calderon et al. (2006), and Mokhtar-Jamai et al. (2009) showed that 16S and COI genes in *Corallium rubrum* have very low variability, making them unsuitable markers for studies of variation at the intraspecific level. This lack of variability in mitochondrial genes seems related to evolutionary processes within the mitochondrial genome (Shearer et al. 2002). Nevertheless, Costantini et al. (2009) and France and Hoover (2002) have shown one substitution in mitochondrial sequences (MSH and COI) between shallow- and deep- water specimens of *Corallium rubrum* and *Corallium ducale* respectively. Such a fixed substitution of one nucleotide might suggest lack of connectivity between shallow- and deep-water populations in both *Corallium* species, but the small sample size of the deep-water collections does not allow further consideration on the evolutionary implications of this genetic variation (Costantini et al. 2009).

Other species like *C. kishinouyei, C. ducale, C. regale* and *C. niobe* have been used in phylogenetic studies at greater taxonomic level (France et al. 1996; France and Hoover 2001; France and Hoover 2002; Sanchez et al. 2003; Mc.Fadden et al. 2006; France 2007) but no detailed phylogenetic studies within the genus *Corallium* have been done up to now (e.g. Sanchez 2010, in prep).

Microsatellite Genetic Variability in *Corallium* Species

Population genetic studies have been done on three of the 19 *Corallium* species: *Corallium lauuense, C. secundum,* and *C. rubrum.* The first two species are deep-water corals (depth range 385-535 m) abundant and widely distributed in the Hawaii. Only few populations of these species have been analyzed using microsatellite loci (Table 2), which are the appropriate molecular markers to examine the occurrence of genetic structuring at different spatial scales.

Microsatellite studies of *Corallium lauuense* indicated significant heterozygote deficiency in most populations, suggesting recruitment in most populations is from local sources with only occasional long-distance dispersal events. Also, two populations appear to be significantly isolated from other populations of *C. lauuense* and may be separate stocks (Baco and Shank 2005; Baco et al. 2006). In contrast, *C. secundum* populations have little heterozygote deficiency and separate into 3 distinct regions. In addition to having fisheries management implications for these corals, the results of these studies also have implications for the management and protection of seamount fauna (Baco 2006).

Population Genetic Structure of *Corallium rubrum*

Genetic structuring in this species was first described using allozyme electrophoresis (Abbiati et al. 1993). These studies showed the occurrence of genetic differentiation among red coral populations at a spatial scale of a few kilometers and a lack of genetic structuring over shorter distances (about 200 m) (Abbiati et al. 1997). However, allozyme markers may have limited power in revealing small-scale genetic structure due to their low polymorphism and mutation rates.

Afterwards, a combination of sequence polymorphism of the Internal Transcribed Spacer (ITS) and species – specific microsatellite loci (Costantini and Abbiati 2006) have been used to analyze the genetic structuring of red coral populations at Mediterranean scale (Costantini et al. 2007a). Both markers revealed a high degree of genetic differentiation between samples throughout the northwestern Mediterranean Sea (though to a different extent). Moreover, microsatellites and ITS-1 sequences showed no correlation between genetic differentiation and geographical distance among the analyzed samples. Such lack of correlation may support an island model of dispersal, where larvae move from one area to another with equal probability, rather than an isolation-by-distance model, where the probability of dispersal between sites declines with increasing geographical distance. The absence of clear patterns should be interpreted with caution because such patterns may hide underlying small-scale genetic structuring (Costantini et al. 2007a).

In 2007, Costantini et al. (2007b), using four microsatellite loci have analyzed small spatial scale genetic structuring in *C. rubrum* samples collected in two location (hundred Kms distance) using a hierarchical sampling design including scales from 10s to 100s of meters. Significant deviations from Hardy-Weinberg equilibrium due to elevated heterozygote deficiencies were detected in all samples and were consistent with the occurrence of inbreeding (mating between consanguineous) and a Wahlund effect (mixing of differentiated gene pools). These results have been confirmed also to recent data by Mokhtar-Jamai et al (2009) and Ledoux et al. (in prep). The two locations showed differences in genetic variability that could be related to differences in habitat characteristics. The size and spatial arrangement of habitat, indeed, may be of great importance for the ecology and population structure of species with limited dispersal range (Palumbi 2004). Significant levels of genetic differentiation were found at spatial scales of 10s of meters, supporting the hypothesis that planulae have limited effective dispersal ability. Furthermore, evidence of inbreeding, the Wahlund effect and high genetic variance within samples suggest that the effective larval dispersal range may be < 10 m (Costantini et al. 2007b). A more recent study, analyzing collecting samples at 1 meter intervals along a 10 m transect have observed a chaotic genetic structuring also at this smallest spatial scale (Costantini et al., in prep).

At least, the find out of deep live red coral colonies have allowed a preliminary genetic characterization of these specimens implying the possible occurrence of genetic isolation among shallow and deep-water populations. These findings suggest that genetic diversity of red coral over its actual range of depth distribution is shaped by complex interactions among geological, historical, biological and ecological processes (Costantini et al. 2009).

Conclusion

Molecular tools have been used to study genetic variability and genetic structuring of 7 *Corallium* species. Conservation issues have been addressed for 3 species: *C. lauuense, C. secundum* and *C. rubrum*. No studies on phylogenetic relationships between *Corallium* species have been performed (but Sanchez 2010 in prep, pers. comm.) so up to now there are no clear evidences about evolutionary relationship within the genus *Corallium.*

Common Genetic Features in *Corallium* Species

All the *Corallium* species analyzed by means of molecular markers have shown a deficit of heterozygotes. This deficit has been explained by the occurrence of inbreeding within samples and of local recruitment. These results are in accordance with the reproductive biology and larval ecology of *Corallium.* For example, in red coral, embryo development takes place within the female polyps for about 30 d, before release of planula larvae (Vighi 1972). Moreover, reduced swimming ability and geonegative behavior of the planulae suggest that, once released, larvae settle in close vicinity of the parental colonies (Vighi 1972). Therefore, reproduction events in red coral are more likely to involve related individuals compared to species with broadcasting development and so *Corallium* populations are primarily self-recruiting.

Spatial Scale of Genetic Structuring in *Corallium rubrum*

Most studies on scales of genetic structuring have been done on Mediterranean *Corallium rubrum* (Fig. 2). Using molecular markers with differing levels of polymorphisms, a complex genetic structuring at different spatial scale has been observed. In fact, a strong genetic structuring at Mediterranean scale with no isolation by distance patterns has been observed. Moreover, a pattern of chaotic genetic divergence at small spatial scales has also been detected. If at Mediterranean scale the genetic structuring observed could be strongly influenced by the environmental features where the species live (e.g. habitat characteristics, geomorphology, and hydrodynamics), at the smallest spatial scale biological processes (e.g. pre- and post-settlement mortality and stochasticity of reproductive success) may favor the occurrence of genetically distinct pools of recruits at meter distances. The assumption, made in most population dynamic studies (Abbiati et al. 1993; Santangelo et al. 2009), that red coral population are closed populations is supported by genetic results (Costantini et al., in prep). Moreover, habitat features together with biological processes favor the structuring in "Evolutionarily Significant Units" at local scales.

Gaps to Fill

This survey of the scientific literature on the genetic features of *Corallium* species shows that a series of gaps have to be filled, to allow suggesting effective guidelines for harvesting strategies and conservation of these species.

1) To understand patterns of genetic structuring and reproductive behaviour of *Corallium* species population genetic analysis have to be extended to all commercial species which have not been yet investigated, e.g. Japanese red coral (*Paracorallium japonicum*), pink coral (*Corallium elatius*) and white coral (*Corallium konojoi*).

2) New molecular markers with intermediate variability compared to nuclear DNA and mitochondrial genes have to be developed to properly address pattern of genetic structuring between populations at regional scale (e.g. the Mediterranean Sea for *C. rubrum*). For *C. rubrum,* it would be essential to extend sampling to the Atlantic, Southern, and Eastern Mediterranean. The scarcity of sampling efforts along the Southern and Eastern Mediterranean and Atlantic coasts suggest the need to develop effective inter-regional collaborations plans.

3) Studies have to include the whole depth range distribution as well as the geographic distribution of the species. While there are now good knowledge about population parameters and connectivity patterns in shallow-water populations, we just begin to study the most exploited intermediate-water and the newly recorded deep-water populations. Moreover, temporal patterns of genetic structuring should be investigated to check if a reduction of genetic variability occurred between ancient and actual populations.

4) Integrating data on different aspects of the ecology, biology, genetics of *Corallium* species should be a priority for management agencies. In particular, future researches have to focus on integration between studies on population structure, population growth rates (e.g. reproduction, recruitment), and connectivity patterns.

Implication for Management

Available genetic data on *Corallium* species, even if fragmentary and mainly derived form shallow water Mediterranean populations (Abbiati et al. 1993; Costantini et al. 2007a,b) provide useful information to infer about size of the 'Management Units,' recovery ability of the species, harvesting strategies, and conservation needs of *Corallium* populations.

The chaotic genetic structuring observed at different spatial scale ranging from Mediterranean to micro suggest that conservation of shallow waters red coral populations has to be planned at regional or local scales. Based on the precautionary principle, also for commercially harvested intermediate-water populations (70-150 m depth) individual harvesting plans of each bank has to be considered. Identification of the commercial banks within the Mediterranean Sea and quantification of the available commercial stocks of the species has to be a priority. Each stock should be characterized from the molecular point of view to identify population boundaries and Management Units. Management strategies at pan-Mediterranean scale should be implemented based on Regional Management Units, by defining harvesting regions and applying rotating harvesting schemes within each region.

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Fig. 1. Genotyping of three *Corallium rubrum* colonies using two microsatellite loci (Cor48 and Cor15).

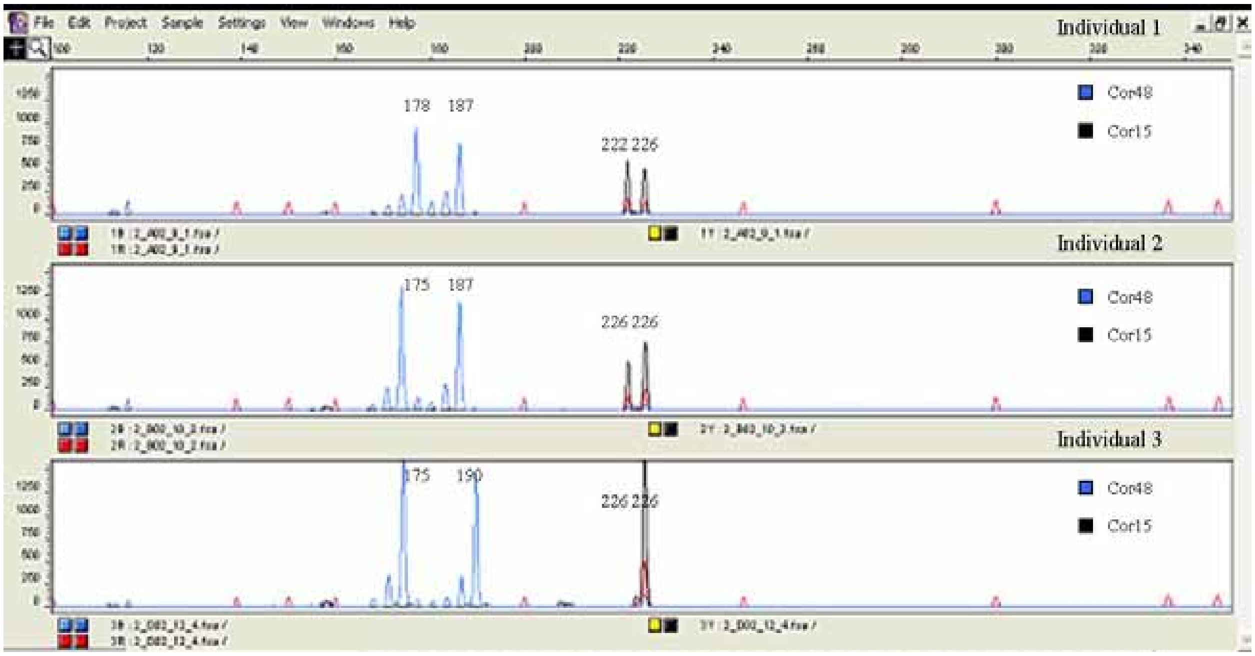

Fig. 2. Map of the *Corallium rubrum* populations analyzed with molecular markers (after Costantini et al. 2007a, modified).

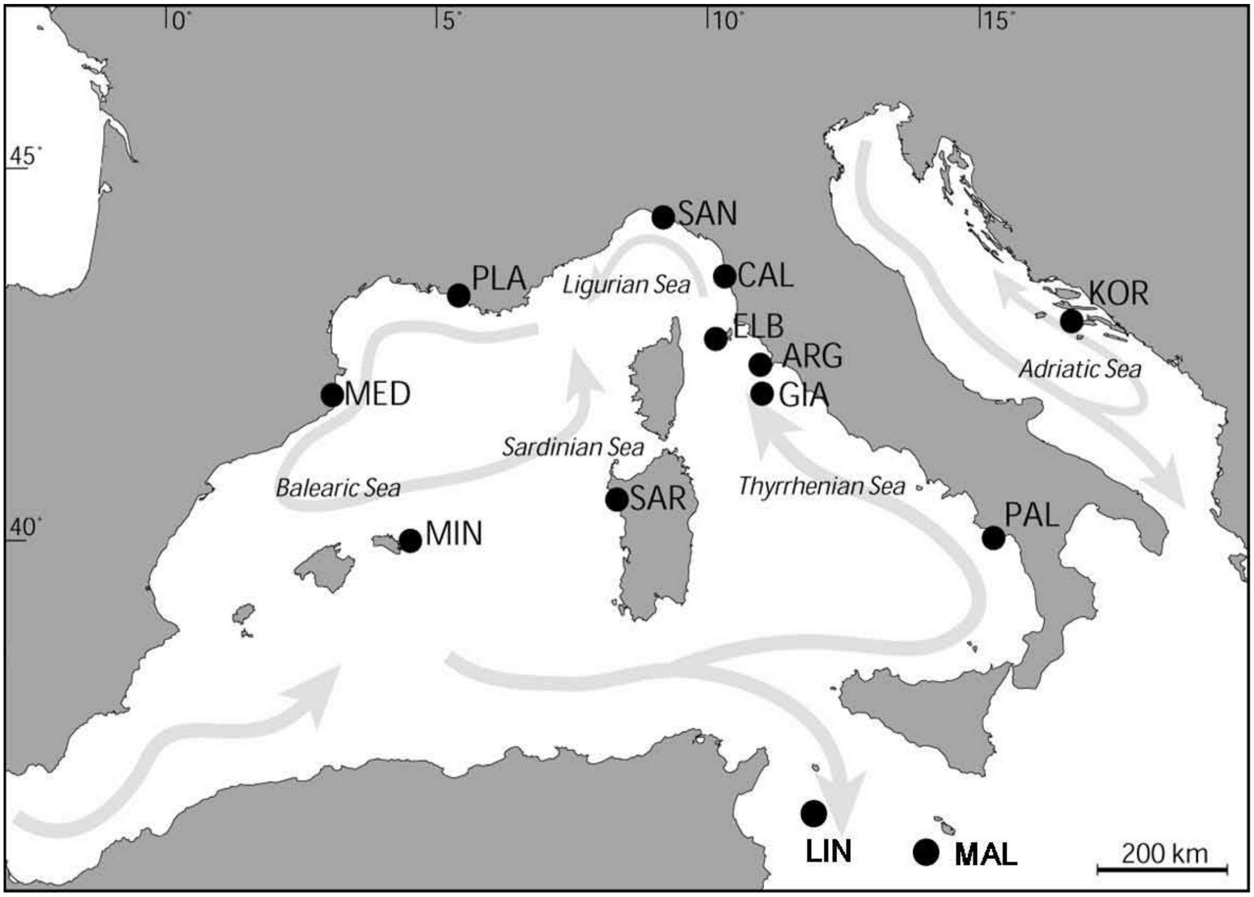

Table 1. Existing references of *Corallium* species analyzed with different molecular markers.

Species	Molecular marker	References
Corallium rubrum	allozyme	Abbiati et al. (1993, 1997)
Corallium rubrum	mtDNA	Costantini et al. (2003); Calderon et al. (2006), Mokhtar-Jamai et al. (2009)
Corallium rubrum	ITS	Costantini et al. (2007a)
Corallium rubrum	microsatellites	Costantini and Abbiati (2006); Costantini et al. (2007a, b); Mokhtar-Jamai et al. (2009)
Corallium lauuense	microsatellites	Baco and Shank (2005); Baco et al. (2006)
Corallium secundum	microsatellites	Baco (2006)
Corallium kishinouyei	mtDNA	France et al. (1996); France and Hoover (2001, 2002); Berntson et al (2001)
Corallium ducale	mtDNA	France et al. (1996); France and Hoover (2001, 2002); France (2007); Brugler and France (2008)
Corallium regale	mtDNA	France and Hoover (2001, 2002)
Corallium niobe	mtDNA	France (2007)

Table 2. Non-Mediterranean populations of *Corallium* analyzed using microsatellite loci.

Species	Studied populations	Distribution
Corallium lauuense	8	Hawaiian archipelago
Corallium secundum	11	Hawaiian archipelago

BIOLOGICAL INTERACTIONS AFFECTING THE GROWTH RATES OF RED CORAL (*CORALLIUM RUBRUM*) COLONIES*

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Abstract

The red coral (*Corallium rubrum*: Cnidaria, Anthozoa) is a significant Mediterranean resource with wide historical, economic, and cultural involvements. Several countries in the Mediterranean Sea have adopted different kinds of strategies for its conservation. On the other hand, the main data necessary for a rational management of a biological resource is the time necessary for the recruits to reach an exploitable size. Data about the growth rate of just settled or juvenile colonies living in shallow waters (< 50 m) are abundant and values of 1 mm year^{-1} for the base diameter and 1 cm year^{-1} for the height of the colony are generally accepted. Nevertheless it is demonstrated that 4-5 years after the settling, the growth virtually stops or becomes negligible: colonies monitored for more than 20 years along the French coast reached an height of about 4 cm and a basal diameter of 0.5 cm. Historical and recent data about the size and density of the shallow water population of Portofino Promontory (Ligurian Sea) are available, indicating important fluctuations of these parameters. Firstly, samples collected during the '50 years, together with contemporaneous popular articles and interviews with old divers, strongly suggest that the size structure of the Portofino population is not significantly changed in the last 50 years, although a slight exploitation of the banks occurred. Actually, the colony size of the colonies is inversely related to their density, suggesting an intraspecific competition linked to the space availability and trophic inputs. Moreover, it is surprising that in the last 10 years the Portofino shallow water populations have shown an unusually fast growth rate, reaching the maximal colony size never recorded in the previous 40 years (15 cm in height and 20 DW g). This unusual fast growth rate was recorded after the mass mortality episodes of 1999 and 2003, involving not only red coral, but also several other benthic species and provoking a significant change in the structure of the coralligenous assemblage. All these evidences suggest that the growth of the Mediterranean red coral is strongly affected by intra- and inter-specific interactions linked not only to local variables by also to stochastic events.

Introduction

The red coral (*Corallium rubrum*: Cnidaria, Anthozoa) is an important Mediterranean resource with huge historical, economic, and cultural involvements (Cicogna and Cattaneo-Vietti 1993; Cicogna et al. 1999). It is widely distributed throughout the Mediterranean: occurring both in commercially exploitable concentrations, as off Spain, Algeria, and Sardinia, as well as at lower densities from the Aegean and southern and eastern Mediterranean to the Sea of Alboran. Some populations were recorded in the Capo Verde Archipelago (Zibrowius et al. 1984).

Preoccupation has been expressed by fishermen and industry with the declining returns to an ever more sophisticated harvesting gears capable of operating at more than one hundred metres depth, which have progressively substituted the primitive dragging equipment. Scuba harvesting tends to be in a "pulse" mode, in which local patches are cleaned out selectively, leaving only inaccessible or non commercial individuals, before another patch is located and harvested in turn (Caddy 1993). Consequently, several countries in the Mediterranean Sea have adopted different kinds of strategies for the red coral conservation, particularly the closure of coral fishery in overexploited areas.

Red coral population density and colony size vary from place to place, also according to depth and exploitation (Tsounis et al. 2006; Rossi et al. 2008). Schematically, we can distinguish two different spatial situations: (i) coastal populations, occurring up to 50 m depth, characterised by high density (up to 1000 colony/m^2) and small colony size (until 5 cm height), most of colonies produce tens of planulae per year; (ii) deeper populations, extending up to 200 m depth and more, characterised by low density and high colony size. These colonies may produce until 2000 planulae per year (Santangelo et al. 2003). Of these two kinds of situations, the second one only is really important from an economic viewpoint while the first one, merely of naturalistic value, constitute a stock of breeders for the species.

After settlement, the growth rate of shallow water colonies is about 1 mm $year^{-1}$ for the base diameter, and 10 mm $year^{-1}$ for the height (Cattaneo-Vietti and Bavestrello 1994) but after 4-5 years, the growth virtually stops or becomes negligible. In fact, long-term studies (22 years) indicate an average growth rates extremely low: 0.24 ± 0.05 mm $year^{-1}$ for the basal diameter and 1.78 ± 0.7 mm $year^{-1}$ for colony height (Garrabou and Harmelin 2002). Similar data were indirectly obtained by examining the growth rings of shallow water colonies: specimens with basal diameter of about 7 mm were at least 30-40 years old with a growth rate of the basal diameter of 0.35 ± 0.15 mm $year^{-1}$ (Marschal *et al*., 2004). Bramanti *et al*. (2005) measured the growth rate of colonies settled on long-term artificial substrates: after four years the colonies exhibited an average annual growth of the stem diameter of 0.62 ± 0.19 mm $year^{-1}$. Similar data were also obtained by Torrents et al. (2008). Practically no information is available for deeper populations, but if these trends are applied to all cases, we may estimate age of several decades for colonies of 10-20 mm of basal diameter and 20-30 cm of height.

Although very few data are available, coral growth rate is probably affected by physical and chemical variables (light, currents, input of organic matter, Ca^{++} availability) and biological ones (food availability, competition). Practically no data are available on intra- and inter-specific competitions and larval behavior which could have a significant role in structuring the deeper populations. Also the thermal anomalies can affect the size and shape of the coral colonies: during these episodes, autotomy of the branch tips was noticed on several colonies (Russo et al. 1999) and the reproductive implications of this phenomenon still need to be clarified.

Finally anthropogenic impact can be very important: an underestimated phenomenon is the impact on coral populations of fishing lines that broke the branches of the colonies.

To give a contribution to the knowledge of the Mediterranean structure and dynamics of the coastal populations, in this paper we discuss on size and density of the red coral along the Portofino Promontory (Ligurian Sea), comparing present and historical data.

Results

Size/Density Relationship Along a Depth Transect

We have conducted a series of measures on the density and size of the red coral colonies along a depth transect on the rocky cliff of Portofino Promontory (Ligurian Sea). This study was conduced during July 2008, by using non-destructive photographic methods. Data were recorded in three stations, at 30, 50, and 70 m depth by scuba diving.

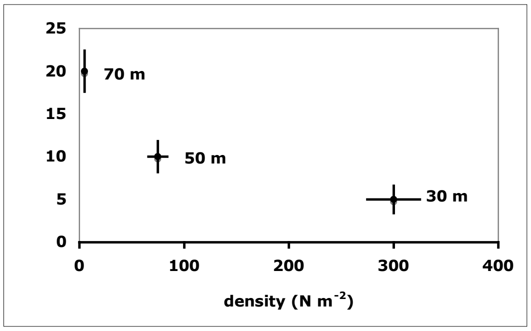

Fig. 1. Density/size relationships along a depth transect on the Portofino Promontory.

The observations indicate that the two variables are inversely related, as shown in Fig. 1. Density is very high at 30 m depth (about 300 colonies m^{-2}), but the average height of the colonies is low (about 5 cm). At this depth, the colonies mainly growth hanged to the roof of the crevices of the coralligenous conglomerate. The biocoenosis includes several sponge species insinuating, encrusting and massive or erected. The stony coral *Leptopsammia pruvoti* is often present. Among bryozoans, *Smittina*, *Rynchozoon*, and *Reteporella* are among the commonest genera.

At 50 m depth, the size of the colonies drastically increases but, contemporaneously, the density is reduced. Here red coral settles perpendicularly to the cliff together with several sponges and bryozoans. *L. pruvoti* is very abundant.

At 70 m depth, the colonies show a commercial size: 1-2 cm in the basal diameter and about 15 cm in height, but their densities drop down to only 2 colonies m^{-2}. Recruits and juvenile colonies are very rare or completely lacking. At this depth, the colonies live on sparse rocks arising from the detritical bottom. The sedimentation is very high and a sheet of thin sediment covers the rocks. *Leptopsammia* and bryozoans are rare, while only erected sponges are common. *Haliclona mucosa* that in shallow waters produces thin crusts inside crevices, here has a thick ear-like shape.

Growth Rate Variation

Several information regarding the community structure of the Portofino red coral in the 50' years of the last century suggest it was not so different from today. A group of colonies collected during the 50' years and now conserved at the Museo di Storia Naturale of Genoa has an average height of 20 cm. In a popular book about describing a long series of diving along the Portofino Promontory, Roghi (1966) stated that in this area the coral was always been very abundant but of small size. All the interviews with old divers that collected coral in this area agree that on the cliff, until 50 m depth, the colonies were abundant but very small; from 50 to 60 m depth, on rocks sparse in the detritical bottoms some branches 15 cm height with a weight of about 100 g were present. An unusual situation was observed on the tip of the promontory (Punta del Faro) were, 80 m depth, colonies until 250 g of weight were collected.

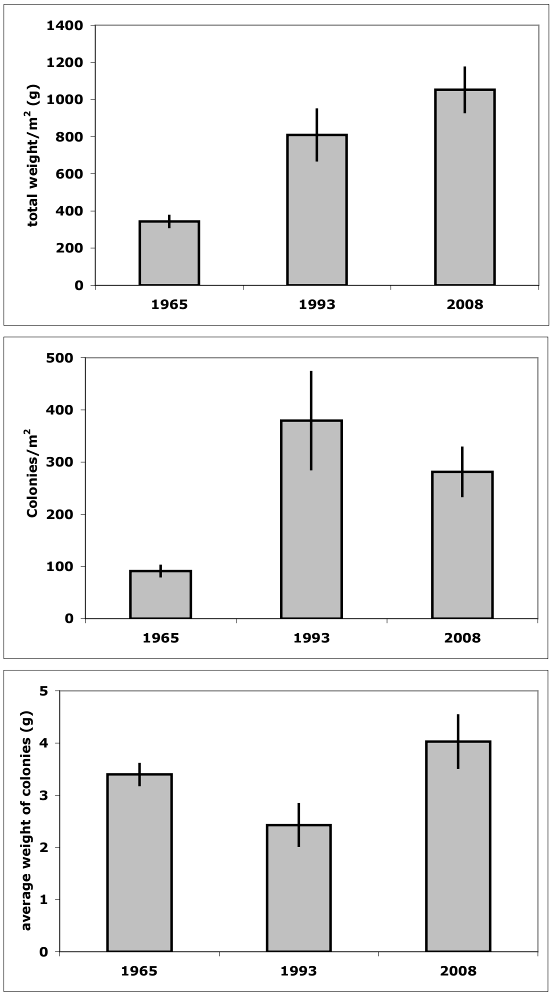

Fig. 2. Historical and present data of biomass (A); density (B) and average colony weight (C) of the coral population of the Portofino Promontory.

The first quantitative information about the colony size of the Portofino coral are due to Marchetti (1965) who recorded, at 30 m depth, a DW biomass m^{-2} lower than 400 g. This datum was determined by a low number of colonies (< 100) with an average weight of about 3.5 g. About 30 years after, Cattaneo-Vietti et al. (1993) came back in the Marchetti stations, recording an increasing in biomass, reaching about 800 DW g m^{-2}. The colony density was increased of more than three times, but the average weight of a single colony decreased until 2.5 g.

During 1999 and 2003 and, with less intensity in 2005 and 2006, the populations of red coral of the Ligurian Sea were strongly affected by episodes of mass mortality, sometimes killing more than 90% of the colonies. Together with red coral also several sea fans, sponges and bryozoans (almost 23 species in 1999 and 14 species in 2003) were affected drastically, changing the structure of the whole biocoenosis (Cerrano et al. 2000, 2008; Perez et al. 2000; Garrabou et al. 2001).

Recent surveys, conduced in the summer 2008, on the same stations, showed a further increasing of the biomass, until 1000 DW g m^{-2}. This value is due to an increasing of the average size of the colonies that sometimes reach 15 cm in height and 20 g in DW (Fig. 3). Contemporaneously, the density of population again decreases (Fig. 2).

Discussion

Among benthic cnidarians, the Mediterranean red coral shows a peculiar life strategy, not completely clarified: its population density is inversely related to colonies size, along both spatial and temporal trends. These structural characteristics, observed studying the red coral populations living along the Portofino cliffs (Ligurian Sea), agree with ROV studies conducted on the Spanish coasts (Rossi et al. 2008).

In shallow populations, density and size of the Mediterranean red coral can be affected by harvesting: recently Tsounis et al. (2006) have demonstrated that the fishing in Costa Brava has deeply influenced the population structures, transforming them from a “forest-like” structure to a “grass plain-like” one. This has been evidenced comparing harvested populations with “natural” ones, living in the Medas Islands MPA.

The harvesting not only affects the size structure of a shallow population for the obvious reason that fishermen collect preferably colonies of large size, but also enhancing the larval settling.

In 1990, we have experimentally scraped all the colonies present in a 30 x 30 cm surface inside a dense Portofino Promontory population. All the colonies were counted and measured. Four years after, all the colonies present in the same surface were again collected: their number was increased, but the average size decreased (Fig. 4). This result suggested a strong intraspecific competition as the available space induced a high larval settling (Cerrano et al., 1999). Under this condition, the coral populations appear like a "copse wood" where, after the cut, the new young trees grow densely and quickly, forming a bushy structure that remains in this situation for a long span of time due to intraspecific competition. Tsounis et al. (2006) stated that 14 years of protection at the Medas Island were not sufficient to reach a "forest-like" structure.

Fig. 3. A large colony of 30 g collected on the Portofino cliff.

At the same, the Portofino coral populations were heavily exploited during the '50-60 years, but in the last 30 years no more fishing activities have been conduced. During this long span of time, these shallow water populations remained in an immature stage, confirming the idea that the "young forest effect" could stop for long time the further size increase of the population.

An open question is why the recruitment is so high only in shallow waters, while in the deeper ones no juveniles were observed although it is well known that the large deeper colonies are able to release thousands of planulae (Santangelo et al. 2003).

It is possible that the high sedimentation recorded 70 m depth, on the rocks emerging from the soft bottom, could prevent the recruits as avoids the settling of other benthic organisms, like encrusting sponges and bryozoans. It is possible to hypothesise that the planulae released by deep colonies, in the absence of a suitable substratum, move to shallow habitats. By this way, the superficial populations are continuously supplied by the larvae produced by themselves and by those released by deeper colonies, while in deep waters the larval settling remains rare, linked to the stochastic presence of favourable micro-environmental situations. Following this hypothesis, the high density and small average colony size of the superficial populations could be a natural phenomenon, locally enhanced by harvesting and due to the high recruitment typical of these habitats.

On the other hand, free from competition, the deep colonies are able to grow more quickly. Moreover, living in more constantly colder water, their final size could be higher as recorded for the greatest part of ectothermic organisms (Atkinson and Sibly 1997).

As indicated by our data, the situation of shallow water population can be changed by stochastic event like the mass mortality episodes occurred in the Ligurian Sea during 1999 (Cerrano et al. 2000) and 2003 and, with low intensity, in 2005 and 2006 (Cerrano et al. 2008). Since the first mass mortality episode, the Portofino populations have shown an unusually fast growth rate, reaching maximal colony sizes (until 15 cm in height and 1 cm of basal diameter, 20 g DW) values never recorded in the previous 43 years.

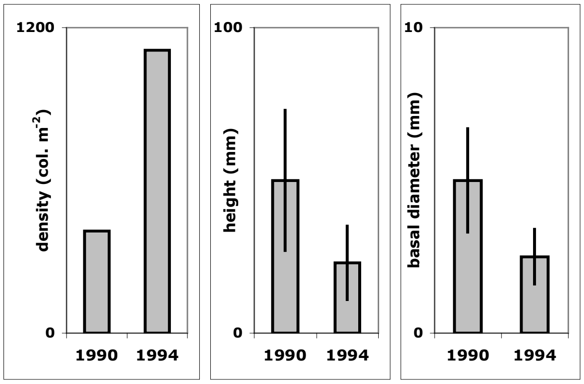

Fig. 4. Comparison of density and size of the original and the reconstituted population after 4 years.

The obvious explication of this phenomenon is that for the few, survived colonies, the intraspecific competition decreased and the greater availability of several resources gave them the opportunity of a faster growth rate. It is intriguing that, although the average size of colonies is now the largest of the past 43 years, the density is greater that in 1965. This fact suggests that intraspecific competition is not the only constrain able to affect coral growth: very likely also inter-specific competition plays a significant role. This is particularly evident in the relationships between red coral and the stony coral *Leptopsammia pruvoti*: on the cliff of the Portofino Promontory although the two species are able to coexist, they tend to colonise alternative areas, along a same horizontal transect, due to imperceptible micro-environmental conditions, by favouring alternately one species or the other (Cattaneo-Vietti et al. 1993).

All these evidences suggest that the growth of the Mediterranean red coral is strongly affected by intra- and inter-specific interactions linked not only to local variables by also to stochastic events.

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LONG-TERM SETTLEMENT PLATES:
SOME CLUES FOR DEMOGRAPHY AND RESTORATION OF MEDITERRANEAN RED CORAL (*CORALLIUM RUBRUM*) SHALLOW WATER POPULATIONS

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Abstract

Recovery of coral populations is a slow process, especially in Mediterranean Sea where octocorals, characterized by slow growth rates, are dominant. Until now, restoration techniques are based on transplantation, a technique requiring high degree of manipulation leading to high colony mortality. Mediterranean red coral (*Corallium rubrum*, L 1758) is a long-lived, slow-growing gorgonian, endemic to Mediterranean rocky shores. Its high economic value determined over-harvesting which brought many coastal, shallow-water populations to depletion. Moreover, shallow-water populations could be extremely vulnerable to mass mortality events putatively linked to global warming. Therefore, these populations need conservation and restoration actions. Due to their fragility, transplantation of adult colonies does not give any effective result. Within this framework we set out a method suitable to foster red coral recruitment on artificial, carbonatic substrates (marble tiles), following a patented protocol. This protocol allowed red coral larvae settlement and growth on marble tiles. In the framework of a study carried out in Italy with 54 100 cm^2 marble tiles, overall, 388 settlers colonized the tiles and their densities varied between 12.37 ± 6.1 and 2.75 ± 2.4 dm-2. Even if mortality affected these colonies (24.35 ± 9.12 colonies % y-1), after 4 years the tiles still harbored a persistent population (19 ± 4.97 dm-2) with positive net-recruitment rates (recruitment-mortality). As permanently colonized tiles may easily be removed and fixed again in new areas by a central screw, red coral re-colonization may be fostered by transferring and re-fixing tiles in areas depleted of red coral colonies. Moreover, none of the colonies settled on such tiles was affected by boring sponges, which are one of the main sources of red coral mortality and also reduce their economic value. These findings suggest marble tiles could be a useful tool both to study recruitment and to foster restoration of red coral shallow-water populations.

Fig. 1. *Corallium rubrum* colony with open polyps.

Mediterranean red coral (*Corallium rubrum*, L 1758) is a colonial Anthozoan endemic to the Mediterranean Sea (Fig. 1). Its bathymetric range is comprised between 10 and 800 m depth (Zibrowius et al. 1984; Costantini et. al. 2009). Due to the high economic value of its axial, carbonate skeleton, this coral has been harvested and traded since ancient times (Fig. 2). Nowadays a reduction of overall fishing yield was recorded and in the last two decades the Mediterranean yield reduced by 2/3 (Santangelo and Abbiati 2001; Tsounis et al. 2007). Red coral is a long-lived, gonochoric, brooder species, whose larvae (planulae) do not travel very far from the parental colonies (Vighi 1972; Weinberg 1979). This species is structured in genetically differentiated, self-seeding populations (Abbiati et al. 1993). Reproduction is discrete and occurs within a limited time interval in early summer (Santangelo et al. 2003). On a bathymetric distribution point of view, two kind of populations can be distinguished:

- Coastal shallower populations (up to 70 meters depth), characterized by colonies with small size, few branches, a small average basal diameter, a high density (Tsounis et al. 2007), and a limited economic value due to colony small size and to parasitic boring sponges infection (more than 50% of the colonies are affected by boring sponges; Corriero et al. 1997).

- Deep populations (below 70 m depth) are characterized by large, sparse colonies with a high economic value.

Fig. 2. Precious handcraft objects obtained from *Corallium rubrum* axial skeleton.

Studies on different shallow-water populations indicate their vulnerability to mortality events due to global warming. In late summer 1999 and 2003, a mass mortality affected several benthic invertebrates (mainly sponges and gorgonians) in the western Mediterranean Sea (Cerrano et al. 2000). Adult colonies of a red coral population dwelling at Marseille were heavily affected by this event (Garrabou et al. 2001) while in the population of Calafuria (Livorno, Italy) recruitment, more than adult colonies, suffered mortality (Bramanti et al. 2005; Santangelo et al. 2007). At the same time, an anomalous temperature increase has been recorded in the same geographic area (Cerrano et al. 2000; Romano et al. 2000). Such anomaly was considered to be (the putative) cause causing the mass mortality (Coma and Ribes 2003).

Data on shallow populations suggest moreover that colony size reduced (and probably density increased) due to the over-harvesting these populations faced (Garrabou and Harmelin 2002; Tsounis et al. 2007; Bramanti et al. 2009). Consequently, several coastal shallow-water populations have been brought to depletion. Therefore these populations need conservation and restoration actions.

To conservation purposes we perform a demographic approach to population through life history tables and population demographic models (Santangelo et al. 2004, 2007; Bramanti et al. 2009). Life history tables, which merge mortality and reproduction of individuals within a population, are suitable for demographic studies of long-lived species and have been proven to be (useful) appropriate conservation tools approaching overexploited species (Gotelli 1991; Ebert 1999; Fujiwara and Caswell 2001; Santangelo et al. 2004, 2007). Life tables moreover represent indispensable tools for compiling transition matrices (non-linear Leslie matrices of population growth), which in turn provide projections of population trends over time in stage-subdivided populations (Tuljapurkar and Caswell 1997).

To restoration purposes we patented a method to avoid manipulation of colonies. Mediterranean red coral is characterized by a slow growth rate (Marschal et al. 2004; Torrents et al. 2005) and therefore the recovery of depleted populations is a slow process. Transplantation of adult colonies is a restoration technique normally used in tropical corals (Oren and Benayahu 1997). This technique is based on the manipulation of the colonies harvested in a place and transplanted to a different one. This manipulation represents a stress that result in a high mortality of transplanted colonies. In the case of *Corallium rubrum*, moreover, fragility of colonies makes transplantation techniques not effective.

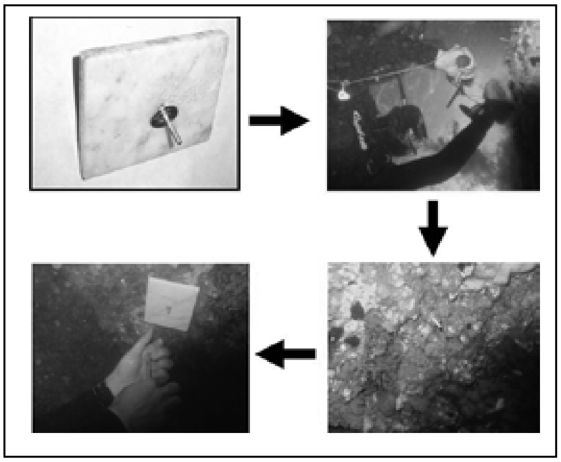

Fig. 3. White marble tiles are fixed to the rocky wall by a central steel screw onto the vault of crevices, in which red coral adult colonies are present.

To obtain reliable data on early life history of *Corallium rubrum* and to develop a restoration technique avoiding manipulation, we set out a method suitable to foster red coral recruitment on artificial, carbonatic substrates according to a patented protocol (marble tiles, Fig. 3).

This protocol allowed red coral larvae settlement and growth. Marble was chosen because its chemical composition is similar to that of the biogenic substrate (coralligenous) on which red coral settles, which is composed mainly of calcareous algae and carbonate skeletons of invertebrates (Bramanti et al. 2003). White tiles, moreover, made for easy identification of red coral settlers and, being permanent, enabled us to follow the life history of both individual settlers and each cohort for an extended period of time. Tiles are photographically sampled for the period they remain submerged so that, when tiles are removed, all the settled colonies can be divided in different cohorts (one cohort for each year of submersion) basing on the identification provided by the photographic sampling. Diameter, height and number of polyps of each colony in each cohort are measured, and the growth rates determined. This procedure allows us to determine colony yearly growth rates (the ratio between the average size of the colonies in two successive cohorts) and the average annual growth rates permitting to group the population colonies into size/age classes.

In the framework of a 4 years study carried out in Calafuria (Italy), 54 marble tiles (100 cm^2 each) have been placed on the vault of crevices where adult colonies were present following the patented method. Tiles were put in place at the end of June, some weeks before red coral larval release, to allow a bioorganic film to cover their surfaces (Keough and Raimondi 1996) and photographically sampled monthly. This procedure provided us with a settlement and survival data series. Four settlement cycles and the subsequent survival of newly settled colonies were thus followed monthly for a 4-year period.

Overall, 388 *Corallium rubrum* larvae settled on the tiles. Density of settled colonies varied between 12.37 ± 6.1 and 2.75 ± 2.4 dm^2. Mortality affected 66.4% of the Year 1 cohort. The yearly survival of cohorts (the survival rate between two consecutive years) was similar throughout the different years 76.4 ± 7.1 (SD) %. The highest mortality affected all cohorts during their first year of life. Despite the mortality, after 4 years the tiles still harbored a persistent population

(19 ± 4.97 dm-2) with positive net-recruitment rates (recruitment-mortality, Fig. 3).

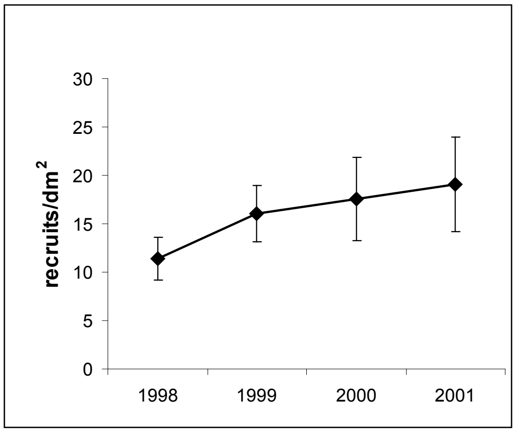

Fig. 3. Net recruitment rate (recruitment minus mortality). Error bars represent SD. Drawn from Bramanti et al. 2005.

Colonized tiles may easily be removed from the substrate and fixed again in new areas (by a central screw). This technique does not imply colony manipulation as colonies settled on tiles are not even touched. Re-colonization of red coral populations may be fostered by removing colonized tiles from a population in good conditions and re-fixing them in depleted areas.

Another source of mortality for red coral colonies is represented by the infection of boring sponges (Corriero et al. 1997) producing holes in the axial skeleton resulting in a reduction of economic value of the colonies and in a higher mortality rate of infected colonies. After the 4 years study, colonies settled on tiles were examined for the presence of boring sponges. Results showed that none of the colonies was affected while more than 50% of colonies of the same age in natural substrate resulted to be affected (Corriero et al. 1997). These findings suggest that marble tiles could be a useful tool both to conservation purposes, giving important demographic data on the first years of life of the colonies, and to restoration purposes of red coral shallow-water populations by means of a transplantation technique that does not imply colony manipulation.

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BIODIVERSITY AND ECOLOGY OF SPONGE BORING INTO PRECIOUS CORALS: A WORLDWIDE OVERVIEW

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Abstract

Boring sponges live inside calcareous substrata where they produce holes and galleries filled by sponge choanosome. A group of these species is associated to precious corals both in the Mediterranean and Pacific Ocean. The sponges produce a spongiosus pattern in the coral scleraxis resulting in a considerable decreasing in its economic value. *Stoeba, Holoxea, Alectona, Delectona, Thoosa, Spiroxya, Cliona, Dotona,* and *Aka* are the most involved genera. *Alectona* and *Spiroxya* (family Alectonidae), both with 6 species, are the most common, while *Cliona* (family Clionaidae), widely diffused also in other organic substrata such as coral reefs, is poorly represented. The total number of boring species recorded in the different species of precious coral is 27 with only two present both in the Mediterranean and Pacific Ocean. Alectonidae family (*Alectona, Dotona, Delectona,* and *Spiroxya*) accounts for 14 species, suggesting a strong affinity of this family for the compact calcitic scleraxis of the precious coral. In particular the genus *Spiroxya* has the strongest affinity for precious coral (with 6 species out of 9, recorded in coral colonies). This affinity is also indicated by the geographic distribution of this genus that has exactly the same Tethyan distribution as the genus *Corallium.*

The way of penetration of boring sponges into precious corals is not completely clarified but it is stated that sponges are not able to penetrate through the living coenosarc. Therefore the penetration of sponges in the coral scleraxis starts from the dead portions of the colonies or from the substratum. The petrographic structure of the substratum (calcareous vs. not calcareous) can therefore affect the sponge infection of the coral population and, on the base of substrate composition, the level of infestation of a bank can be predicted.

The sponge infestation may compromise the survivor-ship of smallest size classes. Although generally the boring activity decreases the steadiness of the colonies, it is difficult that large specimens are detached from the substrate. On the contrary, when sponges attack newly settled specimens (1 mm in diameter), the erosion is able to weak the base of the colonies. According to different kinds of substrata the sponge activity may therefore result in a high level of post-larval mortality.

Introduction

The species belonging to *Corallium* and *Paracorallium* (Octocorallia, Coralliidae) are known all over the world due to their heavy exploitation by the jewel industry. Considering the general slow growth rate of these taxa (Bramanti et al. 2005; Roark et al. 2006), there are several international projects devoted to their protection and management. The main areas where precious coral fishery is strongly active are the Mediterranean Sea for the red coral *Corallium rubrum* (Cicogna et al. 1999) and the Pacific Ocean for several other species (UICN 2007; Parrish and Baco 2007).

Precious coral colonies are characterized by a scleraxis composed of magnesiferous calcite organized in an extremely compact structure of acicular to lamellar calcite crystals that grow centripetally, forming fan-like structures (Cortesogno et al. 1999). Often the collected colonies cannot be carved owing to the presence of boring sponges, strongly decreasing the commercial value of the coral (Liverino 1984).

When occupied by boring sponges the scleraxis of the precious coral shows a series of chambers interconnected by channels giving rise to a spongiosus pattern in the carbonate. The knowledge of the involved sponge species, their relative destructive power, their distribution and their relationship with the affected coral colonies is important to help both coral industry and coral scientists to draw together adequate measures for management and exploitation of this resource.

Morphology of Perforation

Until now no comparative studies were conduced to detect differences in the morphology of the perforations produced by different taxonomic groups of boring sponges. The genus *Thoosa* produces in the coral scleraxis irregular, ovoid, and elongated chambers (2-5 mm in diameter) connected by canals (Azzini et al. 2007). A similar pattern is shown by *Holoxea excavans* but the chambers are smaller (1-2 mm) (Calcinai et al. 2008). The genus *Aka*, belonging to the family Phlaeodictyidae, produces in the coral scleraxis a completely different boring pattern composed by minute oval canals and galleries giving rise to a characteristic spongious aspect of the eroded substratum (Calcinai et al. 2003). A different pattern is shown by the species of *Alectona* and *Delectona* that grow continuously enlarging a single wide boring chamber (Bavestrello et al. 1996a, 1998).

More detailed morphological data on the erosion micro-patterns recognizable on the wall of boring chambers were obtained by SEM observations. The pitting pattern is the result of a two step – chemical and mechanical – activity of peculiar etching cells of boring sponges (Rützler and Rieger 1973). Previous studies (Calcinai et al. 2003, 2004a) have demonstrated that the recorded differences between different species are not related with substrate features. Among the species boring in precious coral the pitting patterns were clearly recognizable at least at generic level. Cliona produces smooth pits while those of *Spiroxya* and *Holoxea* are finger-print like. On the contrary, the scars produced by *Alectona* and *Delectona* create pits with deep concentric, irregular erosion lines. Particularly, *Alectona* shows a radial pattern that overlaps on the concentric bands, making the pits of this genus very distinctive. Finally, in the genus *Aka*, pits are generally regular, with the surface subject to deep grooves that extend to the pit center. There is often an outgrowth in the center of the pit. These data are interesting allowing the identification of borers also in dead or subfossil coral branches deprived of their living parasites.

Biodiversity and Biogeography

In the Mediterranean Sea, during a series of surveys conducted on different red coral populations 16 boring species were identified (Melone 1965; Barletta and Vighi 1968; Corriero et al. 1988; Calcinai et al. 2002; Calcinai et al. 2004a; Calcinai et al. 2007). 13 species were recorded during our studies (Bavestrello et al. 1995, 1996, 1998; Calcinai et al. 2001, 2002, 2004b) on the Pacific species of precious coral. The total number of species involved in the boring activity in the precious coral is 27 with only two species, *Dotona pulchella* and *Alectona verticillata,* being common to both geographic areas and the genus *Delectona* is recorded only in the Mediterranean coral (Table 1).

The genera more involved are 8: *Holoxea, Alectona, Delectona, Thoosa, Spiroxya, Cliona, Dotona, Aka* but sometimes *Jaspis* were also recorded. The most represented genera are *Alectona* and *Spiroxya* (family Alectonidae), both with 6 species, while *Cliona* (family Clionaidae), which is very common in calcareous, organic substrata such as coral reefs, is poorly represented. While *Alectona* has 2 species in the Mediterranean and 5 in the Pacific, *Spiroxya* has 3 species both in the Mediterranean and in the Pacific Ocean. The family Alectonidae (*Alectona, Dotona, Delectona* and *Spiroxya*) accounts for 14 species, suggesting strong affinity for the compact calcite of the precious coral scleraxis. The affinity of the species of this family for precious coral could be related to their typical bathophily.

Nevertheless, while *Spiroxya* is a genus with a strong affinity for precious coral (with 6 species out of 9, recorded in coral colonies), *Alectona* is common in other organic carbonates. This is also indicated by the geographic distribution of these genera: while *Alectona* has circumtropical distribution, the genus *Spiroxya* has exactly the same Tethyan relict distribution as the genus *Corallium* (Calcinai et al. 2004b).

Way of Penetration

The way of penetration of boring sponges into the precious coral is not completely clarified but it is generally accepted that sponges are not able to penetrate through the living coenosarc. Following this idea it is possible to hypothesize three different ways of penetration: (i) the substratum, (ii) dead portions of the colonies, (iii) the borderline of the base where, probably, the coenenchime is thinner.

In all the examined specimens affected by the sponge erosion the boring chambers are more abundant in the base while they strongly reduce and quickly stop in the distal portion of the colony. If the colonies show some dead apical branches, they are never affected by the erosion.

If the penetration arises from the substratum its petrographic structure is able to affect the sponge infection. Coral banks living on calcareous substrata, where sponges are able to penetrate would be more prone to boring activity. On the contrary, corals living on granitic substrates, which cannot be bioeroded, would be free from erosion. Unfortunately, we have not a screening of the percent of affected coral colonies in banks settled on different petrographic substrata but, for example, unpublished data obtained from a Japanese population of *Paracorallium japonicum* settled on basaltic rocks indicate a very scarce incidence of boring.

On the other hand, studies conduced on the carbonatic substrata of the Portofino Promontory have clearly shown that different species of boring sponges have a different level of selectivity toward the coralligenous conglomerate substrate or towards the colonies or *C. rubrum*. For example, *Jaspis jonstoni* and *Spiroxya heteroclita* were recorded commonly in the conglomerate and, sometimes, in the coral colonies. Other species, like *Aka insidiosa* and *Cliona janitrix*, were mainly observed in coral colonies but are rarely able to extend in the surrounding substratum. *Spiroxya corallophila* and *Stoeba* sp. were only recorded in the corals, while *Stoeba plicatus* was only present in the conglomerate. These data suggest that probably the way of penetration of boring sponges in the coral skeleton is different in different species. In more generalistic species, the penetration arises from the substratum, while in species specialized in the coral erosion, the penetration probably start from the borderline of the coral base.

Effect on the Demography of Coral Populations

It is evident that the activity of boring sponges in the coral scleraxis decreases its stiffness enhancing the possibility of break and detach of the colonies from the substratum. Nevertheless, the influence of boring sponges is variable according to the size of the affected colonies. While adult colonies cannot become unstable by erosion, the sponge infestation may compromise the stability of smallest size classes. In fact, when sponges attack newly settled specimens (1 mm in diameter), the erosion is able to weak adhesion of the base of the colonies. According to different kinds of substrata the sponge activity may therefore result in a high level of post-larval mortality. Detailed studies conduced on the rocky cliff of the Portofino promontory clearly indicate that in September, immediately after the summer reproduction of red coral, on the substratum are present thousands of just settled juvenile colonies composed by few polyps and with a basal diameter of about 1 mm. On the contrary, six month later a large majority of these small sponges are not more present on the substratum. A survey conduced on these juveniles specimens indicate that they are affected by sponge erosion, probably arising from the substratum. This fact is strongly supported by the evidence that small colonies, settled on artificial plastic panels, are not affected by the erosion. It is probable that the activity of boring sponges represents the main constrain, at least on carbonatic substrata, in the regulation of the population of red coral (Cerrano et al. 2001).

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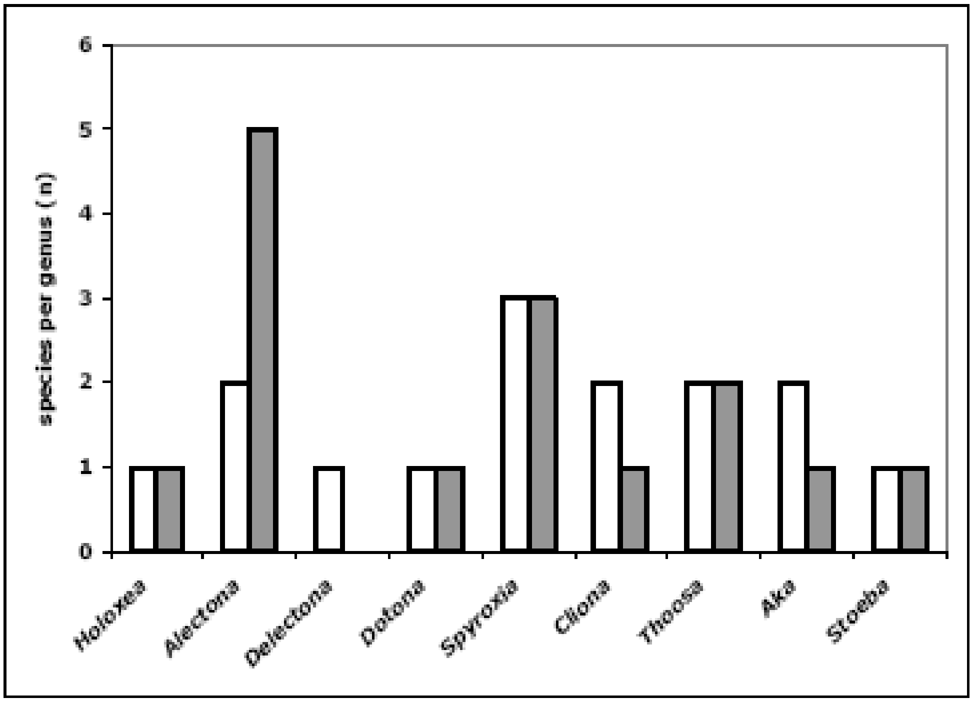

Table 1. Sponge species boring precious corals (*Corallium* and *Paracorallium*) in Mediterranean Sea and Pacific Ocean.

Species		**Locality**	
		Mediterranean	Pacific
Holoxea furtive	Topsent, 1892	X	
H. excavans	Calcinai et al., 2001	X	
Alectona millari	Carter, 1879	X	
A. wallichi	Carter, 1874		X
A. triradiata	Levi & Levi, 1983		X
A. verticillata	(Johnson, 1899)	X	X
A. sorrentini	Bavestrello et al., 1998		X
A. sarai	Calcinai et al., 2008		X
Delectona ciconiae	Bavestrello et al., 1996	X	
Cliona janitrix	Topsent, 1932	X	
C. lobata	Hancock, 1849	X	
C. desimoni	Bavestrello et al., 2005		X
Spiroxya acus	(Bavestrello et al., 1995)		X
S. corallophila	(Calcinai et al., 2002)	X	
S. heteroclita	(Topsent, 1988)	X	
S. levispira	(Topsent, 1898)		X
S. macroxeata	(Calcinai et al., 2001)		
S. sarai	(Melone, 1965)	X	
Thoosa armata	Topsent, 1888	X	
T. bulbosa	Hancock, 1849		X
T. midway	Azzini et al., 2007		X
T. mollis	Volz, 1939	X	
Dotona pulchella	Carter, 1880	X	X
Aka labyrinthica	(Hancock, 1849)		X
A. corallirubri	Calcinai et al., 2007	X	
A. insidiosa	(Johnson, 1899)	X	
Stoeba spp.		X	X

BIOMETRICAL ANALYSIS AND OBSERVATIONS ON DEEP RED CORAL *CORALLIUM RUBRUM* (L.) IN N.W. SARDINIA SHOALS (ITALY)

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Monitoring deep red coral shoals and studying size structure of this species are both very important tasks in areas of intense harvesting. Since fishing dramatically affects the size of the largest colonies, the colony size is a good indicator of harvesting impact. A study was performed on coralligen shoals, emerging from a bioclastic sandy bottom, 7 nm SW of Alghero (Sardinia, Italy). Registered divers practice coral fishing in this area, although only threatening the largest colonies.

The study analyzed some morphometrical parameters of nearly 200 colonies, which were collected at 130 m depth. A linear model to estimate wet weight from the number of apices in the colonies was defined, while observations on deep coral settlement and on the state of the ramifications were also performed. We concluded that the red coral of these fishing grounds seem not to be overexploited and that most colonies are in good health. It seems quite clear that the overall weight of a colony can be effectively inferred on the basis of the number of apices.

EFFECTIVE LARVAL DISPERSAL AND SCALES OF CONNECTIVITY IN *CORALLIUM RUBRUM*

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Dispersal patterns play a fundamental role in determining the dynamics of marine populations defining the extent of breeding units as well as the level of connectivity among them. Persistence, resilience, and recovery of marine populations affected by anthropogenic and natural threats depend on the supply and survival of recruits. Understanding spatial scales of genetic structuring provides indirect estimates of species dispersal ability. Limited dispersal reduces chances for re-colonization and could promote genetic drift, reduction of the evolutionary potential of the species, and increase risk of population extinction. *Corallium rubrum* is a long-lived, slow-growing gorgonian. Red coral is one of the most exploited subtidal sessile invertebrates in the Mediterranean Sea, mostly owing to human harvesting. The main goal of this study is to assess the level of connectivity and effective larval dispersal capability of the species using microsatellites. Scales of genetic structuring were analyzed in *C. rubrum* samples collected in the Ligurian Sea in a range from meters to 100s of meters. At spatial scales of 10s of meters, a surprisingly strong pattern of genetic structuring has been found, supporting the hypothesis of limited dispersal ability of the planulae and suggesting a high inbreeding rate. Significant heterozygote deficiencies and chaotic genetic structuring at spatial scales of 1 meter have been also detected. These findings suggest that biological processes (e.g. pre- and post-settlement mortality and stochasticity of reproductive success) may favor the occurrence of genetically distinct pools of recruits at meter distances. The outcomes of these studies are of great importance to infer about red coral populations resilience and to identify the appropriate scales for the conservation of this species.

DEEP-WATER *CORALLIUM RUBRUM* (L. 1758) FROM THE MEDITERRANEAN SEA: PRELIMINARY GENETIC CHARACTERISATION

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The precious red coral *Corallium rubrum* lives in the Mediterranean Sea and adjacent eastern Atlantic Ocean on subtidal hard substrates. *Corallium rubrum* is a long-lived gorgonian coral that has been commercially harvested since ancient times for its red axial calcitic skeleton and which, at present, is thought to be in decline because of overexploitation. The depth distribution of *C. rubrum* is known to range from ca. 15 – 300 m. Recently, live red coral colonies have been observed in the Strait of Sicily at depths of ca. 600 – 800 m. This record sheds new light on the ecology, biology, biogeography, and dispersal mechanism of this species and calls for an evaluation of the genetic divergence occurring among highly fragmented populations. A genetic characterization of the deep sea red coral colonies has been done to investigate biological processes affecting dispersal and population resilience, as well as to define the level of isolation ⁄ differentiation between shallow and deep-water populations of the Mediterranean Sea. Deep-water *C. rubrum* colonies were collected at two sites (south of Malta and off Linosa Island) during the cruise MARCOS of the R⁄V Urania. Collected colonies were genotyped using a set of molecular markers differing in their level of polymorphism. Microsatellites have been confirmed to be useful markers for individual genotyping of *C. rubrum* colonies. ITS-1 and mtMSH sequences of deep-water red coral colonies were found to be different from those found in shallow water, suggesting the possible occurrence of genetic isolation among shallow- and deep-water populations. These findings suggest that genetic diversity of red coral over its actual range of depth distribution is shaped by complex interactions among geological, historical, biological, and ecological processes.

FEEDING CHARACTERISTICS OF THE RED CORAL *CORALLIUM RUBRUM*

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Corallium rubrum is a characteristic gorgonian of the Mediterranean Sea. Quantitative data on prey ingestion and selection by this species are important issues for defining its ecological role, and also explaining its distribution and abundance. Whereas several studies have examined feeding habits of gorgonians in general, only two have been performed on *C. rubrum* specifically (Tsounis et al. 2006; Picciano and Ferrier-Pagès 2007). Tsounis et al. (2006) found high feeding rates of *C. rubrum* on detrital particulate organic matter and copepods, which each represented from 15 to 50% of the diet of the red coral. In terms of carbon, this food can bring up to 3192 ng C polyp-1 d-1 to *C. rubrum.* There was, however, a high annual variability in the rates of prey capture, compared to other gorgonians. Picciano et al. (2007) investigated the feeding rates on smaller prey, in the pico-nanoplankton size. The effects of flow, prey concentration and seawater temperature were tested. It was shown that *C. rubrum* was able to prey on both pico- and nanoplankton cells, with a preference for flagellates, which represented from 43 to 70% of the C and N ingested from small prey. Flow speed (2, 6, and 11 cm s-1) had no effect on grazing rates. Conversely, these rates increased with the increase in pico-and nanoplankton concentration and with temperature. In the range of concentrations typically found in the Ligurian Sea, the ingestion of pico- and nanoplankton can bring 148 ng C (polyp)-1 d-1 and 28 ng N (polyp)-1 d-1 to the red coral. This type of food represents only ca. 4.5% of the total carbon gained by *C. rubrum* from the different sources, but might be important in terms of nitrogen, phosphorus, and other essential elements.

SMALL-SCALE DISTRIBUTION OF JAPANESE RED CORAL OFF AMAMI ISLAND, SOUTHERN JAPAN

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Using a ROV, small-scale distribution patterns of Japanese red coral (*Paracorallium japonicum*) populations were investigated at the depths of 196 – 211 m off Amami Island, southern Japan in March 2009. The ROV navigated 1158 and 1475 m covering the areas of 23,160 and 29,490 m^2 at each site. The average density was 0.47 colonies/100 m^2. Variance/average ratio and Morisita's Iδ indicated that the distribution pattern of Japanese red corals was aggregated.

An additional remark on economic aspects of Japanese precious corals will be reported.

RADIOCARBON-BASED AGES AND GROWTH RATES OF HAWAIIAN *CORALLIUM* SP.

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The radial growth rates and ages of the Hawaiian deep-sea coral *Corallium* sp. were determined using radiocarbon measurements. Specimens of *Corallium secundum* were collected from 450 ± 40 m depth at the Makapuu deep-sea coral bed off the southeast coast of Oahu, Hawaii, USA, using a submersible (PISCES V) from the Hawaii Undersea Research Laboratory. The primary source of carbon to the calcitic *C. secundum* was determined to be in situ dissolved inorganic carbon (DIC). Using 'bomb 14C' time markers we calculated radial growth rates of 170 μm yr^{-1} and ages of 67 ± 9 to 71 ± 9 years for two specimens up to 28 cm tall. These radial growth rates are similar to the radial growth rates (110 ± 20 μm yr^{-1}) of an Atlantic specimen determined by excess lead-210 (Pbex) dating (Druffel et al. 1990). The calculated age (71 ± 9 years) for the one specimen collected intact with a height of 28 cm is two times larger than the age calculated (29 years) based on equations correlating colony height (length) and age based on growth ring counts (Grigg 1976, 2002). Examination of thin cross sections (petrographic method) in these specimens yielded a maximum of 7 density growth rings. These results suggest that further research is required to refine the radiocarbon results and validate periodicity of any growth rings. Finally, we will present some preliminary results that Sr/Ca measurements in *C. secundum* specimens may be a viable proxy of sub-surface temperature variability.

BIOMINERALIZATION IN *CORALLIUM RUBRUM*: ORGANIC MATRIX COMPARATIVE STUDY OF SCLERITES AND SKELETON

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Biomineralization is the dynamical and physiological process by which organisms transform ions in solution into a solid structure: the biomineral. Biominerals are composed of two fractions: a mineral fraction and an organic fraction named the organic matrix (OM). This organic matrix is mainly composed of proteins, lipids, and sugars. It is responsible for the nucleation, growth, orientation of the crystals, as well as the micro- and macro-architecture of the final skeletal product. The comparative study of various animal models is necessary for a better understanding of biomineralization. The genus *Corallium*, including the red coral *Corallium rubrum,* is a very interesting model to study biomineralization since it possesses two different skeletal structures with very different shapes: an axial skeleton and sclerites. The comparative study of proteins present in the OM of axial skeleton and sclerites has allowed us to treat a mechanistic aspect of biomineralization within a same species. Moreover we have determined that part of the color of the skeleton and sclerites are due to pigments present in the OM.

DETERMINATION OF *CORALLIUM RUBRUM* POPULATION AGE STRUCTURE

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Introduction

Management approaches based on a detailed knowledge of specific population demographic features are fundamental to ensure long-term exploitation sustainability (Knittweis et al. 2009). Demography focuses on the specific dynamics of each population, allowing to project population structure over time. This approach allows setting out local conservation strategies for wildlife and for exploited species structured into discrete local populations, such as the Mediterranean red coral (Abbiati et al. 1993). Regarding corals, long-term studies are scarce due to their slow growth and longevity (Connell 1997; Garrabou and Harmelin 2002).

Because of its high economic value, the precious Mediterranean red coral *Corallium rubrum* (Cnidaria, Octocorallia, Gorgonacea) has been harvested for more than 2000 years and its shallow-water populations (living between 20 and 70 m depth), indicate a regression and even a partial economic extinction (Tsounis et al. 2007). Demographic studies based on sound age structure and growth rate assessment in different populations are nevertheless scarce (Santangelo et al. 2009). In this study we compared the age structure and the basal growth rate of two shallow *Corallium rubrum* populations dwelling in two marine protected areas.

Colony and Population Age Assessment

In this study, a sclerochronological approach has been applied to supply basic knowledge on colony growth rate and population age structure of two shallow *Corallium rubrum* populations.

These dwell within two distinct Marine Protected Areas in Spain and Italy: Cap de Creus (Costa Brava, North-Western Mediterranean; 42°29',21 N; 3°30',18 E, Spain) and Portofino (Eastern Ligurian Sea 44°18',18 N 09°12',83 E, Italy). These populations are differently managed: in Cap de Creus, *C. rubrum* professional harvesting is regulated, while in Portofino harvesting is banned since 1999. Despite this, illegal harvesting by poacher occurs in the Spanish area, seriously affecting the local Mediterranean red coral population.

The age of the *Corallium rubrum* colonies has been determined according to an indirect method by counting growth rings in thin sections (50 µm thick) of the colony axial skeleton (Marschal et al. 2004). This sclerochronological technique labels the circular layer of the organic matrix deposed each year (Fig. 1).

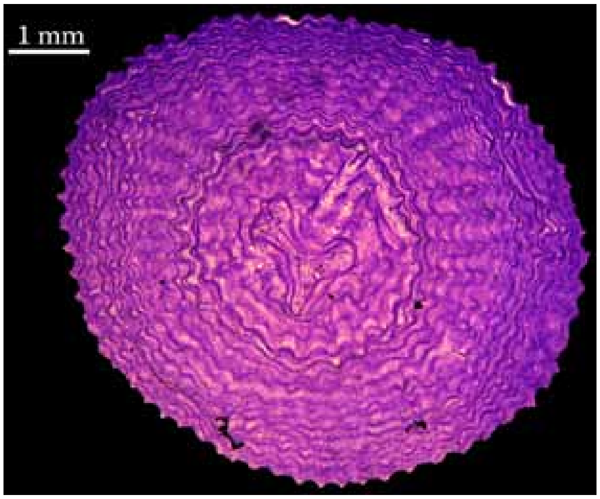

Fig. 1. Thin section (50 µm thick) of the axial skeleton of a colony of *Corallium rubrum.*

According to Marschal et al. (2004), each growth ring corresponds to a year of colony life except for the first 3 or 4 years when the calcium carbonate deposition of the core of the colony is still in progress, resulting as an irregular shape in the centre of the thin section.

Colony age corresponds to the number of rings counted in the axial skeleton to which 4 further years have be added, i.e. the first years of colony life. The annual diameter growth rate is the quotient of the colony basal diameter and the estimated age.

Populations Age Structure

The average population age is 25.3 ± 6.5 SD year and 18.7 ± 3.2 SD year, respectively, at Portofino and Cap de Creus. The oldest colony detected in Portofino is aged 39, while the oldest one in Cap de Creus is of age 27.

The estimated annual diameter growth rate (average basal diameter/colony age) is 0.22 ± 0.04 SD mm/yr for the population of Portofino and 0.24 ± 0.06 SD mm/yr for that of Cap de Creus.

Our results indicate, for both populations, a significant negative linear correlation between the annual diameter growth rate and colony age (Pearson's correlation coefficient: $P = 0.001$). For both populations, the relationship between colony age and colony basal diameter is well fitted by a power curve (AIC test; Fig. 2). Such findings highlight a decrease of the diameter growth rate during the life-span of the colony.

Implications of this Analysis

The difference between the two age structures indicates that the population of Portofino is recovering from previous exploitation occurred until the 1970s (Bavestrello et al. 2009). The population of Cap de Creus, still object of both legal and illegal harvesting (Tsounis et al. 2007), shows a shorter life span by about 25%, and a population structure dominated by young colonies as confirmed by recent data (Tsounis et al. 2006; Vielmini et al., in preparation).

The colony growth rates found are similar to those measured in other populations (Garrabou and Harmelin 2002; Torrents 2007), suggesting a stable growth pattern within and between the investigated areas. It is worth noting that colony diameter growth could be strongly affected by habitat features (Torrents 2007).

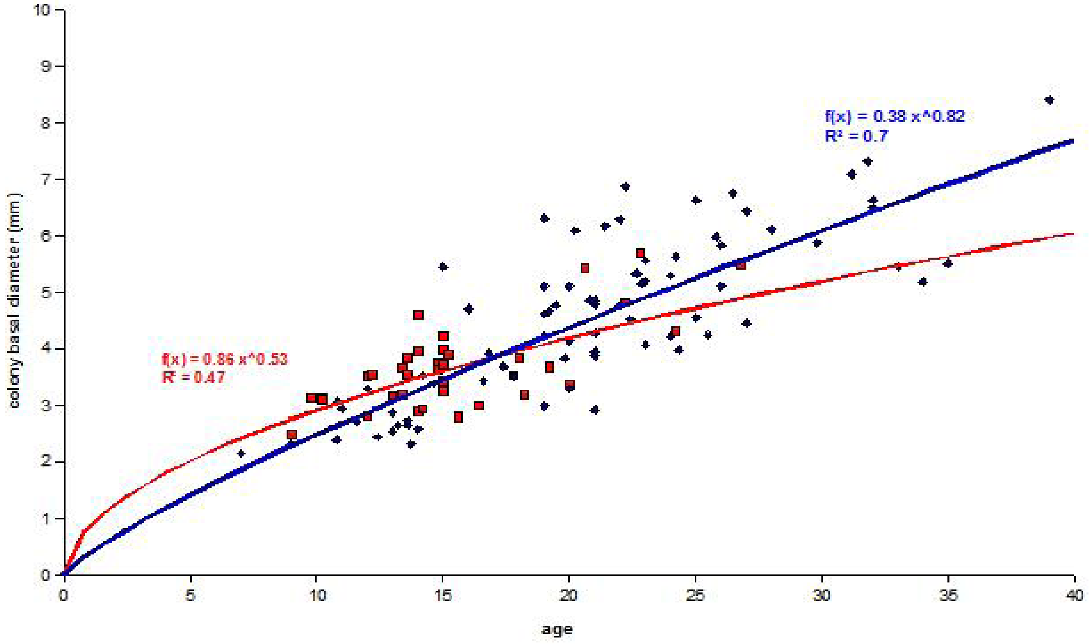

Fig. 2. Relationship between colony basal diameter (mm) and age in the two Mediterranean red coral populations (Portofino: blue spots, N = 75; Cap de Creus: red spot N = 36).

The decrease in diameter growth rate with age suggests that diameter may not be the most reliable descriptor of colony growth. Other descriptors, such as weight or branching pattern, should be taken into account to assess Mediterranean red coral.

Nowadays, the colony minimum size limit for commercial harvest of *C. rubrum* in Cap de Creus is fixed above 7 mm; in the light of our findings, such limit could represent a conservative measure to allow adult colonies to reproduce about 25 times during their life-span. Despite this, it is worth to note that colonies bigger than 7 mm in diameter are very scarce in Cap the Creus (only 4 on 163 colonies collected on whole, and not considered in population age determination because of morphological limitation).

Further, a sustainable fishery management plan should maximize the yield by harvesting colonies at their most productive age (Grigg 1976). Management should ensure an adequate number of sexually mature individuals (Grigg 1976): While 7 mm base diameter is above the age of sexual maturity, it does not allow for an efficient fishery with maximum sustainable yield, and according to recent studies it may not be adequate to ensure the survival of the populations (Santangelo et al. 2007; Tsounis et al. 2010).

Data on age structure, merged in static life-history tables, will be the base to set out demographic models that will allow to project population trends over time. This approach, applied to populations with different life-histories, will allow to compare their demographic structures and trends and to set out conservation and management strategies suitable for specific local populations.

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Section IV

Management

POPULATION DYNAMICS AND LIFE HISTORY TRAITS OF *CORALLIUM RUBRUM* POPULATIONS: IMPLICATIONS FOR SUSTAINABLE MANAGEMENT AND TRADE

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Abstract

Population demographics, especially density, abundance, size structure, and morphology (branching pattern), as well as certain life history traits (e.g. growth rates, reproductive strategy, and longevity), must be considered when developing fisheries management strategies for precious corals in the family Coralliidae, as these provide indicators of the status of these species and their vulnerability to harvest. All species of Coralliidae are sessile, modular (colonial) gorgonians characterized by slow-growth, low rates of natural mortality, and a long lifespan. They typically occur at low densities, but are capable of forming large, highly branched, tree-like structures in absence of disturbance. Most representatives in this family broadcast gametes into the water column on an annual cycle, relying on external fertilization and an extended planktonic development phase, while the endemic Mediterranean species, *C. rubrum*, is a brooder that releases well-developed, competent planula. This trait has allowed *C. rubum* to form dense assemblages in shallow water, where populations are dominated by small (< 5 cm tall), unbranched colonies. These populations exhibit high rates of early mortality, especially in environments frequently disturbed by natural stressors (e.g. temperature anomalies, bioerosion) and heavy collection pressure. However, this is not the normal situation: *C. rubrum* colonies are capable of achieving a much larger size (30-50 cm height) and more extensive ramifications, as reported historically, in deep water populations, and in shallow water when protected from fishing. The brooding life history strategy may have allowed the persistence of *C. rubrum* in marginal environments and when subjected to heavy fishing pressure, because planula display lower rates of mortality and higher settlement success than related broadcast spawning species. Nevertheless, these populations are highly susceptible to extirpation due to the selective removal of the largest colonies by SCUBA divers, followed by collection of progressively smaller colonies; these smaller colonies produce exponentially fewer larvae per reproductive event than large colonies and they reproduce only a limited number of times before being removed from the population. Furthermore, *C. rubrum* exhibits a single annual discrete reproductive event unlike other corals that are brooders, and local sources of planula are needed to maintain populations due to limited potential for long-distance dispersal. Deep populations may be even more vulnerable to extirpation, since they occur at much lower densities; they may experience allee effect (depensation) if harvest further reduces colony density below levels needed for successful fertilization. An increase in the minimum size of legal harvest (to at least 10 mm diameter and 10 cm height) is needed to rebuild overexploited stocks of *C. rubrum* and provide insurance against catastrophic disturbances. This measure would maximize reproductive output by increasing colony size, allowing colonies to develop third order branching patterns, and increasing the number of times a colony reproduces before removal by collectors. Harvest should be limited in deeper areas (> 50 m) where densities are lower until population dynamics and life history traits from the deep populations are better understood. Other management approaches, such as an increase in the number and size of no-take marine protected areas, are needed to maintain

high reproductive output and compensate for losses due to fishing pressure and other stressors outside of protected areas.

Introduction

Habitat forming corals are modular organisms made up of multiple, identical interconnected units (polyps) that form massive, plating, encrusting, and branching colonies. These corals are permanently attached to the bottom with exception of a short dispersal period during their larval phase. Like unitary animals, corals can be classified as r- or k-selected depending on their life history strategy, although some species exhibit a continuum across these traits. Most k-selected corals form large, long-lived colonies that expend considerable energy in growth and maintenance, and less in reproduction. These include some of the dominant framework corals found on shallow reefs (e.g. *Montastraea annularis*), many of which are hermaphroditic (Szmant 1991). K-selected corals broadcast millions of gametes into the water column during a single discrete event, once per year, which are fertilized externally. These larvae spend an extended period in the water column during their development phase, and have a high potential for long-distance dispersal, but they tend to exhibit very high rates of larval mortality and low settlement success. K-selected corals tend to live for decades to centuries, often sustaining partial mortality that increases over time, but colonies continue to grow indefinitely, and the likelihood of total colony mortality declines with size (and age) (Bak and Engel 1979; Bak and Meesters 1998). These corals must also achieve a certain minimum size before first reproduction, but individual colonies can reproduce indefinitely, as long as they remain above that minimum size.

In contrast, r-selected species are often considered “weedy species” that begin reproducing at a smaller size. These corals invest more energy in reproduction and less in growth, but they tend to have relatively short life spans. They are often the first species to colonize an area after a disturbance because they have naturally high production rates and great inter-annual variation in recruitment driven by stochastic environmental factors (Musik 1999). R-selected species include most brooders; these species have separate male and female colonies, where fertilization is internal, and females release well-developed planula. They produce fewer gametes per reproductive event as compared to broadcast spawners, but larvae have higher rates of survival and colonies often reproduce monthly on a lunar cycle to overcome shortfalls in larval release. Larvae are competent shortly after release and settle within close proximity to the parent, which may also enhance their success by colonizing habitats where their parents were most successful.

Modular Organisms

In addition to selected advantages associated with the different modes of reproduction, there are numerous advantages to a modular life history, such as the ability to survive with partial mortality. However, these organisms require very specific conditions for successful settlement (e.g hard substrate, low rates of sedimentation and algal biomass, and a narrow temperature range); once they settle and begin growing, they are generally unable to relocate if the conditions become unfavorable. They do exhibit the potential to adapt to their environment through various mechanisms such as modifications in growth form. For instance, some species of corals that contain zooxanthellae (symbiotic algae) form hemispherical colonies in shallow water, becoming more plate-like in deeper environments to maximize their surface area for optimal light capture. Branching corals may form short, thickened, robust branches in shallow areas with high wave exposure and longer, slender branches in calm protected environments. Branching species also often dominate large areas and individual colonies attain large dimensions (Gilmore and Hall 1976). Large sizes increases resistance to all but the most devastating physical disturbances and implies greater longevity, while small size implies either a cessation in growth, slow growth, or high colony mortality (Szmant 1986).

Modular organisms also exhibit highly complex growth patterns that can mask the age–size relationships that are characteristic of unitary organisms such as fishes (Hughes and Jackson 1980; Hughes 1984, 1990; Hughes and Tanner 2000). For instance, predation, disease, and other chronic disturbances that cause partial mortality can result in colonies of an identical age with dramatically different sizes or branching patterns. The combination of such variability in partial mortality and annual variation in recruitment makes it unlikely that a coral population ever achieves a stable age distribution, unless they are driven to an altered population structure dominated by small individuals that never reach their full potential for growth such as that observed in certain shallow *C. rubrum* populations (e.g. Calafuria, Italy; Santangelo et al. 2004). Because they are permanently attached to the substrate, they are also more susceptible to total colony mortality associated with human activities, such as collection, than motile fisheries species.

Reproduction and Recruitment

While short-term population dynamics of large, massive, or fast-growing branching species is influenced mostly by rates of recruitment, their ability to colonize new areas or areas that were catastrophically disturbed, and their ability to persist depends on the degree of success of reproduction (Szmant 1986). Reproductive strategies vary across genera and families of corals, with some species reproducing sexually through brooding and others via broadcast spawning, and some also capable of asexual propagation through fragmentation, polyp bailout, and other mechanisms. A coral's reproductive strategy is not necessarily correlated with polyp size or morphology, but reproductive differences may imply important differences in evolutionary selective pressures (Szmant 1986).

The family Coralliidae is one example of gonochoric corals that have a well defined seasonal pattern of sexual reproduction, which occurs only once per year (Santangelo et al. 2003; Torrents et al. 2005; Tsounis 2005; Tsounis et al. 2006b). Within the family, most species are thought to be broadcast spawners, while *C. rubrum* is the only representative known to be a brooder (Grigg 1993). This unique trait has major implications for the survival of *C. rubrum* when exposed to catastrophic acute disturbances (e.g. unusual temperature anomalies) and pressure associated with harvesting. First, the planula released by *C. rubrum* have a much shorter pelagic stage, which allows them to bypass high rates of mortality associated with planktonic development. They also exhibit higher recruitment rates, at least in shallow water, because they tend to settle in locations where their parents were successful. Nevertheless, there are also several factors that limit reproductive output in *C. rubrum*. Most corals that brood larvae are smaller than broadcast spawners; they reproduce on a lunar cycle, with many reproductive cycles per year, to compensate for the lower larval production per gametogenic cycle as compared to broadcast spawners that release millions of gametes (von Moorsel 1983; Szmant 1986; Richmond and Hunter 1990). *C. rubrum* only reproduces once per year, which results in much lower annual levels of larval production. Populations of brooders also tend to have shorter dispersal phases, which results in a high degree of genetic separation on a short spatial scale, and the maintenance and survival of these populations requires local sources of healthy reproductive populations to replace colonies that die or are collected.

Brooders are also more sensitive to changes in density, because the chance for successful fertilization is much lower. Colonies that are broadcast spawners synchronously release a large a pool of gametes that have a high likelihood of direct contact and fertilization and an obligatory development period before they become competent to settle (Willis 1990). *C. rubrum* is more similar to a pine tree that releases pollen. The pollen is ready immediately and becomes less viable with time. It requires a chance encounter with a female colony for successful fertilization, which will occur only if colonies are located within close proximity or water currents are suitable to transport sperm to female colonies. The magnitude of the dispersal for a brooder like *C. rubrum*, in terms of number of larvae dispersing and distance travelled, is much less than larvae of broadcast spawning corals (Willis 1990)

Size-dependent Reproduction

One of the most critical biological aspects for a sessile (attached) organisms that form complex, branching colonies and have long life-spans is colony size, as 1) reproductive output continues to increase with size and age; 2) growth to a larger size conveys a greater resistance to disturbance; and 3) it implies longevity. This is partially due to the modular nature of *C. rubrum*, where each polyp is interconnected with other polyps by a series of canals that are responsible for the translocation of water and nutrients, allowing all polyps to function together as a single, larger unit. These colonies must reach a certain size before they become sexually mature, but once that size is achieved they can reproduce indefinitely. In branching gorgonians, reproductive output increases exponentially with size and the largest colonies in the population are thought to produce 90% or more of the offspring (Babcock 1991; Coma and Gili 1995; Beiring and Lasker 2000; Santangelo et al. 2003; Torrents et al. 2005; Bruckner 2009).

Although *C. rubrum* is a brooder, it exhibits many traits in deep water that are similar to other gorgonians that are broadcast spawners (including other species of *Corallium*), presumably because fishing pressure and large scale environmental disturbances are less common which allows these corals to achieve much larger sizes. Most species in the family Coralliidae are in the low-productivity range as colonies are relatively slow-growing and long-lived, with population turnover estimated to occur once every 15-25 years (Grigg 1976) or longer, based on more recent estimates of age (Marschal et al. 2004). Brooding and early reproduction may be an adaptation that allows the coral to occupy marginal habitats in shallow water, because the colonies can never achieve a large size before dying (Santangelo 2003), which results in a much more rapid population turnover. These populations usually display high rates of recruitment (0-32 recruits/m^2 per yr from 1995 to 1999 in Spain (Linares et al. 2000), and 0-12.5 recruits/m^2 per yr from 1979 to 2000 in France (Garrabou et al. 2001)), although recruitment occurs in pulses with no successful settlement in some years, up to 95% of the larvae die before settling (Tsounis 2005), and 66-70% of the new recruits die over the first four years of life (Bramanti et al. 2005). Small colonies that dominate shallow areas of the Mediterranean today are also more vulnerable to total colony mortality, and their contribution to future generations is much less than larger colonies because they contain substantially fewer reproductive modules (polyps).

Significant differences in the size of *Corallium rubrum* colonies have been reported between locations and depths, and most areas affected by coral fishing and recreational diving have shown a general trend of declining size structure over the last four decades. For instance, colonies collected in the 1950s and 1960s were frequently up to 50 cm height and 2 cm diameter. A 1962 collection off Costa Brava, Spain consisted of colonies with basal diameter of 10-45 mm (mean = 16 mm) and height of 10-50 cm (mean = 11.5 cm) with the largest corals estimated at 50-80 years in age (Garrabou and Harmelin 2002). Colonies sampled off Costa Brava were still substantially larger in 1986 than that observed today with 85% of the colonies having a basal diameter > 5 mm (García-Rodríguez and Massò 1986). Shallow populations from Costa Brava (10-25 m depth) are now skewed towards small corals (mean height = 3.1 cm, max = 20 cm; mean diameter = 4-5 mm), most of which are young (< 8 years old) and only 35% have basal diameters > 5 mm. Colony height increases with depth to 4 cm height at 25-50 m and 6 cm at 50-90 m; the largest colonies (13-16 cm height) are found in non-harvested areas below 50 m depth (Rossi et al. 2008). Colonies in an adjacent protected area (Medas Island, Spain) closed to fishing for 15 years were 20-50% larger (mean = 4 cm height, max = 20 cm) than colonies at similar depths in fished areas off Costa Brava. Populations examined in 1998 in fished areas off France (Riou archipelago) were larger (mean height = 6 cm; range = 4-13 cm) than that reported for Spain (although small colonies were not examined in this study), but these colonies were still only about half the size of a similar habitat in France protected from fishing since 1983 (mean = 11.8 cm, range = 8-17 cm).

Differences in total reproductive output are directly related to colony size structure and the degree of branching. *Corallium rubrum* are gonochoric brooders that were reported to first produce gonads at 2-10 years age (minimum 2-3 cm height, 1.8-3.6 mm diameter), with colonies achieving 100% fertility at 4-6 cm height. The total number of polyps increased exponentially with colony size from about 25-90 polyps in a small (2-3 cm height) single branched colony to over 4000 in a 12 cm tall colony with over 35 branches, and 15,000 for colonies 30 cm in height. Even in the Ligurian Sea, where colonies never exceed 10 cm in height and most had few branches, the number of planula increased 7 fold from the smallest reproductively mature colonies (1.4-2.3 mm diameter, 24 planula) to the largest (> 4.6 mm diameter, 158 planula) (Santangelo et al. 1993). While small colonies may be the most important component in terms of reproductive contribution in some shallow populations today (Santangelo et al. 2007), this is only because the small colonies are numerically dominant, versus very few larger colonies. Nevertheless, when compared to their potential to achieve larger sizes the contribution of these small colonies to future generations would be much less if a population exhibits a more normal size frequency that is not skewed towards juvenile colonies. They are also less likely to sustain the synergistic impacts of fishing, natural stressors and climate change, and degraded areas have a delayed potential for recovery due to limited potential for long distance dispersal.

Relationships between Size and Density

Abundance and biomass are usually important factors in assessing population status and trends of fishery species. However, for sessile colonial species, size and relationships with density are more important measures, as size is a major determinant of first reproduction, reproductive output, and colony survival, and density is related to the likelihood of fertilization. In the case of *C. rubrum*, smaller colonies tend to occur in large aggregates because they settle relatively close to their parent; these smaller-sized colonies lack a branching morphology and exhibit higher rates of natural mortality. As they increase in size, they require more space, but survival also increases with size. If they are able to reach a large size, populations will ultimately become less dense, with a lower overall abundance throughout a bed, but populations will potentially have a higher number of polyps overall. For instance, a single large colony 300-500 mm in height can contain more polyps (up to 10,000 or more) than 100 or more small colonies that are 30-50 mm height (approx. 100 polyps), like those found today in the Mediterranean. The increase in polyps is partially related to size (larger colonies have more polyps overall), but large colonies lack polyps at the basal portions and polyps may be more dense but smaller at the branch tips. Most importantly, polyp number also increases in proportion to the degree of branching, which is much more extensive in large colonies. For these reasons, size/age structures give a better indication of population decline, as the fishery is size-selective (largest colonies are removed first) and a decline in the number of large colonies may result in an increase in small colonies as more space becomes available to support settlement of larvae.

Data on the population structure are also more useful in identifying a changing proportion of mature/immature colonies, which is more functional as a basis for management decisions that need to ensure minimum recruitment, especially for sessile animals that require a certain density to ensure fertilization success (Bruckner 2009; Tsounis et al. in press). Abundance data cannot be directly compared among populations or within individual beds over time, due to their patchy occurrence within these beds, differences in the available habitat within an area occupied by this coral, and highly variable features such as crevices and outcrops that are not uniformly distributed throughout the habitat. Also, numbers of colonies per unit area are unlikely to provide an indication of the population status or trends due to their life history traits, which include: 1) a sessile (attached) existence; 2) density-dependent recruitment within localized areas that result in dense populations of small, unbranched colonies; 3) the ability to form of large, highly branched, three-dimensional colonies that are long-lived and will reproduce annually for the duration of their lifespan, in the absence of physical disturbance (collection).

In Spain, depth was found to be only weakly correlated to population abundance while there was a stronger correlation with size, with larger colonies found in deeper water where fishing pressure was lower (Tsounis et al. 2006b). The weak relationship between density and depth may be due to small scale variation in environmental and habitat attributes. In very shallow areas (18-25 m) colonies occur in dense aggregations in cracks and crevices, under overhangs and on the walls and ceiling of small caves, where they form very small patches. In contrast at depths below 35 m, colonies occur in the open at lower densities but they cover a larger area and are larger in size. This trend was apparent several decades ago, where densities in Palma de Mallorca were reported at 55 colonies per square meter at 40 m depth and 20 colonies/m^2 at 60 m depth along the Costa Brava, while 90-100 colonies/m^2 were observed in Corsica (FAO 1984). These abundances are much lower than reported in the Ligurian Sea (Santangelo et al. 1993), but those populations may consist of 2/3 or more juvenile colonies. One of the limitations of these data is related to differences in sampling regimes; the scraping technique detects all corals, small and large, while other methods under count recruits. Furthermore, recruitment in the densest populations (Ligurian Sea) appears to be an order of magnitude higher than other areas and juvenile mortality is lower (Bramanti et al. 2006), but some of these dense shallow populations are much more susceptible to mass mortality events and partial mortality from sponges and other factors (Garrabou et al. 2001) and population turnover is very rapid, with few colonies ever achieving a minimum diameter of 7 mm.

Recommendations for Improved Management

- Increase minimum size of harvest to 10 mm basal diameter and 10 cm height: With exception of new measures adopted in Sardinia, most other locations in the Mediterranean that use size limits in their national coral management plans establish a minimum size of harvest for *C. rubrum* at 7 mm basal diameter. In one of the earliest demographic study of *C. rubrum*, García-Rodríguez and Massò (1986) documented the harvest of colonies that were 5-14 years in age which they concluded were well below maximum sustainable yield (MSY). Based on recent age studies that indicate *Corallium* colonies are 2-4 times older and growth rates are 2.6-4.5 times lower than previously thought (Marschal et al. 2004; Roark et al. 2006). Tsounis et al. (2007) estimated MSY of 98 years, whereas the current practice of harvesting colonies once they achieve a 7 mm basal diameter (11 year old colonies) results in only 6% of the potential yield. This increase in size would allow colonies time to develop branches, reach 100% sexual maturity, and reproduce multiple times before collected.

- Reduce collection at depths above 50 m depth: These populations are reported to be overexploited throughout the Mediterranean. Collection needs to be limited until colonies reestablish a larger size structure. Once these areas recover, collection should be limited to small portions of the total habitat and large-size colonies only (e.g. above 10 cm height).

- Create networks of protected areas (MPAs): MPAs should encompass all depths/habitats occupied by *Corallium* and portions of each bank where *Corallium* is collected. Existing no take areas (protected areas) for *C. rubrum* are relatively small and it is unclear whether they are sited such that they would replenish fished areas, given the high degree of genetic structure and evidence that populations are self seeding (Costantini et al. 2007).

- Rotational harvest: It is unclear how effective this measure would be unless rotational periods exceed 30-40 years to allow full recovery of populations as colonies in areas protected from fishing for 15-30 years are still less than half the reported historic size (Caddy 1993; Francour et al. 2001; Tsounis et al. 2006a).

- Limit harvesting in deep water: Proposals to limit collection to 80-130 m (mixed gas diving) appear to be short sighted at this time because we know too little about these populations. This move to deeper water may be a reflection of the depleted nature of the resource – all acceptable (large) colonies have been removed from shallow water and collectors are now targeting areas that have not been fished for 20 years or more (e.g. since elimination of the dredge). Harvest in these areas should be restricted until population structure is quantified and more data as both growth rates and recruitment may be much different in deep water due to environmental variations.

- Establish monitoring plans: Baseline studies on population dynamics must be completed before a new area is open to fishing. Conservative estimates of landings from these areas should be adopted based on the size of the bank that contains *Corallium*, its abundance and size structure. Collection areas should then be monitored on an annual basis to determine collection impacts and to modify measures as needed to prevent a shift in size structure as that observed in shallow water.

- Enforcement: Better monitoring of landings that include data on numbers of colonies, sizes (height and diameter), and numbers of branches, along with total weight, should be undertaken at ports and marinas, instead of voluntary reporting. Divers should be required to submit daily log books, including site locations, and strict penalties should be adopted for offenses. Once a minimum size is established, there should not be a variance allowed (e.g. 20% as included in the Sardinia plan), as this diminishes the value of a minimum size and it is an indication that inadequate numbers of larger colonies exist in an area if collectors are removing smaller corals.

Conclusions

For a modular organism that characteristically forms highly complex, branched colonies, and can reach sizes of 30-50 cm, a mean height of 3-5 cm, as reported from most shallow areas (< 50 m) in the Mediterranean, is equivalent to a loss of 80-90% of the reproductive modules (polyps) of individual colonies, due to the absence of 2nd, 3rd and 4th order branches. These small colonies can become sexually mature at a young age (2-3 cm height), although they don't achieve 100% fertility until about 6 cm height and 10-20 years in age or older. The spawning potential in *C. rubrum* (and other gorgonians) increases exponentially with size, with larger arborescent colonies producing up to 90% of the recruits. Given settlement rates of no more than 5% of the total larval production, and continued removal of colonies by fisheries after they have reproduced no more than one or two times, typical shallow population today may produce 80-90% fewer recruits than in the 1960s, and about half of that produced by populations that have been protected from fishing for 15-20 years and contain colonies twice as large.

Using only colony abundance and density as an indication of population size and viability can be misleading, as dense populations are limited to only *C. rubrum* and these tend to be dominated by small, reproductively immature colonies. For colonial organisms, change in population structure (size frequency distribution) is a more suitable measure of decline than changes in the absolute numbers of colonies. Commercial extraction primarily eliminates the largest corals, followed by smaller colonies over time, but it is the largest, oldest colonies that contribute most to the replenishment of the population. Furthermore, shifts in the size structure of populations due to fishing pressure can be directly compared, while density and abundance cannot. This is because these measures differ depending on how they are assessed (colony density measured over the entire suitable habitat is much less than the density of small patches occupied by the coral within this habitat), and the life stage of the population. In fact, a less-dense population is likely to represent an older, more stable and viable population as open substrates of suitable habitat can support high numbers of recruits, but these exhibit size-related survival that increases as the colonies get larger. Thus, populations with a high abundance and density, such as those seen in Mediterranean shallow water, are an indication of frequent continuing perturbations responsible for rapid turnover of populations and a persistent state of early-stage recovery. This is similar to observations of other corals that brood their larvae; however, most other corals that are brooders are considered early colonizing, "weedy" species, while *C. rubrum* is a long-lived species that may be attempting to adapt to increasing localized (direct human impacts) and global stressors (climate change). These types of populations are much less resilient to other stressors and are more likely to exhibit localized extirpations when compounded by fishing pressure than populations that contain a mix of small (10-50 mm tall), medium (60-140 mm), and large (150-500 mm) colonies, like that formerly observed in the Mediterranean and still present in some deep-water areas that have not been targeted by fisheries for several decades.

Throughout most of the Mediterranean, *C. rubrum* colonies in shallow water now form small, high density aggregations within much larger areas of suitable habitat, while the corals become less dense and larger in size in deeper areas with lower fishing pressure. These dense shallow aggregations are dominated by recruits and small adult colonies, generally no more than 3-5 cm in height with few colonies over 10 cm in height, whereas historically colonies were 20-50 cm in height. Because of the sessile nature of the species, further reductions in density associated with the selective removal of the largest colonies in deeper coral beds may alter reproductive potential due to allele effects. Also, the smaller organisms in shallow water may experience catastrophic mortalities when fishing pressure is compounded by other stressors such as climate change.

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LESSONS LEARNED FROM NATIONAL TRADE REGULATIONS ESTABLISHED FOR THE RED CORAL, *CORALLIUM RUBRUM*

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The timely restricted (January 1987 – June 1997) strict protection of *Corallium rubrum* in Germany through the listing of the species in Annex 1 of Germany's Federal Ordinance on Species Conservation resulted in a total prohibition of any commercial trade into Germany, both from EU and non-EU Member States.

Due to this situation German, customs was confronted with commercial imports of pre-manufactured and manufactured products made of other *Corallium* species. The listing revealed significant (irresolvable) identification problems on the species level for enforcement officials in particular for pre-manufactured products, jewelry, or products made of coral dust.

Wrong identifications lead to wrong declarations of seizures of red coral shipments from countries where the species doesn't occur in the wild.

In the light of a current pending consultation process initiated by the U.S. government for a possible CITES listing of the entire family Coralliidae, and based on Germany's experience with its past national protection of *Corallium rubrum,* the U.S. proposal is not only evaluated but also recommendations are made how to enhance conservation and management of red corals on our planet by taking other suitable approaches under CITES.

CITES NON-DETRIMENT FINDINGS FOR PRECIOUS CORALS

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The implications of a potential CITES listing for Coralliidae are discussed, especially with respect to the requirement under CITES to make a 'non-detriment finding' before any export is permitted. In this respect, the outcome of the workshop on non-detriment findings, held in Mexico (November 2008), and the general guidelines and principles recommended by that meeting are presented, especially with respect to aquatic invertebrates. This guidance on aquatic invertebrates suggested an ongoing cyclical process of: a) assessing risks, b) regulating harvests, c) recording harvests, trade, and population responses and, finally, d) reviewing, revising, and refining, if necessary, the management measures. Case studies from the workshop, especially those for black and stony corals, provide examples of approaches to non-detriment findings for taxa, already listed on CITES, which have similar life histories to red corals. Some of the perceived difficulties of any CITES-listing for Coralliidae, especially with respect to nomenclature, identification of worked specimens, and administrative burdens, are also addressed with respect to experience from CITES-listed taxa such as black and stony corals and recent discussion in the Hong Kong workshop (March 2009).

REGULATION OF PRECIOUS CORAL FISHERIES IN THE WESTERN PACIFIC AREA

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Precious coral of the Mediterranean Sea (Mediterranean red coral) introduced to Japan as one of the Buddhist Jewelry about more than 1200 years ago, and this is the first record that the precious coral appear in Japan. Buddhist scriptures described as the heaven (paradise of Buddha) decorated with the seven treasures, namely Gold, Silver, Precious Coral, Crystal, Lapis Lazuli, Agate, and Giant Clam Shell.

In Buddhism, precious coral is referred as the one of the treasures of paradise and is used to decorate Statue of Buddha along with other gem stones until present time. This is most evident in Lamaism (Tibetan Buddhism), where precious coral used not only to decorate religious statues, but also as religious artifacts, such as personal talismans.

According to the stabilization and extension of Japanese Society many objects imported from China in Eighth Century, of which generation represented by Emperor Shoumu (701-756). His treasures preserved in the National Treasure House named “Hyo-So-In” of To-daiji Temple. These treasures were donated to the To-daiji Temple by the Empress Koumyou on June 21st of 756 AD which was 49 days after the death of her husband, Emperor Shoumu, as 49 days are an important date for the deceased person in Buddhism.

This collection features many relics of ancient Persia, China, and other ancient countries, and these examples are no longer exist in their mother (native) countries. The number of collection of this treasure house is 9020 items in total.

Beads and small branches of Mediterranean red coral are included in this collection. The beads were used in the decoration of a crown which the Emperor Shoumu wore at the ceremony for newly built statue of Buddha in 752 AD.

On precious coral, these situation continued long time in Japan. For instance, in the Tokugawa-Shogunate (ruled by Samurai, from 1607 to 1867 AD), foreign trade was strictly restricted and only permitted with Holland (Netherlands) and China at the Port of Nagasaki (Deshima), Kyushu, Japan.

Import of precious coral from the Mediterranean Sea during these days can traced from the records of trade with Holland which were preserved in the national Archives of both countries. Volumes of trade of precious coral were not great, and most of the precious coral brought to Japan were used as specific gifts to the Shogun and officers of Tokugawa Shogunate. Journals of the successive Heads of the Dutch Trade Delegations to Japan, preserved in the Central National Archives of the Netherlands in Hague, reveal that the director of each delegation was obligated to travel to Edo (now, Tokyo) for an audience with the Shogun.

At that time, the trade delegation heads brought many gifts for Shogun, his Prince and other top level officials of the Tokugawa Shogunate, and the Mediterranean red coral always included in these gifts.

Similar gifts were also presented to the officials at the port of Nagasaki, in which Mediterranean red coral were presented to the important Offices in the port. It is said that Mediterranean red coral was regarded as one of the most valuable gifts during the Tokugawa Shogunate Period. During Tokugawa Shogunate, precious coral was also imported via China through the trade routes between the Mediterranean area and China. Although the amount of Mediterranean red coral from China was not so big as that from Holland, trade records indicate that precious coral was always included among the cargoes of ships from China.

So we, the Japanese, have a special emotion to the Mediterranean red coral, and wish to say our special thanks for the people of the Mediterranean area for their long time supply and support.

Despite the long history of the using of precious coral in Japan, precious coral fisheries in Japan have a rather short history to compare with the Mediterranean red coral fisheries. Because precious coral off the coast of Japan inhabits depths of more than 70 to 100 meters, it was hard to harvest them using the primitive fishing methods at that time.

Coral fisheries in Japan did not start until the early 18th century. Also unlike Mediterranean coral, coral in Japan did not wash up on beaches after storms or heavy surf, because they lived on the deep seabed. On the other hand, the Tosa Clan in Tokugawa Shogunate prohibition against gathering coral was not strictly enforced. While the Clan did not wish to see common people develop unregulated fisheries and free trade in its Domain, neither did it intend to levy severe penalties for contingent coral harvests that accompanied other types of fishing. This is supported by the document issued 1838 AD that stated anyone harvesting precious coral was prohibited from selling it freely and should offer to the Tosa Clan in stead of selling to the outside. A warning was added stating that anyone violating this regulation would be punished.

During the Meiji Restoration the feudal system was abolished along with all Tosa Clan regulations and laws. Soon afterward precious coral fisheries began operating along the coast of the Muroto region (Tosa Bay) in 1871.

The equipment used at this time was the coral gathering net that Mr. Konojoi Ebisuya had invented. Modern equipment still uses the same basic principles Ebisuya used in designing his net. Konojoi Ebisuya's work in opening and developing coral fisheries was recognized when he was given an award at the 1897 Fisheries Exhibition. Also white precious coral (shiro) was dedicated in his honor as *Corallium konojoi* by Kishinoue in 1903. At the present, coral fisheries in Japan operate in Kochi area (Tosa Bay) by net and southern part of Kyushu by submarine. Both fisheries operations are regulated by the provincial government of each area. The details of the regulations are presented by the previous report by Hideki Moronuki.

Explanation 1.

Detail of harvest amounts of the past 20 years from Tosa Bay, Kochi, Japan is explained with the data in each year including harvest amount, traded price, and number of boats. From these data, there are no signs of over-harvest or depletion of precious coral resources along the Japanese coast. Further, harvested coral by boat are almost all dead ones and its percentage is 85 to 90% of total harvest amount.

Explanation 2.

Displayed actual material of three species of precious coral (*C. japonicum, elatius,* and *konojoi*) in various phases (alive, 3 phases of dead material, to worm eaten phase), and natural to manufactured ones. People can understand that dead material is still useful for manufacturing and rather hard to discriminate the differences among these final products of these samples. So they can understand that dead coral are still useful and no problem for manufacturing.

Explanation 3.

Recently, the Taiwan Government established very severe regulations of the coral fisheries around the Taiwan area, which started from 2008. Issue of fisheries licenses is strictly investigated. Annual harvest amounts of each boat are strictly restricted. Each boat must be set up with GPS equipment, so each boat can be traced by the government. Fisherman must be present daily reports on his fisheries results within 3 days after the fisheries operation. Permit areas for coral fisheries around the Taiwan territory are strictly regulated.

Report of harvest amount in Taiwan (2009)(unit is kg):

January	0.111	February	140.147	March	154.964
April	346.447	May	348.615	June	478.286
July	263.352	August	325.004	September	355.692

These reports will be issued every month in the future.

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THE INCLUSION OF *CORALLIUM JAPONICUM, CORALLIUM KONOJOI, CORALLIUM ELATIUS,* AND *CORALLIUM SECUNDUM* IN APPENDIX-III OF CITES.
THE ITALIAN EXPERIENCE OF CORPO FORESTALE DELLO STATO.

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Abstract

Until about two decades ago, much of the red coral worked in Italy came from *Corallium rubrum*, characteristic of the entire range of the Mediterranean Sea. Currently, about half of the manufactured product comes from the Chinese area. In 2008, four species of red coral from People Rep. of China (*Corallium japonicum, Corallium konojoi, Corallium elatius,* and *Corallium secundum*) were included into Appendix-III of CITES. This was applied by the European Union with Reg (EC) 407/09 (entry into Annex C). This inclusion requires specific procedures for the import and re-export of raw coral and finish products derived from it, about the enforcement of which is responsible in Italy the State Forestry Corps. In fact, for specimens importation of the four species considered, either need a Certificate of Origin, or re-export certificate or an export license. Sales in Italy and then to the EU does not require specific permissions, but in case of re-export to countries outside the EU, it is required that the specimens are accompanied by an export certificate, issued by the CITES Service of State Forestry Corps. At this moment, about 50% of raw red coral is purchased in Italy from Pacific area/P. Rep. of China/Taiwan and it is often very difficult to distinguish a finish product made with Chinese Coral in comparison to another from *C. rubrum*, as in the raw product you can recognize morphological and microscopical differences.

The species of *Corallium* and *Paracorallium* (Bayer and Cairns 2003) genus are commercially exploited by man for over 5000 years. Manufacturing activity in red coral in Italy is an important source of income for many people, with small firms located in Naples hinterland and, in particular, in Torre del Greco. Until about two decades ago, much of the raw material processed in Italy came from *Corallium rubrum*, characteristic of the entire range of the Mediterranean Sea. Currently, about 40% of rough/semi-rough product comes from Pacific/Japan/Philippines/ PDR of China/P of Taiwan area.

On April, 2, 2008, by Notification n° 27, the CITES Secretariat in Geneva informed Parties that, at the request the People's Democratic Republic of China, four species of red coral – *Corallium japonicum, Corallium konojoi* (synonym of *C. konjoi*), *Corallium elatius,* and *Corallium secundum* – have been added in Appendix-III of CITES. This inclusion in the European Union only became operational on 22 May 2009 with the publication of Reg (EC) of Commission n° 407, May 14, 2009, replacing the EC Reg 318/2008, and where these four species of red coral have been included in Annex C of modified Reg (EC) Council Regulation n° 338/97. This inclusion required the adoption of specific procedures for the import and re-export of raw coral and by-products.

The inclusion in Annex C of Reg (EC) 338/97 requires exact obligations for the State Forestry Corps, that is in charge for certification activities and control of specimens of species protected by CITES. State Forestry Corps discharge these duties across more than 50 offices spread all over the country: CITES Territorial Services and CITES Operations Units for customs controls, both coordinated by a CITES Central Service established in Rome (Fig. I). For the importation of live coral or dead, rough, parts and derivatives "specimens" belonging to one of four species considered, if they do not come from People's Republic of China, they must always be accompanied by a "Origin certificate" or re-export certificate issued by the Official CITES Authority of the exporting country. When instead such specimens come from PRC, they must be accompanied by an export permit issued by the Official CITES Authority of that country. In either cases, when the specimens entry into Italy, CITES Operations Units of the Forestry Corps, fill a specific form named "Import Notification" on the basis of the documentation accompanying goods at customs point. The subsequent sale in the country and EU, based on Article 8 of Reg. (EC) 338/97, does not require specific authorization under the CITES legislation. In any case, the seller will provide care to the client, about the purpose of resale outside the EU, the information on the CITES document of importation.

In case of re-export to countries outside the European Community of specimens with coral belonging to four species in question, under provisions of article 5.4 of Reg. (EC) 338/97, the same specimens need of a re-export certificate, which is issued by the CITES Service of Forestry Corps. This kind of certification is issued, as provided in Article 5 of Reg. (EC) 338/97, only on the basis of documentary evidence attesting the correct importation of source material.

As instead regards the other species of coral belonging to the genus *Corallium* sp, in particular *C. rubrum*, which at present are not subject to the provisions of CITES and Reg. (EC) 338/97, CITES Service of the State Forestry Corps provides for the issuance, at the request of the subject, of a so-called "declaration of non-inclusion," which is placed on the bills of sale on the basis of documentary evidence of the non-inclusion in the lists of CITES. For personal and households effects, under the CITES legislation is not required any certificate, preserving the possibility of stricter domestic measures by the Parties. It was launched a consultation on this matter with some states outside the EU, trough Italian Main CITES Management Authority which is constituted by the Ministry of Environment and the protection of Territory and Sea: the United States, in particular, have confirmed that any kind of document is not required for this type of objects as species included in Appendix-III.

And now, with the next figures (1, 2) are showed provided data on notifications for import compiled in 2009 (May – September 2009) by CITES Operations Units (NOC) and re-export certificates issued by CITES Territorial Services (SCT) of State Forestry Corps. Against n° 31 import notifications related to three of the four species considered, compiled by NOC operating in the regions of Veneto, Lombardia, Lazio, and Campania, it was issued a total (for the same period) of n° 31 re-export certificates, by SCT operating in Vicenza, Rome, and Naples in particular.

Further, during the period 1/1/2009 – 10/09/2009, on a total amount of 149 issued Import Notifications, about 25% regarded the 4 species of *Corallium* included in Appendix-III. In that period, CITES Service of Forestry Corps in Naples has issued 26 re-export certificates, that are about 6.5% of the total re-export documents. In these few months of application, more than an increasing of the issued certificates (+ 6.5%), Naples Forestry Corps have pointed out an increasing of the necessary time to deliver permits, due to the considerable checks of the big amount of pre-convention rough, semi-rough, manufactured material, and relative documentation. As already mentioned, at this time approximately 40% of the rough/semi-rough coral used for manufactured product crafted by Italian companies is purchased in Pacific/Japan/Philippines/PDRC/P of Taiwan

12	Total C. elatius
4	Total C. konojoi
15	Total C. secundum
31	**Total Corallium spp.**

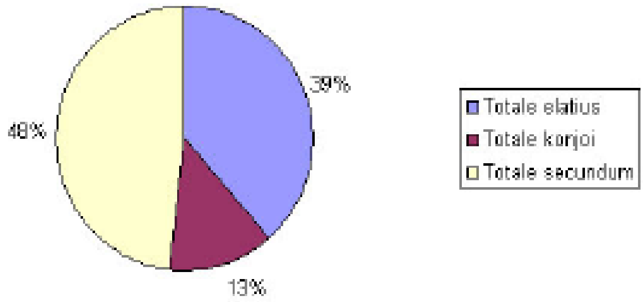

Fig. 1. Import notification delivered from 1/1/2009 to 10/09/2009.

15	Total C. elatius
4	Total C. japonicum
12	Total C. secundum
31	**Total Corallium**

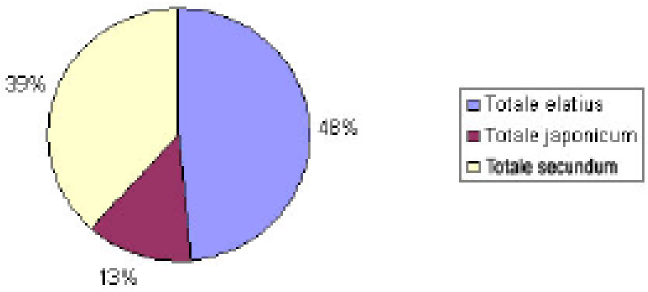

Fig. 2. Re-export certificates delivered from 1/1/2009 to 10/09/2009.

area. This is possible because red coral belonging to the species *C. japonicum* in particular and *C. elatius* and *C. secundum* presents chemical and physical characteristics that make it very similar to *C. rubrum*, so that the worked products, especially in the smaller items such as small beads, cabochons, or other shapes used in jewelry, looks alike very similar from each other and consequently it is very difficult to recognize the single species.

This fact can creates difficulties for those who, as officers of the State Forestry Corps but generally CITES Enforcement workers, have to do routine controls required by rules and subsequently issue specific certificates for specimens in entry/exit from Italy.

On the contrary, in rough or semi-rough products it is possible identify peculiar differences in the distribution and orientation of color and canals, as you can see in every piece of coral like these showed in the next picture (Fig. 3).

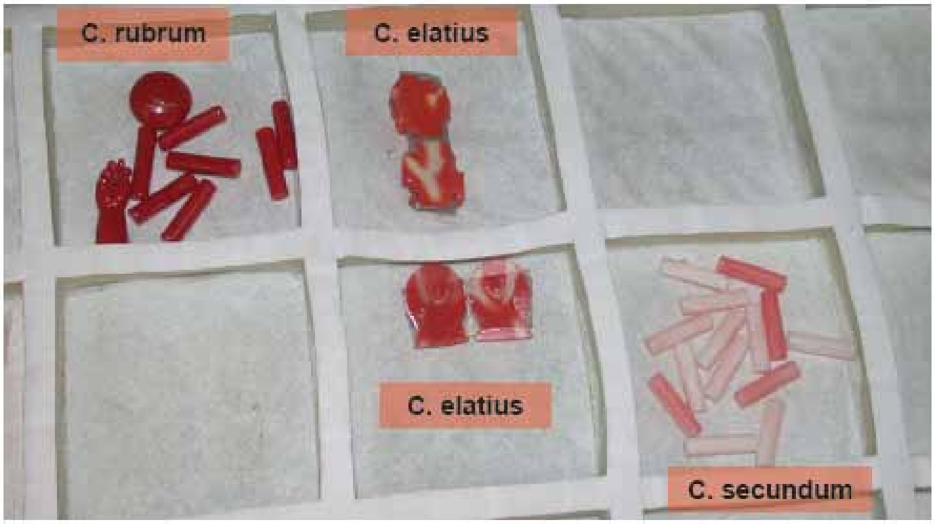

Fig. 3.

As results of such identification problems, there were some cases of shipment seizures about manufactured products, even if they were escorted by official declaration of Italian competent authority, with labels declaring that they have been obtained by the species “Corallium rubrum,” not subjected to CITES provisions.

Conclusions

Therefore, on the basis of the considerations set out above, the short lack of time from CITES inclusion and the findings after the first few months of application of Reg. (CE) 407/09, there are real difficulties associated with:

- Identification of specimens.
- Increase of administrative activity and time taken for checking of invoices, bills, accounts, and other administrative documents, also to cover stocks of coral, everything necessary for the issuance of certificates.

Priority should therefore look for measures to ensure at the same time:

- Conservation of species.
- Avoid of contentious in their application.
- Bearable burden for the certification and control authorities.
- Reliability and efficiency of technical–administrative action to reduce at minimum level the possibility of contentious, related in particular to identification of species and big amount of pre-convention stocks.

IMPLICATIONS OF AN APPENDIX-II LISTING OF THE GENUS *CORALLIUM* FOR A SUSTAINABLE INDUSTRY

Stephen Nash
CITES Secretariat

The presentation examines the implications of a possible listing of the genera *Corallium* and *Paracorallium* in Appendix-II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) on the red coral industry. As with any species listed in Appendix-II, international trade is allowed under specific circumstances, upon advice from a Scientific Authority. The presentation will review the conditions and State obligations under the Convention that a listing of *Corallium*/*Paracorallium* would entail, and consider practical issues relating to law, science, management, and administration. A further consideration is whether such a listing is enforceable, taking into account matters of identification, treatment of personal effects, and pre-Convention specimens. Included in the discussion is consideration of counterfeit red coral and red coral substitutes, the possible impacts of a split-listing by species and/or geographical populations, the impact on the reporting burden, and taxonomic uncertainty. After a careful consideration of the implications of a listing, Parties will be able to decide whether CITES offers the best means to ensure protection from over-exploitation and support for a long-term future for the red coral industry.

LACK OF COMPREHENSIVE CENSUS DATA HAMPERS CONSERVATION AND MANAGEMENT OF *CORALLIUM RUBRUM* COLONIES

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Besides being listed in a suite of European and regional environmental legislation to which Malta is party (e.g. Habitats Directive, SPA Protocol, Bern Convention) and in Maltese environmental legislation (e.g. LN 311 of 2006, as well as in the local Red Data Book), no systematic census of *Corallium rubrum* (Qroll ahmar in Maltese) has been conducted to date within Maltese coastal and offshore waters. Anecdotal evidence exists of the presence of red coral in relatively deep waters around the Maltese Islands, but no definite distribution map for the species within Maltese waters exists, rendering the adoption of a coherent conservation and management plan for the species difficult. Such a situation has arisen from the verbatim transposition of Habitats Directive species lists into local environmental legislation. A similar scenario exists for large swathes of the Eastern Mediterranean, where records of the red coral species have transpired from sporadic sampling events. The situation is compounded by sweeping statements such as the one which claims that the only commercially valuable red coral beds are now located along North African coasts from Morocco to Tunisia, off the western coast of Sardinia (Bonifacio Straits), and along the Spanish coasts. In addition to the need for a comprehensive distribution map of red coral in the Mediterranean, the need for a harmonized pan-Mediterranean regulation and management framework, possibly under the aegis of FAO, is also felt. At present, whilst *Corallium rubrum* is strictly protected in Malta and Gibraltar, where no exploitation is contemplated, regulated exploitation is permissible in a number of Mediterranean countries, including Spain, France, and Tunisia.

EUROPEAN UNION LEGISLATION ON WILDLIFE TRADE (CITES)

M. Valentini
European Commission DG. ENV – E2 – CITES Team

The presentation aims to give an overview on the European Union legislation implementing the CITES provisions, fixing stricter rules, fostering common interpretation, scientific and enforcement coordination.

Tasks and responsibilities of Scientific Authorities, as well the rules of procedure of the Scientific Review Group, that coordinates the Scientific Authorities of the 27 Member States; Annexes A, B, C, and D to the EU Regulation Import, export procedures, and the consequences of the listing; Stricter rules in the EU legislation; Gaborone amendment; Annotations to the listing; Consultation with third countries; How the non detrimental findings are carried out; Delivery of the SRG opinion; SRG import restrictions and mechanisms for trade suspension.

Working Group Reports

CONCLUSIONS FROM SCIENCE AND MANAGEMENT WORKING GROUP

The working group expressed support for cross-Mediterranean approach to red coral management – for example through the GFCM. Desirable to have a common assessment of current management, monitoring and research measures across the region.

Need local management plans under this regional ‘umbrella’ – using case studies (e.g. Sardinia/Hawaii) to improve management.

A working group needs to be formed to work post-conference on developing these plans and to seek funding – there is scope to strengthen lobbying for such funding from sources such as EC, national governments and private sector.

Management should be based on key scientific parameters such as population structure, density genetics, colony and population growth rates (reproduction and recruitment) and connectivity; management should be adaptive based on feedback from fishery dependent and independent data and input from relevant stakeholders.

The group agreed that shallow water populations are well studied but deeper water populations are less well studied and extrapolating from shallow water studies (in selected locations) may not be appropriate.

There is a general consensus that shallow water populations are, or have been, over-exploited but the overall extent of decline in the Mediterranean is not known. Therefore, there is a clear need to determine the extent of decline and/or recovery.

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).

Deep water populations (typically 70-150 m) are a priority for research and fishery management because these are the most heavily exploited populations and knowledge of population parameters are poorly known. These populations should be managed by selective harvesting using appropriate size limits. The deepest populations (> 150 m) are not harvested, some may never have been harvested, and should not be subject to harvest and could provide refugia for the species.

The decision to ban non-selective gears was a major step forward in the regulation of the fishery. However, there is consensus that management measures and enforcement in the Mediterranean overall should be improved further taking into account the case studies referred to above. Such management measures should be population specific and include, but not be limited to, minimum basal diameter and height of colony and branching pattern, quotas, regulation of collection methods, harvest reporting and monitoring, harvest rotation periods and the number and extent of no-take zones/protected areas. These management measures should be adaptive and be informed by proper and comprehensive scientific research on, inter alia, stock status and management models. Absence of scientific information is not sufficient excuse to not manage populations on a precautionary basis.

Experience has shown that management regimes that are not adequately enforced fail to yield the anticipated conservation benefits. There is a strong need for existing and future management measures to be properly enforced with inter alia sufficient resources and penalties – including confiscation – that are commensurate with the offence and represent a meaningful deterrent.

The working group emphasised the need for further research to underpin the management and conservation of the species; research should be collaborative and the results shared between Mediterranean countries and internationally. Regular stock assessments and national reporting, in the context of regional management, is desirable.

CONCLUSIONS FROM THE TRADE WORKING GROUP

It was not possible for the workshop, in plenary, when considering the report of the trade working group, to reach any appropriate consensus, on trade related issues, because some participants objected to any reference to any CITES listings while others felt that discussion of the implications of a hypothetical CITES Appendix-II listing were essential. This report represents general agreement of the working group but consensus was not reached on all of the text.

Identification

Corallium rubrum is the focus of the Mediterranean Workshop. However, since there are other *Corallium* in trade in the Mediterranean, four of which are already subject to international controls, identification difficulties already arise even in the absence of any CITES Appendix-II listing. Different species of Coralliidae are utilized in manufacturing of jewelry and semi-finished products, and discriminating between species is a challenge. Many of the issues discussed here, including identification and pre-Convention materials, are not unique to coral. Many of these issues apply to all countries, including Italy and other Mediterranean countries already trading in CITES-listed products and lessons may be learned from the implementation of already existing CITES listings. It was also noted that industry expertise and opinion should be included and taken into consideration for implementation.

There are six species in the Coralliidae family that are commercially traded. It has been suggested that, in the event of an Appendix-II listing, amending CITES Resolution CONF. 12.3, to allow Parties to declare worked specimens at the family level would alleviate many identification challenges. However, reporting at the family level would limit the data available to asses the impact of trade on individual species, and this should be taken in to account in making non-detriment findings. Moreover, it was represented by some participants that significant administrative problems could arise related to the identification at the family level in deciding whether to issue an export or re-export permit.

The following were recommended as tools to assist in identification. Industry expertise and opinion should be sought to ensure the identification tools are accurately represented. Moreover, it is recognized that these tools may not allow identification to the level of species in all cases of semi-finished and finished Coralliidae products:

1) ID guide to precious corals – tools need to be available online and in hard copy form;
2) Reference collection;
3) Training of customs officials and training the ‘trainers;’
4) List of spp. and country of origin;
5) Access to government-approved experts for consultation (customs officials need access to scientists);
6) Capacity building (developing countries in particular);
7) Forensic tools (which may not be available for all countries, or feasible when it requires damage of the product);

8) Secretariat is creating a wiki identification website.

Additional needs: implementation plan useful before adoption; adopt taxonomic reference for corals.

Administrative Burden

It was recognized that there are heavy administrative burdens associated with a CITES listing, including burdens to CITES management authorities for issuing permits and reporting trade, burdens to enforcement officials, and to industry. Recognition that national governments could develop procedures for dealing with pre-Convention stockpiles of Coralliidae specimens with inventory measures. It was also recognized that there are mechanisms under CITES that could be used to reduce these burdens (including use of personal effects exemption and streamlined permitting procedures). In many CITES countries, these mechanisms are not currently applied and it is up to national governments to determine their use. Ultimately, if there is a CITES listing proposal, the Parties will need to decide if the conservation benefits to the resources outweigh the administrative burdens. As for any CITES listing, it was agreed that there needs to be a real benefit and need for conservation of the species before proposing a listing. It is recognized that these will be burdens that apply to all countries, including developed countries.

1) There was the recognition that systems are in place to lessen administrative burden, and it is the choice of national governments to implement these systems.
2) Personal effects. Not all countries recognize CITES personal effects exemption (EU, US do recognize personal effects exemption). Those that do recognize it, it's often not recognized consistently.
3) Streamline permit procedure (e.g. using partially filled out forms).
4) Delayed implementation in order for countries to ready themselves (and industries) for a listing, in order to minimize the burden.
5) Money and added capacity.
6) Direct animals committee to review/update existing notification on stony corals and taxonomic references/guide; do the same for precious corals. This issue is not unique to corals and could apply to other species listed under CITES.

Socioeconomics and Livelihoods

Socioeconomic and livelihood impacts that can accompany a CITES listing must be considered. For example, it was noted that only 31 shipments of Appendix-III listed species were re-exported from Italy, from beginning of 2009, representing an 80% reduction in the trade. A concern was also expressed about the perception of a CITES listing as being a 'non-green.' The Appendix-II listing of *Strombus gigas* was cited as an example that led to the collapse of the demand for objects made from this species. The consumer perception is that they're buying something endangered. A marketing strategy may be beneficial in altering this perception.

There are many different forms of trade in corals, not just jewelry, and they must also be considered. Res. 12.3 potential revision is working towards identification of products at the family level. This could be a potential solution to identifying different species in the same product or piece.

It is recognized that there are challenges and enforcement issues relating to the international coral trade, such as poaching and illegal harvesting, the most environmentally – and cost-effective methods are to manage enforcement at the harvesting site with enforcement of national laws and adequate penalties.

It was noted that Taiwan adopted its own enforcement legislation in December 2008. It is critical to have cooperation between range states to effectively control the illegal harvest.

Appendix

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2. Workshop Agenda

International Workshop on Red Coral Science, Management, and Trade: Lessons from the Mediterranean

University of Naples "Parthenope"
Villa Doria D'Angri
Via Petrarca, 80
September 23rd – 26th 2009

The aim of this Workshop is to define a management strategy for the Mediterranean red coral, emphasizing the various problems of conservation and the most suitable methods of sustainable harvest and trade.

Preliminary Program

September 22nd afternoon:

Arrival of participants and registration at Villa Doria D'Angri, Via Petrarca, 80.

4.30pm - Meeting of the Steering Committee

September 23rd Morning: Plenary Session

8.30am - Registration

9.30am - Welcome of Authorities (Chair: E. Bussoletti/D. Cottingham/A. Maturani)

Minister/Vice Minister MATTM
Dr. Aldo Cosentino, Director General DPN MATTM
Prof. Gennaro Ferrara, Rector of University of Naples "Parthenope"
Prof. Raffaele Santamaria, Dean of Faculty of Science and Technology, University of Naples "Parthenope"

10.00am - Mediterranean red coral *(Corallium rubrum)*: historical assessment. An overview of the role red coral played in the Mediterranean history, culture, traditions and economy.

- 10.00-10.25 - **C. Ascione** - The precious Mediterranean red coral: an historical, cultural, economic heritage.

- 10.25-10.50 – **J. G. Harmelin** Lacaze-Duthiers' legacy: advances in scientific knowledge of *Corallium rubrum* from French works after 1864

- 10.50- 11.15 **G. Santangelo,** L. Bramanti, I. Vielmini, M. Iannelli - The history of research and harvesting of the Mediterranean red coral: potential and limits.

11.15am - Coffee Break

11.30am-1.15pm - Introductory speeches

- 11.30-11.55 – **S. Rossi**, G. Tsounis, J.-M. Gili: The deep transformation of the Mediterranean red forest: the Catalonian coast case study

- 11.55-12.20 – **R. Cannas**, Caocci F., **Follesa M.C**., Grazioli E., Pedoni C., **Pesci P**., Sacco F., **A. Cau**: Multidisciplinary data on the status of red coral (*Corallium rubrum*) resource in Sardinian seas (Central Western Mediterranean).

- 12.20-12.45 - **A. W. Bruckner**: Rate and extent of decline in *Corallium* (pink and red coral) populations: are existing data adequate to justify a CITES Appendix II listing?

- 12.45-13.10 - **R. W. Grigg**: Management of precious corals: local science and enforcement versus a listing by CITES

1.15pm - Lunch time

2.45pm-6.30pm:

- 2.30–2.50 **-_M.Taviani**, A.Freiwald, L. Beuck, L.Angeletti, A. Remia, A. Vertino, M. Dimech, P. Schembri: The deepest known occurrence of the precious red coral *Corallium rubrum* (L. 1758) in the Mediterranean Sea.

  A. Vertino, H. Zibrowius, **M. Taviani**. Fossil ancestors of family Coralliidae in the Mediterranean basin

  P. Montagna, D. Vieulzeuf, M. López Correa,.J. Garrabou, **M. Taviani**, C. Marschal, C. Linares, M. McCulloch, S. Silenzi, A. Freiwald: Geochemical investigation of *Corallium rubrum* from shallow and bathyal settings in the Mediterranean Sea

Harvest, Manufacturing and Trade – (Chair: R. Cattaneo-Vietti/N. Iwasaki/L. Noguchi)

- 2.50-3.10 – **A. Bailey**:_Overview of Law Enforcement Issues Regarding the Trade in *Corallium*.

- 3.10-3.30 – **A.E. De Simone**: Diffusion of Coral in the world; symbol, use and trade.

- 3.30-3.50 – **C. Dounas**, D. Koutsoubas and M. Salomidi: Red coral (*Corallium rubrum*, L. 1758) fisheries in the Greek Aegean and Ionian Seas.

- 3.50-4.10 – **A. Dridi**, A. Zoubi and S. Taleb:_The exploitation of red coral in Morocco.

- 4.10-4.30 – **B. Öztürk**: Red coral and ıts actual sıtuatıon ın Turkey.

4.30-4.45 – Coffee Break

- 4.45-5.05 – **M. Pani**: Analysis of FAO Statistics of harvest of *Corallium rubrum* in the Mediterranean 1978-2007.

- 5.05-5.25 - **P. Stampacchia**: Il comparto del corallo di Torre del Greco.

- 5.25-5.45 – **S.J. Torntore**: Coral as Product: Analyzing Production and Market Perspectives.

- 5.45-6.05 – **R. Doneddu**: Red coral management strategies in Sardinian coastal waters: a successful experience.

- 6.05-6.25 - **E. Cooper**: Development of a Guide to the Identification of Precious Corals

September 24th 9.00am-1.00pm: Plenary Session

Science: Biology and ecology of red coral (Chair A. Zoubi/M. Abbiati/B. Roark)

The status of knowledge on biology and ecology of the Mediterranean red coral *Corallium rubrum* (L 1758) will be discussed with comparative information for Pacific species.

- 9.00-9.20 – **M. Abbiati**, F. Costantini, C. Fauvelot, E. Pintus: Genetic structuring of *Corallium rubrum* in the Mediterranean Sea: implication for management and conservation.

- 9.20-9.40 – **G. Bavestrello**, C. Cerrano, R. Cattaneo-Vietti: Biological interactions affecting the growth rates of red coral (*Corallium rubrum*) colonies.

- 9.40-10.00 – **L. Bramanti**, Vielmini I., Santangelo G.: Long-term settlement plates: some clues for demography and restoration of Mediterranean red coral (*Corallium rubrum*) shallow water populations.

- 10.00-10.20 – B. Calcinai, C. Cerrano, N. Iwasaki and **G. Bavestrello**: Biodiversity and ecology of the sponge boring into precious corals: a worldwide overview.

- 10.20-10.40 – L.A. Chessa and **M. Scardi**: Biometrical analysis and observations on deep red coral *Corallium rubrum* (L.) in N.W.Sardinia shoals (Italy).

- 10.40-11.00 – **F. Costantini**, C. Fauvelot, E. Pintus, M. Abbiati: Effective larval dispersal and scales of connectivity in *Corallium rubrum.*

11.00-11.15 – Coffee Break

- 11.15-11.35 – **F. Costantini**, M. Taviani, A. Remia, E. Pintus, P.J. Schembri, M. Abbiati: Deep-water C*orallium rubrum* (l. 1758) from the mediterranean sea: preliminary genetic characterization.

- 11.35-11.55 – **C. Ferrier-Pagès:** Feeding characteristics of the red coral *Corallium rubrum.*

- 11.55-12.15 – **N. Iwasaki**, T. Fujita, G. Bavestrello, R. Cattaneo-Vietti: Small-scale distribution of Japanese red coral off Amami Island, Southern Japan.

- 12.15-12.35 - **E.B. Roark,** T.P. Guilderson, R.B. Dunbar: Radiocarbon-based ages and growth rates of Hawaiian *Corallium* sp**.**

- 12.35-12.55 – **S. Tambutté**: Biomineralization in *Corallium rubrum*: organic matrix comparative study of sclerites and skeleton.

- 12.55-13.15 – **I. Vielmini**, Bramanti L., Tsounis G., Rossi S., Gili J.M., Cattaneo-Vietti R., Santangelo G.: *Corallium rubrum* age structure determination.

1.15pm - Lunch Time

2.45pm – 6.45pm: Plenary Session

Management (Chair A. Maturani/V. Fleming)

The group will compile and assess information on the existing national management strategies, how the various jurisdictions are operating, and their adequacy in the different Mediterranean experiences. Comparisons with other World regions experiences are welcome (for example Hawaii black coral and Pacific red coral harvest).

- 2.45-3.05 - **A. W. Bruckner:** Changes in size structure of fished *Corallium rubrum* populations and implications for sustainable management and trade.

- 3.05-3.25 – **J. Dietrich**: Lessons learned from national trade regulations established for the red coral, *Corallium rubrum.*

- 3.25-3.45 – **V. Fleming**: CITES non-detriment findings for precious corals.

- 3.45-4.05 - **S. Kosuge**, H. Kiuchi, Y. Tanabe and K. Kamei: Precious coral fisheries regulation in the western Pacific area in comparison with Sardinian regulation.

- 4.05-4.25- **M. Mei**, L. Corbetta, S. Di Domenico, P. Pandolfi: The inclusion of *Corallium japonicum, Corallium konojoi , Corallium elatius and Corallium* secundum in Appendix III of CITES. The Italian experience of Corpo Forestale dello Stato.

- 4.25-4.45 - **S. Nash**: Implications of an Appendix II listing of the genus *Corallium* for a sustainable industry.

- 4.45-5.05 **A. Deidun**: Lack of comprehensive census data hampers conservation and management of *Corallium rubrum* colonies

- 5.05-5.25 –. **M. Valentini**: European Union legislation on wildlife trade (CITES)

- 5.25-5.45 **M. Scarpati**: Red Coral harvesting: past, present, future (Video).

5.45 – 6.00 pm Coffee Break

6.00 – 7.00 Discussions (potential contingency to absorb delays)

8.30pm - Gala Dinner at Villa Doria D'Angri Terrace

September 25th 9.30am-1.30pm: Meetings of three Working Groups

a) **Harvesting , Manufacturing and Trade Working Group (**P. Stampacchia, L. Noguchi**)**
b) **Scientific Working Group (**G. Bavestrello, B. Roark**)**
c) **Management Working Group (**G. Santangelo, V. Fleming**)**

1.30 pm – Lunch Time

2.00pm-3.30pm – continuation of Working Groups Meetings

3.30pm - Visit to Torre del Greco with the following program:

- visit to the "Red Coral Museum";
- visit to a red coral manufacturing emplacement;
- dinner and historical Neapolitan music show.

September 26th morning/afternoon:

Final Common Report of the three WGs (Chair: E. Bussoletti/D. Cottingham)

Outcomes to correctly sustain harvest and trade of Mediterranean red coral, potentially extended to Pacific red coral.

- Sustaining research on specific scientific topics on which the lack of knowledge was assessed, which will lead to a rational harvesting (based on sound scientific data) of the resource and to rearing experiments.

- Evaluate the opportunity, as a follow-up of the event, to establish a Capacity Building Program specifically addressed to red coral in order to transfer know-how and positive experiences to other countries.

- Developing recommendations on changes to management approaches to enhance conservation.

- Identifying strong local management system and enforcement efforts to prevent unsustainable harvest of red coral, and analysing gaps where more steps are needed for the management

- Recommending additional measures that could be implemented on a local, regional, national, or international scale that are necessary to address possible threats affecting red coral and that could help to foster population recovery, and where these need to be applied.

OFFICIAL EVENTS:

- **Gala Dinner at Villa Doria D'Angri on September 24th, 20.30**

- **On the evening of September 25th**, **a visit to Torre del Greco** with the following program is planned:

    - visit to the "Red Coral Museum";
    - visit to a red coral manufacturing emplacement;
    - Dinner and historical Neapolitan music show.

3. Workshop Coordinators:

Ezio Bussoletti
David Cottingham

4. Steering Committee:

Marco Abbiati, Italy
Giorgio Bavestrello, Italy
Andy Bruckner, USA
Riccardo Cattaneo-Vietti, Italy
Angelo Cau, Italy
Jean-Georges Harmelin, France
Sadao Kosuge, Japan
Drosos Koutsoubas, Greece
Jeremy Linneman, USA
Laura Noguchi, USA
Glynnis Roberts, USA
Serge Rossi, Spain
Giovanni Russo, Italy
Roberto Sandulli, Italy
Giovanni Santangelo, Italy
Marco Taviani, Italy
Abdelaziz Zoubi, Morocco