



# Onboard Scientific Observers Provide a Realistic Picture of Harvesting and Management Priorities for the Precious Red Coral (*Corallium rubrum* L.)

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Mediterranean red coral *Corallium rubrum* is considered the most precious coral worldwide. Harvesting activities are performed by licensed scuba divers and managed through the recent pan-Mediterranean management plan issued by General Fisheries Commission for the Mediterranean (GFCM) along with measures locally enacted, imposing limits on licenses, harvesting season, minimum depth of dive, and size. The use of Remotely Operated Vehicles (ROVs) is prohibited, with the only exception being for scientific purposes. Despite measures already in force, the implementation of additional management tools has been recently recommended. This article reports results from the first monitoring campaign on *C. rubrum* harvesting based on ROVs for seabed exploration and Onboard Scientific Observers (OSOs), carried out from 2012 to 2015 along the coast of Sardinia (Mediterranean Sea—Western basin). More than 450 dives were monitored, confirming how ROV's support eases the scouting of exploitable banks, leading to increases in catches. OSOs reported the collection of colonies below the minimum reference size and catches/dive above limits. Onboard observers collected data also on colony diameter, which is crucial for the estimation of population size structure and exploitation status. OSOs proved to be valid tools in providing additional and reliable information on red coral harvesting, thus deserving to be included among mandatory measures for the sustainable exploitation of red coral in the Mediterranean Sea.

**Keywords:** *Corallium rubrum*, logbook, management plan, Mediterranean Sea, onboard observers, ROV

## INTRODUCTION

The Mediterranean red coral (*Corallium rubrum*, Linneus, 1758, Octocorallia, Anthozoa, Cnidaria) is a slow growing, long-lived, and habitat-structuring gorgonian, endemic to the Mediterranean Sea and Atlantic rocky bottoms (Garrabou and Harmelin, 2002; Cau et al., 2015, 2016). It is a sciaphilous species living at depths ranging from 5 to 1000 m (Costantini et al., 2010; Knittweis et al., 2016), although more commonly found between 30 and 200 m (Rossi et al., 2008; Taviani et al., 2010). Because of its red calcium carbonate skeleton, *C. rubrum* is the precious coral par

excellence and was used as jewelry, currency, and religious talismans as early as 30000 years ago, thus becoming one of the most valuable but also vulnerable resources in the Mediterranean Sea (Tescione, 1973; Garrabou and Harmelin, 2002; Garrabou et al., 2017).

During recent years, Remotely Operated Vehicles (ROVs) started being employed to scout for exploitable beds (GFCM, 2017a), enhancing the accessibility also to deeper areas. However, their use presented different problems, from damages to benthic ecosystems (Western Pacific Regional Management Council (WPCouncil), 2007) to illegal remote-controlled harvesting (GFCM, 2010). The potential unregulated use of ROVs, even only for seabed exploration (i.e., prospection), was soon identified as a possible cause for a sudden and unsustainable increase in the amount of coral harvested (Tsounis et al., 2010, 2013; Bruckner, 2014). Therefore, as a precautionary principle, the use of ROVs in red coral fishery has been prohibited since 2011 in all the GFCM competence areas (GFCM, 2011) and is allowed only for scientific purposes, as a monitoring non-destructive tool to study the status of deep-sea coral (Bavestrello et al., 2014; GFCM, 2016, 2017b, 2019). However, to date, how the use of ROVs for seabed exploration might influence red coral catches has never been scientifically quantified. Despite the recommendation made by GFCM, its sustainability as prospection support is still a frequent matter of debate among fishermen and scientists (Cannas et al., 2019 and references therein).

While a regional adaptive management plan for red coral was established in 2017 (GFCM, 2017b), a recent workshop in 2019 (WKREDCORAL) urged the effective implementation of current measures to manage red coral (Food and Agriculture Organization, 2019a). Among tools already in force in fishery worldwide, the use of Onboard Scientific Observers (OSOs) has been recently proposed and recommended at different round tables also for red coral harvesting (Food and Agriculture Organization, 2019a; GFCM, 2019). However, it has not been included among the compulsory measures neither in national management nor in the recent GFCM pan-Mediterranean plan, possibly due to the lack of scientific data demonstrating their efficacy in red coral management. Observers at sea are specifically trained biologists officially in place for commercial and non-commercial fisheries worldwide to collect data on catch, bycatch, fishing effort, and impacts on protected species (Furlong and Martin, 2000; Porter, 2010; Faunce and Barbeaux, 2011; Brooke, 2012; Mangi et al., 2015; Gilman et al., 2017). They could represent a link between fishermen and scientists, thereby promoting communication and bridging existing gaps between science and policy (Cotter and Pilling, 2007; Gray and Kennelly, 2017).

The present research reports results from a first pilot study on *C. rubrum* harvesting based on the use of ROV as prospection support and Onboard Scientific Observers (OSOs). The monitoring campaign was carried out from 2012 to 2015 along the northwestern coast of Sardinia, which is documented among the most productive areas of red coral in the western Mediterranean Sea (Santangelo et al., 1993; Cannas et al., 2010; Cau et al., 2013; Cattaneo-Vietti et al., 2016). In order to conserve and sustainably exploit banks, since 1979, the

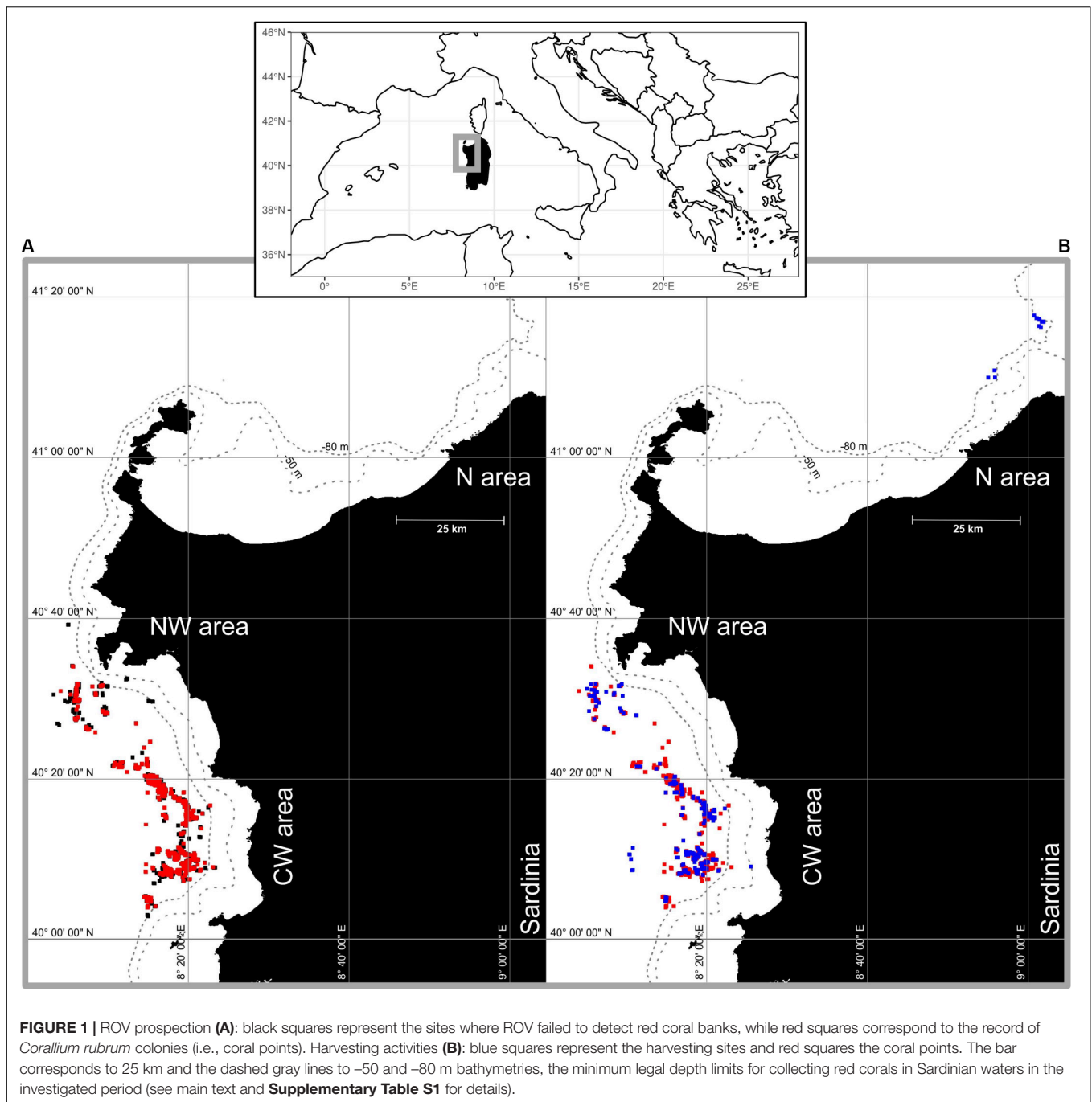
Autonomous Government of Sardinia has enacted specific measures to regulate harvesting: a licensing system, a restricted fishing period, a maximum daily quota ( $\leq 2.5$  kg/day per diver), and a minimum legal size of basal diameter (usually 10 mm with the exception of 2013, 8 mm; see **Supplementary Table S1**; Cannas et al., 2011; Cau et al., 2013; Follesa et al., 2013). The sustainable exploitation is the main aim of any management plan, even of those recently enacted for red coral harvesting (GFCM, 2017b, 2019). Furthermore, it is the inspiring principle of the FAO Code for Responsible Fisheries (Food and Agriculture Organization, 1995) as well as the objective of the European Common Fisheries Policy (CFP) for the conservation and sustainable exploitation of fisheries resources [Regulation (EU) No. 1380/2013]. We acknowledge that red coral is a slow growing, centennial species, with a time of recovery of decades after overexploitation (Cattaneo-Vietti et al., 2016; Cannas et al., 2019). However, we here use the term “sustainable” from a management point of view, for which sustainability is defined through three different perspectives: social, economic, and environmental (Food and Agriculture Organization, 2019b). In this framework, “sustainable” refers to the need to achieve a balance between fulfillment of both present and future human needs, i.e., social and economic demands, and the conservation of the natural resource (Caddy and Griffiths, 1995). In particular, our study aimed at providing valuable scientific data for an improved management of red coral, as indicated in paragraph 23 of the CFP: “The objective of sustainable exploitation of marine biological resources is more effectively achieved through a multiannual approach to fisheries management, establishing as a priority multiannual plans reflecting the specificities of different fisheries” (Regulation (EU) No. 1380/2013).

This study aims to assess the usefulness of ROVs for scouting red coral banks since their potential use as prospection support is still frequently debated, but no study has ever evaluated it so far. In order to do this, we tested as to whether sea bottom exploration carried out with ROV during routine harvesting practices might lead to an increase in the number of red coral banks found and in total catches. Besides this, we here aim to evaluate the effectiveness of onboard observers as science and monitoring tools in red coral harvesting campaigns since they have been recommended but not imposed yet by GFCM. To achieve this goal, data collected by OSOs are analyzed and compared with those available so far (i.e., logbooks). The outcomes of this study are discussed to evaluate the possible implementation of specific OSOs programs and their inclusion among mandatory measures in the adaptive management plan for the sustainable exploitation of red coral in the Mediterranean Sea (GFCM, 2017b, 2019; Cannas et al., 2019).

## MATERIALS AND METHODS

### Study Area

The scientific monitoring campaign was carried out during official *C. rubrum* harvesting seasons (usually from May/June to September/October, see **Supplementary Table S1**), from 2012



to 2015, in three areas located off the northern (N, off Santa Teresa di Gallura), northwestern (NW, off Alghero), and central-western (CW, off Bosa) coasts of Sardinia (Figure 1). The experimental campaign has been realized by the University of Cagliari and financed by the Autonomous Region of Sardinia, in order to acquire detailed scientific data on effort and respect of the management measures enacted in the competence area. Details on official harvesting seasons and the relative periods monitored by OSOs are indicated in **Supplementary Table S1**. A total of seven commercial boats and nine licensed SCUBA

divers were monitored by 21 OSOs. All the licensed SCUBA divers participated on a voluntary basis to the campaign, and only in presence of an observer, they could have the ROV on board and used it for prospection of red coral banks. During the official harvesting season, they could harvest red coral even in the absence of OSOs, providing that they disembarked the ROV and recorded the mandatory data on the logbook. OSOs were biologists and, before working onboard, attended a compulsory training course on data collection methods and procedures. Observers were extensively trained in measuring

red coral colonies and logging data in order to standardize and improve the validity and reliability of collected information.

During monitored days, the observers collected information on ROV activity as well as data on depth of dive, size, and weight of the catches for which local binding management measures exist (**Supplementary Table S1**).

## ROV Propection

Each boat used its own ROV: five boats used the model Prometeo by Elettronica Enne and one used Flat Platform6+ by the same manufacturer. OSOs recorded the operational time of each ROV deployment (deployment time) along with the number of sites explored using ROV (total points) and those characterized by red coral banks (coral points).

## Catch Recording and Sampling

For each harvesting dive, the observers recorded coordinates (not reported here for the privacy restrictions imposed by the financing authority), maximum depth, and total amount (kg) of coral harvested. In addition, they also measured the basal diameter (mm) of all the colonies, excluding those with broken bases. As prescribed in regional regulations (Regional Decree N. 1204/DecA/83 del 08.08.2012), the basal diameter was measured in the stem, in the mid between the base and the first branch. Weight of individual colonies were calculated from the diameter according to Follesa et al., 2013 ( $W = 0.4984D^{1.8356}$ , where  $W$  is the weight in g, and  $D$  the basal diameter in mm). Finally, each colony was labeled with a unique code and photographed for further checks and analyses of the branching pattern useful to infer population structure (Follesa et al., 2013). Small portions were also sampled and preserved in ethanol to be used for studies on reproduction, genetics, and growth.

## Observers' Data vs. Data From Logbook

Whenever possible the data collected by the observers were compared with those reported in logbooks, directly compiled by the divers and transmitted to the competent office (Source Regione Autonoma della Sardegna 2019, henceforth RAS, 2019). Only aggregated data by year were made available, including the total amount of coral caught for each season by all licensed divers, the minimum and maximum depth of exploitation dives, as well as the numbers of harvesting days at sea. Such data have been used, with permission of the competent authority, for the purpose of this study. Data related to single divers have not been included in this article for privacy reasons. Anyone interested in them can ask the access permission to the competent office (Servizio Pesca – Assessorato dell'Agricoltura e Riforma Agro-Pastorale – Regione Autonoma della Sardegna). As concerns the yield expressed as number of colonies/dive, these values were obtained from the observers' data for the period under investigation (2012–2015), while available in the logbooks only since 2016 and onward.

## Statistical Analyses

Data on ROV propection and catches, such as ROV deployment time, depth of dive, daily catch weight, and size of basal

diameter, were analyzed using R studio Desktop v1.1.456 (R Core Team, 2016) and XLSTAT-Base (2018). Once the assumption for normality was violated (Shapiro–Wilk test;  $P < 0.0001$ ), nonparametric tests were used to calculate the presence of significant differences among years, areas, boats, and divers using both pairwise (Kolgomorov–Smirnov test) and multiple pairwise comparisons (Kruskal–Wallis test and Steel–Dwass–Critchlow–Fligner procedure).

In order to evaluate the effect of ROV propection on red coral harvesting, we tested for a significant correlation between the number of hours that each boat invested in propection (i.e., ROV propection boat<sup>-1</sup>; h), and (i) the number of explored sites with red coral banks (i.e., n. coral points boat<sup>-1</sup>) and (ii) the weight catch per boat (catch boat<sup>-1</sup>; kg).

Finally, in order to ascertain the lack of biases due to differences between observers performing measurements, bi-plots of Canonical Analysis of Principal Coordinates (CAP) were prepared using Euclidean distance-based matrix and the routines included in the software PRIMER 6+ (Clarke and Gorley, 2006). The absence of segregation among points belonging to different a priori assigned categories (i.e., observers) and the elevated misclassification percentage allowed us to assess the absence of biases due to the factor “observer.”

## RESULTS

### Monitoring Data

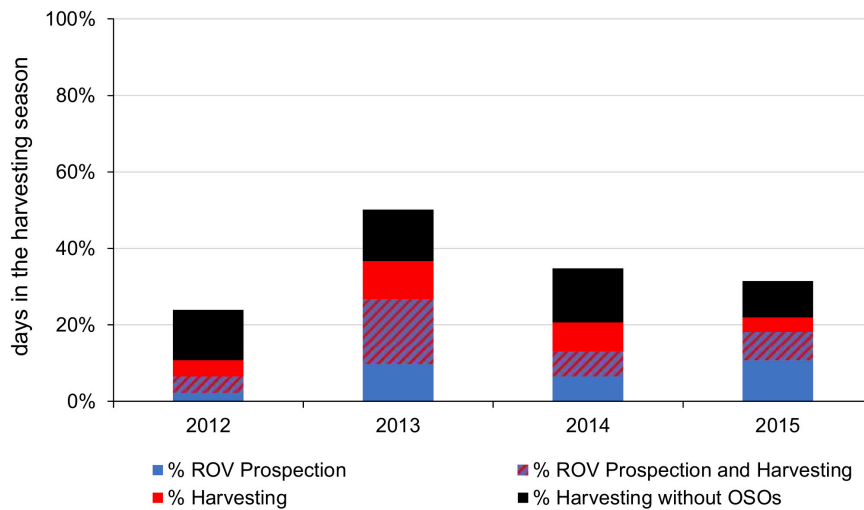
From 2012 to 2015, the divers were at sea, for ROV propection, harvesting, or both activities during 35% of the official harvesting season, considering both the days monitored by OSO and those not monitored but included in the logbooks. Operative days within a harvesting season reached a maximum of 50% in 2013 and a minimum of 25% in 2012 (**Figure 2**). Onboard Scientific Observers monitored more than half of operative days (65%). The total number of monitored days, considering all areas, were 509, whose 134 (26%) dedicated only to ROV propections, 137 (27%) to harvesting dives, and 238 (47%) to propection followed by a dive.

### ROV Propection

**Table 1** reported all the data related to ROV activity, such as the number of propection days, deployment time, total points surveyed, and those with red coral banks. Data on the use of ROV were acquired through a total of 351 valid propection days and a total deployment time of 514 h and 12 min.

During the study, the monitored boats deployed ROV for propection for 72% of the monitored days as average. The averaged percentage of the use of ROV for seafloor exploration increased during 4 years, with the lowest value (55%) registered in 2012 and the highest one (82%) in 2015. Conversely, the percentage of harvesting days decreased from 2012 (43%) to 2015 (18%).

The daily hours dedicated for propection increased during the study period, both as overall trend and per single boat. The average daily time (ROV hours day<sup>-1</sup>) was 1 h 27', ranging from 1 h 12' to 2 h 33' in 2013 and 2015, respectively (**Figure 3A**).



**FIGURE 2 |** Percentage of days in the harvesting season (2012–2015) dedicated to the different activities at sea.

**TABLE 1 |** ROV prospection.

Year	Boat	Total (valid) prospection days	ROV deployment time	Total points	Coral points
2012	Boat 2	22 (18)	16:45:00	159	97
	Boat 3	19 (19)	22:36:00	205	96
	Boat 4	13 (12)	33:41:00	309	120
	Boat 5	21 (21)	21:11:00	323	212
<b>Total 2012</b>		<b>75 (70)</b>	<b>94:13:00</b>	<b>996</b>	<b>525</b>
2013	Boat 2	54 (51)	35:25:00	404	218
	Boat 3	33 (21)	34:50:00	436	259
	Boat 4	46 (42)	94:54:00	897	455
	Boat 5	56 (56)	53:04:00	871	622
	Boat 7	38 (38)	36:53:00	341	125
<b>Total 2013</b>		<b>227 (208)</b>	<b>255:06:00</b>	<b>2949</b>	<b>1679</b>
2014	Boat 2	6 (6)	6:50:00	53	32
	Boat 3	6 (6)	9:17:00	121	71
<b>Total 2014</b>		<b>12 (12)</b>	<b>16:07:00</b>	<b>174</b>	<b>103</b>
2015	Boat 3	12 (12)	20:26:00	169	105
	Boat 4	25 (25)	85:00:00	806	426
	Boat 7	21 (21)	43:20:00	411	109
<b>Total 2015</b>		<b>58 (58)</b>	<b>148:46:00</b>	<b>1386</b>	<b>640</b>
<b>Total</b>		<b>377 (351)</b>	<b>514:12:00</b>	<b>5505</b>	<b>2947</b>

Year; monitored boat; number of days invested in prospection (valid data); operational time of ROV deployment; total number of surveyed points (total points); and those with red coral banks (coral points).

Considering each boat singularly, the lowest time dedicated to prospection was registered in 2013 for boat 2 (41 min) and the highest one (3 h 24') in 2015 for boat 4 (**Figure 3B**).

Overall, from 2012 to 2015, 5505 points were explored with ROV, whose more than half (54%), as average, were characterized by red coral banks (coral points). We found a significant correlation between hours invested to exploring sea bottom by each boat (ROV prospection boat<sup>-1</sup>) and the number of points

found with red coral banks (n. coral points boat<sup>-1</sup>; **Figure 4A**). In addition, also the total weight of catches per boat (catch boat<sup>-1</sup>) increased with the increase in time dedicated to ROV prospection (**Figure 4B**).

## Catch Monitoring

Total monitored harvesting dives were 463 and have been realized outside the interdicted areas identified by the Sardinian regulation. Data related to number of dives, total amount (weight) of red coral harvested, total number of red coral colonies collected, and those measured are reported in **Table 2**.

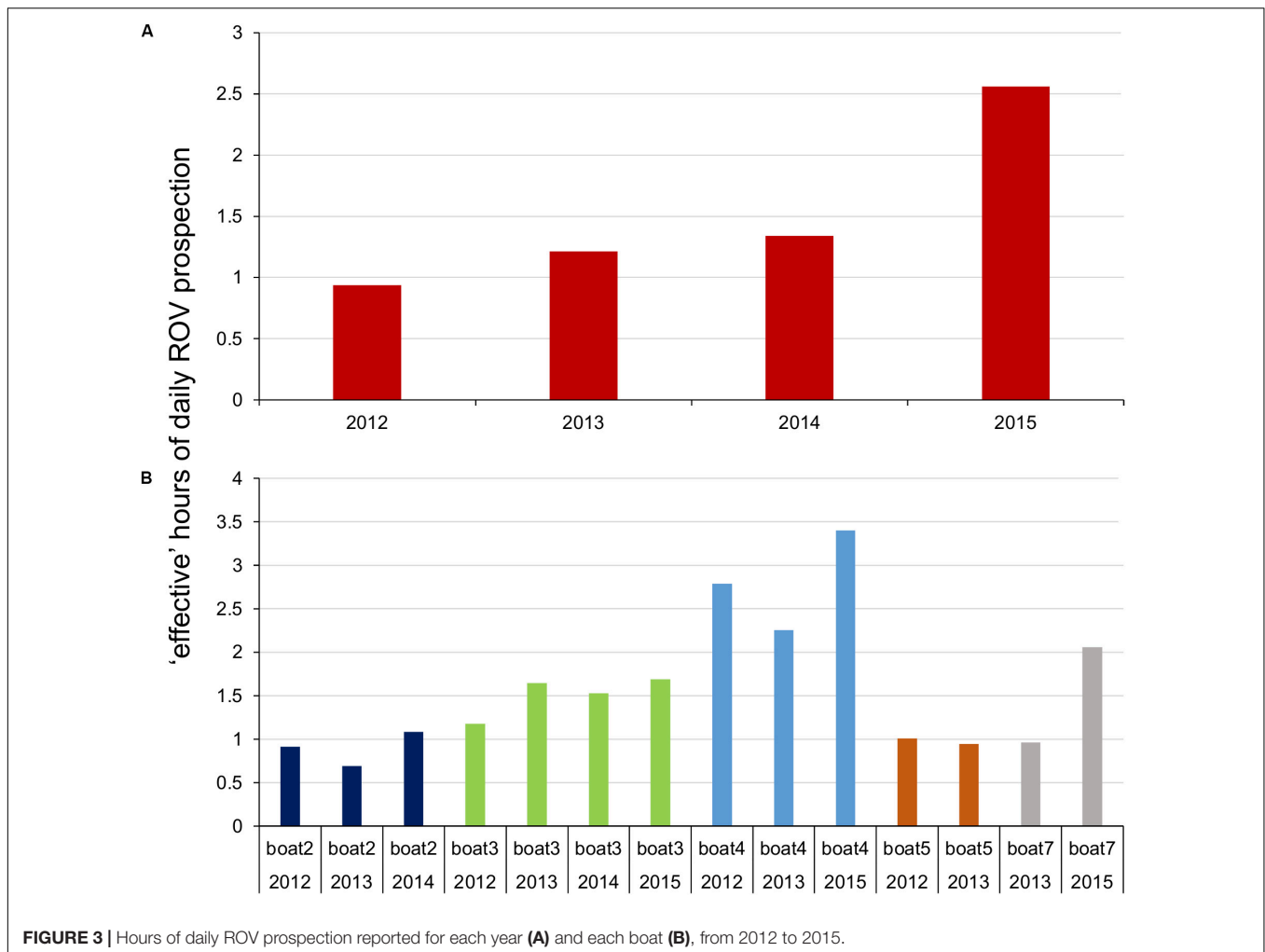
## Depth

Overall, depth of dives ranged from 59 m (recorded in 2013) to 135 m (in 2015; **Figure 5A**). Two dives were performed outside the legal limit of 80 m, at the very beginning of the 2013 harvesting season. The depth of dive significantly varied across areas and years (see **Supplementary Data** and **Supplementary Table S2**). Dives performed off the northern coast were significantly shallower than those performed off the CW and NW coasts. The depth of dives significantly changed also among different years in the same area: dives performed in 2015 off the CW coast were significantly deeper than those carried out in 2012 in the same area.

## Weight

A total of 1355 kg of red coral colonies were collected during the monitored days. The amount of coral taken in each dive ranged from 0.15 to 12 kg in 2013 and 2015, respectively, both in CW area (**Figure 5B**). The weight of red coral colonies collected was significantly different for the investigated temporal and spatial factors (see **Supplementary Data** and **Supplementary Table S3**).

The limit of 2.5 kg coral/day per diver has exceeded >40% of times as average. Such percentage ranged from 5 to 73% of dives in 2013 in NW and CW area, respectively (**Figure 6A**).



**FIGURE 3** | Hours of daily ROV prospection reported for each year (A) and each boat (B), from 2012 to 2015.

The weight of the harvested coral was measured onboard, after the dive, and thus can be overestimated, because colonies could be still wet and not completely clean of the rocky substrate and epibionts. When considering a tolerance of 20% in weight due to the uncomplete clearness of the colony, the percentage of dives exceeded 3 kg weight/day limit was still high, > 30% on average, ranging from 0 to 57% in 2013 in NW and CW area, respectively.

### Size

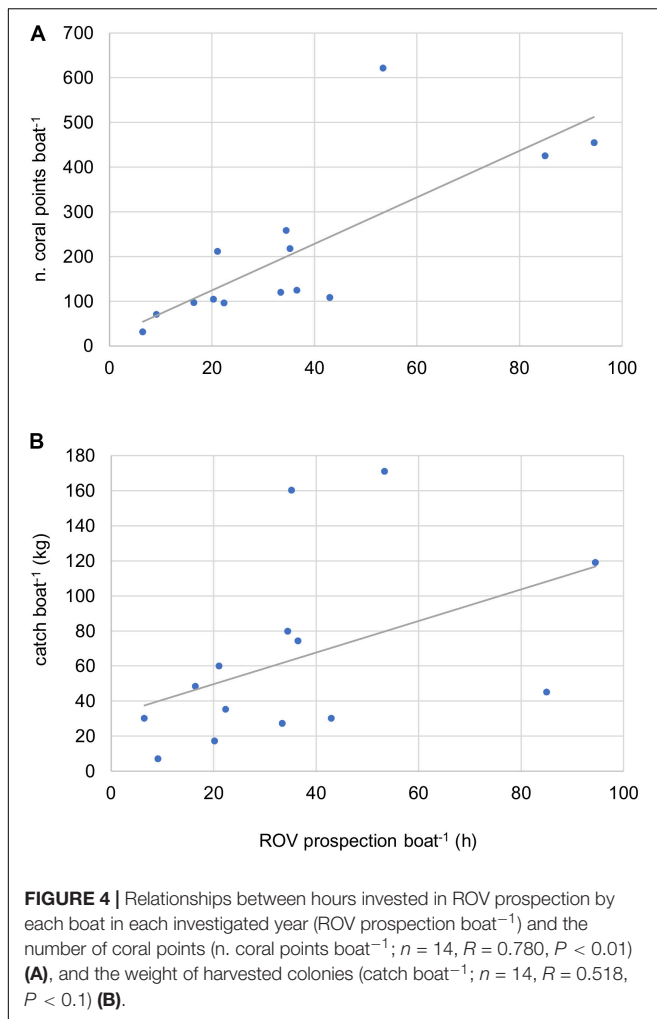
A total of 19667 red coral colonies were collected, whose 18333 had intact basal and thus have been measured. The basal diameter ranged from 2 mm to a maximum of 37.7 mm both in CW area in 2014 (Figure 5C). The size of basal diameter was significantly different across years and areas (see Supplementary Data and Supplementary Table S4).

The limit of 10 mm of basal diameter was complied with only half of the harvested colonies, as average, with the lowest value recorded off the N coast, where only 20% of the collected colonies were of the allowed size (Figure 6B). Under water, the size of corals is difficult to appreciate especially by divers plunging at deeper depth. Furthermore, the measurement is subjected to additional errors due to the shrinkage of the coenenchyma (living

tissue) as the colonies dry. Even when considering a tolerance of 20% in the measurement of basal diameter, allowing the harvesting of colonies up to 8 mm, the percentage of undersized colonies was high, being 20% on average and ranging from 9 to 42% in 2015 (NW) and 2012 (N), respectively. Colonies whose diameter was lower than 7 mm (i.e., minimum conservation reference size imposed by GFCM, 2019) were 8.5% of the total harvested colonies. Such percentage ranged from 2 to 20% in 2015 (NW) and 2012 (N), respectively. However, if the amount of undersized colonies is expressed as percentage in weight (as in the GFCM plan), it totaled only 3.4% of the total catches.

### Comparisons Between Observers' and Logbook Data

Table 3 shows the data derived from logbooks, compulsory compiled by the licensed SCUBA divers and transmitted to the competent authority at the end of each harvesting season. Overall, all the divers involved in the campaign reported deeper dives and higher kg/dive values than the ones not participating and hence not using the ROV. In addition, mean values of coral kg caught per dive (mean W/D) reported in logbooks (Table 3)



were much lower than the ones recorded by the observers on board (Table 2). As concerns the number of colonies caught per dive, the values recorded by OSOs for the divers involved in the project were almost double (on average  $39 \pm 10$ ) than the ones they included in the logbooks (on average  $22 \pm 16$ ; source RAS, 2019).

## DISCUSSION

During recent years, a variety of scientific surveys demonstrated the status of overexploitation for *C. rubrum* in some areas of the Mediterranean Sea (Santangelo et al., 2007; Tsounis et al., 2007; Santangelo and Bramanti, 2010), even if data reported so far confirmed that measures enacted in Sardinia have guaranteed a sustainable management (Follesa et al., 2013; Cannas et al., 2015, 2016). Given the concerns regarding red coral fishery, US and EU proposed to include the genus *Corallium* in Appendix II of the CITES in 2007 and in 2009, but both proposals were not accepted, based on the expectation that local measures could be more efficient (Food and Agriculture Organization, 2009, 2010; Cannas et al., 2019).

**TABLE 2 |** Catch monitoring.

Year	Boat	SCUBA diver	Area	nD	tW	nC	nM	Mean W/D	Mean C/D
2012	Boat 1	A	N	15	36.7	1180	1180	2.4	79
	Boat 1	B	N	15	36.1	1095	1095	2.4	73
	Boat 2	C	CW	20	48.4	556	516	2.4	28
	Boat 3	D	CW	15	35.2	421	356	2.3	28
	Boat 4	E	CW	12	31.8	564	521	2.7	47
	Boat 4	F	CW	10	22.8	487	459	2.3	49
	Boat 5	G	CW	24	62.3	894	806	2.6	37
	Boat 5	H	CW	16	57.2	781	664	3.6	49
<b>Total 2012</b>				<b>127</b>	<b>330.5</b>	<b>5978</b>	<b>5597</b>	<b>2.6</b>	<b>47</b>
2013	Boat 2	C	CW	58	160.2	1883	1675	2.8	33
	Boat 3	D	CW	28	79.8	951	880	2.9	34
	Boat 4	E	CW	26	128.2	1397	1020	4.9	54
	Boat 4	F	CW	25	110.7	1163	1376	4.4	47
	Boat 5	G	CW	65	226.6	1676	3116	3.5	26
	Boat 5	H	CW	40	115.2	3258	1541	2.9	82
	Boat 7	J	NW	45	74.3	1623	1399	1.7	37
<b>Total 2013</b>				<b>287</b>	<b>895</b>	<b>11951</b>	<b>11007</b>	<b>3.1</b>	<b>42</b>
2014	Boat 2	C	CW	9	30.1	299	295	3.3	33
	Boat 3	D	CW	4	7	78	77	1.8	20
<b>Total 2014</b>				<b>13</b>	<b>37.1</b>	<b>377</b>	<b>372</b>	<b>2.9</b>	<b>29</b>
2015	Boat 3	D	CW	10	17.2	294	292	1.7	29
	Boat 4	F	CW	11	45	562	561	4.1	51
	Boat 7	J	NW	15	30.2	505	504	2.0	34
<b>Total 2015</b>				<b>36</b>	<b>92.4</b>	<b>1361</b>	<b>1357</b>	<b>2.6</b>	<b>38</b>

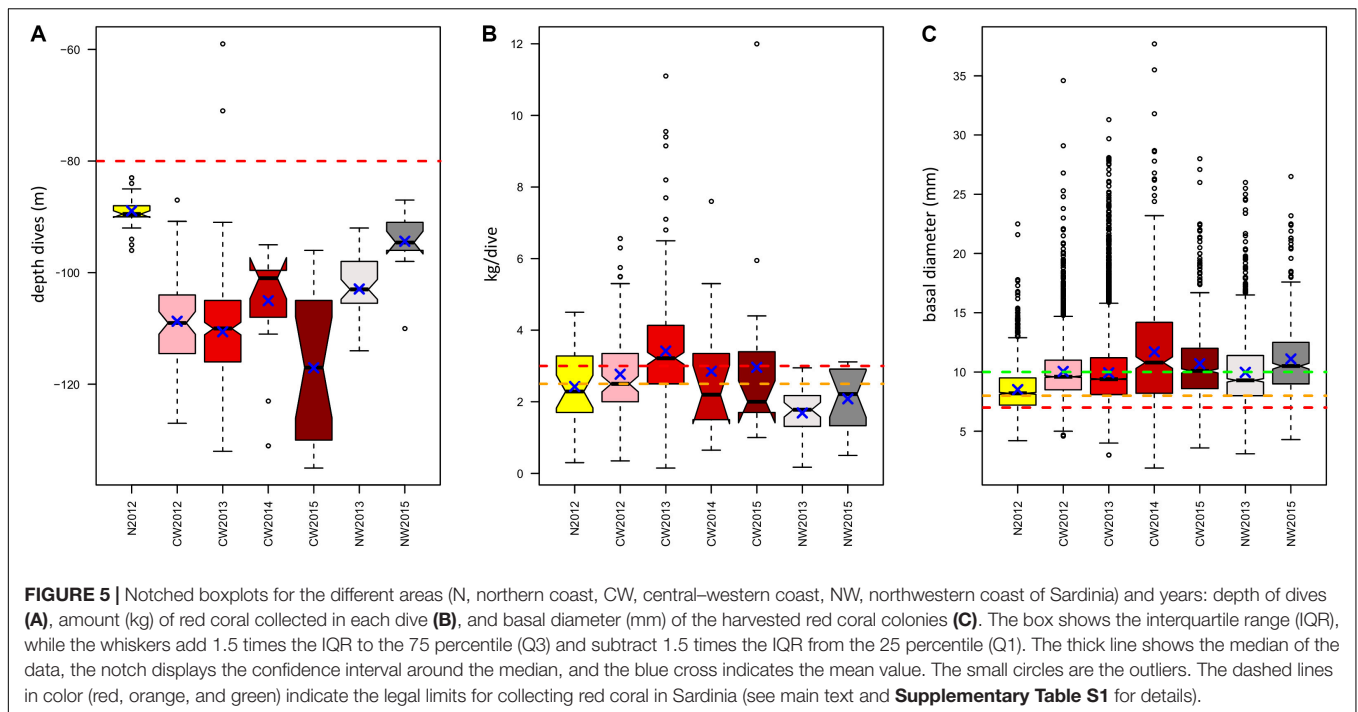
Year; monitored boat; SCUBA diver; area (N, northern Sardinian coast, CW, central-western Sardinian coast, NW, northwestern Sardinian coast); nD, total number of dives; tW, total weight of red coral harvested (kg); nC, total number of red coral colonies collected; nM, total number of red coral colonies collected and measured; mean W/D, mean weight of red coral caught per dive (kg); mean C/D, mean number of colonies caught per dive.

Following these indications, the GFCM has recently established a pan-Mediterranean management plan for the exploitation of red coral in the Mediterranean Sea (GFCM, 2017b, 2019). Actually, in Sardinia, stricter measures than the ones imposed by GFCM have been in place since 1979 (Cannas et al., 2019).

This study provides pivotal information for the management and conservation of Mediterranean red coral banks. Our results demonstrate, on the one hand, how ROVs prospection for red coral harvesting may lead to an increase in catches and, on the other hand, emphasize how current management measures could be strengthened through the mandatory use of Onboard Scientific Observers.

## ROV Prospection

Since 2011, a precautionary prohibition of the use of ROVs for red coral harvesting has been imposed on the whole GFCM competence area, based on the assumption that the use of ROV can increase the yield per dive (Tsounis et al., 2010, 2013;



GFCM, 2011), which, however, has never been scientifically demonstrated. During our study, ROVs were exceptionally allowed to be used for seabed exploration prior to dives for the scientific purposes outlined above, namely, to measure the effects of its prospection support on catches.

In our research, ROVs were used extensively, being a valid tool for the efficient and quick search of a “suitable” bank to harvest. However, it is noteworthy to remember that, despite the nominal length of the harvesting season is of several months, the effective “productive” days at sea represented ca. a third of the available days (Figure 2), due to inherent limits imposed by the weather conditions and the human physiology (divers cannot dive at great depths, such as the ones where commercial banks dwell, every single day and/or in bad weather conditions).

Our results showed how the daily time dedicated to underwater prospection and location of the red coral banks increased throughout the studied period, with a peak in 2015. Conversely, the percentage of days spent for harvesting activities decreased. It is premature to describe this as a general trend, considering the limited number of years included in the experimental campaign and the restricted number of divers that voluntarily participated in it. Moreover, our results highlighted that professional divers differed in their behavior regarding the time spent in ROV prospection: some boats (i.e., boat 3 and 4 all monitored years and boat 7 in 2015; Figure 3B) invested more hours in exploration than others, probably because they were scouting for “less known” sites in deeper or “never-exploited” areas. Therefore, it could be difficult to identify a unique driving cause for the observed data. If we consider the overall pattern (i.e., more time spent in prospections and less in dives that are deeper and deeper), this could be interpreted in two opposite ways. On the one

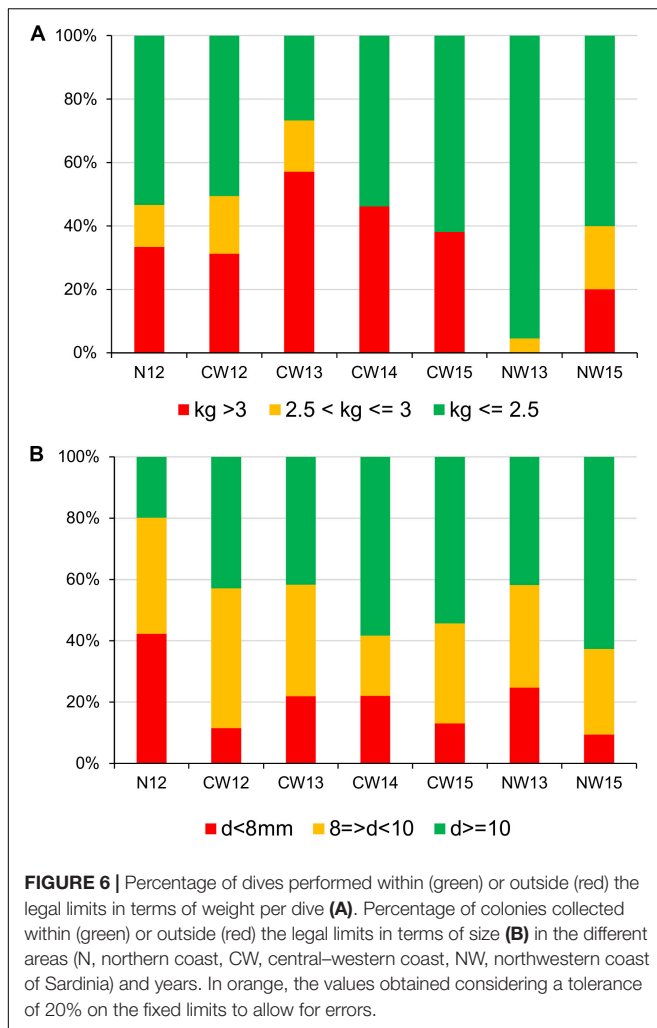
hand, throughout the years, divers progressively understood the importance of spending more time in ROV-guided prospections to avoid plunges in smaller banks and to make more selective and profitable dives in larger and denser ones, decreasing the proportion of time dedicated to harvesting. On the other hand, more time dedicated to ROV-scouting could be instead the consequence of the rarefaction of banks, which are found with increasing difficulty and only in deeper areas. The most valid explanation is probably a combination of these two opposite views: ROV is increasingly used by divers because it allows them to have shorter and safer dives, reducing the time spent underwater in a very risky activity, but our results could also suggest a decreasing availability of shallower exploitable banks in some areas. More data, from a larger number of divers and areas, extending the monitoring over more years, are needed to have a clearer picture and to draw definitive conclusions.

In our study, the usefulness of ROV for prospection has been confirmed by the significant correlation we found between hours dedicated to exploring seabed and the number of coral points, as well as the increase in catches per boat with time spent for prospection. Therefore, our data indicated that the use of ROV eases the identification of relevant exploitable red coral banks and permits an increase in catches, often above the allowed daily quota. OSOs reported indeed that 30% of these catches were above the limits, emphasizing that the use of ROVs, even only for seabed exploration, could lead to a serious risk of overexploitation.

## Catch Monitoring

In 2012, the GFCM put in place a series of measures, including the establishment of its own data collection protocol to obtain data





on red coral annual landings from the national administrations of member countries (GFCM, 2012; Cannas et al., 2019). The Autonomous Region of Sardinia started collecting information on catches through logbooks in 1996. Later, in 2017, the established GFCM management plan for red coral in the Mediterranean Sea imposed also that member states shall establish a system of daily and/or annual catch limitation in

order to keep harvesting within “biologically sustainable levels” (GFCM, 2017b). Despite measures imposed so far, experts and scientists suggested that current management plan for red coral should be enforced with more effective tools (Food and Agriculture Organization, 2019a). The use of onboard observers has been recommended but not imposed yet to collect scientific information on red coral harvesting in the Mediterranean (GFCM, 2019). We here report, for the first time, data collected by OSOs on red coral harvesting, comparing them with those available so far in order to evaluate their effectiveness as science and monitoring tools.

Onboard Scientific Observers reported that licensed divers, despite respecting the upper depth limit, plunged deeper and deeper over the years, especially in CW area. This result could be explained considering that the use of ROV helped divers to scout “suitable” banks, especially those dwelling in deeper waters, which are more difficult to find without a ROV presurvey. These are expected to host larger colonies of higher commercial values (Rossi et al., 2008), as previously reported for the CW coast of Sardinia, where deep-sea banks are mostly constituted (38%) by larger colonies (>10 mm basal diameter; Cannas et al., 2010), thus inducing divers to perform deeper dives. Data reported by OSOs further highlighted that fishermen disregarded the limits imposed by the Autonomous Region of Sardinia regarding the weight of catch per day, for >30% of the dives. A peak was registered in CW area in 2013 where >3 kg/dive of red coral were collected during half of the monitored dives. Also, the analysis of the size of the basal diameter pinpointed how about 20% of the harvested colonies had a basal diameter <8 mm, and about 8.5% were <7 mm in diameter. Considering the harvest control rule recently imposed by GFCM (2019), when the percentage of undersized colonies (<7 mm) overpass 10% in weight of the catch, controls and surveys of population size structure should be implemented. Our data indicated that in Sardinia we are far below the GFCM threshold (only 3.5% in weight of red corals were undersized), confirming that the levels of exploitation are still under control. We report here both values (% in number and % in weight of undersized colonies of the total catch) also to highlight the difference between them. To monitor the structure of the population and document the shift of the size distribution in case of depletion, we believe that the proper indicator is the number of small colonies in the catch. Furthermore, from a management perspective, it represents a

**TABLE 3 |** Logbook data.

Year	Divers not in the campaign				Divers in the campaign			
	Depth (min; max)	nD	tW	Mean W/D	Depth (min; max)	nD	tW	Mean W/D
2012	16; 112	191	246.3	1.3	80; 130	322	558.5	1.7
2013	80; 110	501	623.7	1.2	59; 132	434	535.2	1.2
2014	50; 82	43	57.0	1.3	95; 131	26	42.0	1.6
2015	65; 103	275	357.8	1.3	87; 135	67	117.2	1.7

The first four columns show the data regarding divers active in a given year but not involved in the experiment, while the last four columns show the data for the divers participating in the monitoring campaign. Depth, minimum and maximum depth of the exploitation dives (m); nD, number of dives; tW, total weight of red coral caught (kg); mean W/D, mean weight of red coral caught per dive (kg).

more sensitive and conservative limit, as a sort of early warning of potentially dangerous changes in the population in response to an excessive exploitation. On the contrary, the 10% limit in weight could be reached too late, when the population is already “suffering,” being composed of only a few medium colonies and the majority of small corals.

Anyhow, these results (i.e., the documented fraction of undersized colonies, especially in some areas) should raise awareness regarding the conservation status of red coral populations and the need to enforce all the current MCS measures as well as to implement new ones. In order to guarantee the sustainable exploitation previously described for the study area, there is the need to increase the knowledge on the size structure of the exploited populations. Size parameters have been proved to be crucial to assess the status of precious corals and to develop sustainable fishery management plans (Montero-Serra et al., 2015; Cannas et al., 2019). In this framework, the measure of the individual size of colonies collected by OSOs and thus the implementation of OSOs programs should be pivotal to acquiring such data, enforcing the harvest control rule and guaranteeing the sustainable exploitation of the resource.

Our results also highlighted that the weight of catches per dive was underestimated in logbooks (Table 3; on average 1.55 kg dive<sup>-1</sup>) compared to actual catches (Table 2; on average 2.84 kg dive<sup>-1</sup>). Onboard observers recorded also a higher number of colonies caught in each of the dives performed during 2012–2015 campaigns, compared to logbook data for the following seasons (2016 and 2017), when the experiment was over and in addition, they were no longer allowed to use ROV. Logbooks are self-certifications, whose validity and reliability are often questioned and need to be validated. Besides logbooks, harvest statistics for *C. rubrum* in Sardinia have also been reported in the FAO global capture database, since the late 1970s. Such data have been mainly provided by red coral import–export and jewelry production wholesalers (Cannas et al., 2019 and reference therein), and therefore, they could present shortcomings and should be considered cautiously (e.g., possible conflict of interest for an industry data provider; some data may refer to trade information rather than to actual annual harvest). Comparing data on harvested weight reported in logbooks and in the FAO database, for Sardinia, between 2012 and 2015, we found that total red coral catches declared in logbooks were about 2.5 tons (RAS, 2019), which was around 16 times less than that reported in the FAO dataset (40.2 tons). A similar trend has been reported also for other countries exploiting red coral (Cannas et al., 2019). Even if the FAO data are eventually overestimated because of mixing trade and fishery data, the values reported in the logbooks are underestimated. This is a common trend in fishery worldwide: recent studies showed indeed that logbook data of recreational and non-recreational fisheries did not adequately report catches and thus cannot be trustable alone to estimate total catch (Faunce, 2011; Uhlmann et al., 2014; Gray and Kennelly, 2017; Schewe and Dutton, 2018).

Results reported here should raise awareness considering that the only data available so far for red coral harvesting are those reported in logbooks by divers or in the FAO dataset by traders.

Our results confirmed how at-sea observers, and the important data they collect, could represent a further step towards a more efficient management also for precious coral fisheries (Cannas et al., 2019). Scientific observers onboard proved to be an efficient data source to validate information reported in logbooks and/or to implement them, i.e., recording not only the total weight and the percentage of undersized colonies in weight, as it is now mandatory in the GFCM data collection system, but also their individual sizes. Such data are essential, otherwise, the progressive shift of harvesting pressure to younger age classes could be unnoticed.

The need to develop and include OSOs programs among mandatory measures for red coral harvesting is of paramount importance and evident urgency, in order to collect reliable information and to enforce any sound management plan.

## CONCLUSION

This study provided evidence of how, even in controlled conditions (i.e., with OSOs), ROV proved to be a useful support for scouting and reducing the “searching” phase on the one hand, but also the cause of an increase in catches. Our results confirmed the relevance of the decision made by GFCM in 2011 regarding the prohibition of using ROV even for seabed exploration, since its use, especially in uncontrolled conditions (i.e., without OSOs), could lead to a shift toward a non-sustainable exploitation.

Onboard Scientific Observers demonstrated to be a valid and irreplaceable tool in drawing a truthful picture of the Mediterranean red coral fishery. OSOs reported the occurrence of undersized colonies and amounts of harvested corals above the limits imposed by the local regulations. In addition, data on weight catch reported in logbooks were underestimated compared to those reported by OSOs.

As recently stated in different GFCM meetings and reports, the enforcement of the current MCS system with the adoption of new, additional monitoring control and surveillance measures should be of high priority. Among them, official onboard observer programs should be developed and included among mandatory measures for all countries involved in red coral harvesting, also considering the recent implementation of the management plan for the Mediterranean Sea and the need to have trustable yield data for the whole basin. Besides this, the evaluation of the status of the resource is mandatory in order to adjust fishermen needs and management policies to scientific evidence. A high level of mutual respect between fishermen, politicians, and researchers could support the collection of high-quality data facilitating the sustainable exploitation of Mediterranean precious coral.

## DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because restrictions apply to the availability of these data, which

were used under license for this study. Requests to access the datasets should be directed to “Servizio Pesca – Assessorato dell’Agricoltura e Riforma Agro-Pastorale – Regione Autonoma della Sardegna.”

## AUTHOR CONTRIBUTIONS

RC contributed to the conception and design of the study. RC, LC, and AC organized the database, performed the statistical analysis, and wrote the first draft of the manuscript. All authors read, reviewed, and approved the submitted version.

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## REFERENCES

- Bavestrello, G., Abbiati, M., Angiolillo, M., Betti, F., Bo, M., Canese, S., et al. (2014). “Remotely operated vehicles (ROVs) as powerful tools for the evaluation of the conservation status of deep red coral banks in UNEP/MAP-RAC/SPA,” in *Proceedings of the Second Mediterranean Symposium On The Conservation Of Coralligenous And Other Calcareous Bio-Concretions*, Portoroz.
- Brooke, S. G. (2012). Federal fishery observer programs in the United States: over 40 years of independent data collection. *Mar. Fish. Rev.* 76, 1–38. doi: 10.7755/mfr.76.3.1
- Bruckner, A. W. (2014). Advances in management of precious corals in the family corallidae: are new measures adequate? *Curr. Opin. Environ. Sustain.* 7, 1–8. doi: 10.1016/j.cosust.2013.11.024
- Caddy, J. F., and Griffiths, R. C. (1995). *Living Marine Resources And Their Sustainable Development: Some Environmental And Institutional Perspectives*. FAO Fisheries Technical Paper. No. 353. Rome: FAO.
- Cannas, R., Caocci, F., Follesa, M. C., Grazioli, E., Pedoni, C., Pesci, P., et al. (2010). “Multidisciplinary data on the status of red coral (*Corallium rubrum*) resource in Sardinian seas (central western Mediterranean),” in *Proceedings of the International Workshop on Red Coral Science, Management, and Trade: Lessons from the Mediterranean NOAA Technical Memorandum CRCP-12*. NOAA, Silver Springs, MD.
- Cannas, R., Caocci, F., Follesa, M. C., Pedoni, C., Pendugiu, A. A., Pesci, P., et al. (2011). The red coral resource in Sardinian seas: a multidisciplinary survey on *Corallium rubrum* populations. *Studi Trent. Scienze Nat.* 89, 9–18.
- Cannas, R., Follesa, M. C., Cau, A., Cau, A., and Friedman, K. (2019). *Global Report on the Biology, Fishery and Trade of Precious Corals*. FAO Fisheries and Aquaculture Circular No. 1184. Rome: FAO.
- Cannas, R., Sacco, F., Cau, A., Coluccia, E., Follesa, M. C., and Cau, A. (2015). New insights into connectivity patterns of mesophotic red coral (*Corallium rubrum*) populations. *Hydrobiologia* 759, 63–73. doi: 10.1007/s10750-015-2198-0
- Cannas, R., Sacco, F., Cau, A., Cuccu, D., Follesa, M. C., and Cau, A. (2016). Genetic monitoring of deep-water exploited banks of the precious Sardinia coral *Corallium rubrum* (L., 1758): useful data for a sustainable management. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 26, 236–250. doi: 10.1002/aqc.2522
- Cattaneo-Vietti, R., Bo, M., Cannas, R., Cau, A., Follesa, C., Meliàdò, E., et al. (2016). An overexploited Italian treasure: past and present distribution and exploitation of the precious red coral *Corallium rubrum* (L., 1758) (Cnidaria: Anthozoa) Italian. *J. Zool.* 83, 443–455. doi: 10.1080/11250003.2016.1255788

of the manuscript; and in the decision to submit the article for publication.

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## SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2020.00482/full#supplementary-material>

- Cau, A., Bramanti, L., Cannas, R., Follesa, M. C., Angiolillo, M., Canese, S., et al. (2016). Habitat constraints and self-thinning shape Mediterranean red coral deep population structure: implications for conservation practice. *Sci. Rep.* 6:23322.
- Cau, A., Cannas, R., Sacco, F., and Follesa, M. C. (2013). *Adaptive Management Plan For Red Coral (Corallium rubrum) in the GFCM Competence Area*. Rome: FAO.
- Cau, A., Paliaga, E. M., Cannas, R., Deiana, G., Follesa, M. C., Sacco, F., et al. (2015). Preliminary data on habitat characterization relevance for red coral conservation and management. *Itali. J. Geosci.* 134, 60–68. doi: 10.3301/ijg.2014.40
- Clarke, K. R., and Gorley, R. N. (2006). *PRIMER v6: User Manual/Tutorial*. Plymouth: Primer-E, Ltd.
- Costantini, F., Taviani, M., Remia, A., Pintus, E., Schembri, P. J., and Abbiati, M. (2010). Deep-water *Corallium rubrum* (L., 1758) from the mediterranean sea: preliminary genetic characterisation. *Mar. Ecol. Prog. Ser.* 31, 261–269. doi: 10.1111/j.1439-0485.2009.00333.x
- Cotter, A. J. R., and Pilling, G. M. (2007). Landings, logbooks and observer surveys: improving the protocols for sampling commercial fisheries. *Fish. Fish.* 8, 123–152. doi: 10.1111/j.1467-2679.2007.00241.x
- Faunce, C. H. (2011). A comparison between industry and observer catch compositions within the Gulf of Alaska rockfish fishery. *ICES J. Mar. Sci.* 68, 1769–1777. doi: 10.1093/icesjms/fsr093
- Faunce, C. H., and Barbeaux, S. J. (2011). The frequency and quantity of Alaskan groundfish catcher-vessel landings made with and without an observer. *ICES J. Mar. Sci.* 68, 1757–1763. doi: 10.1093/icesjms/fsr090
- Follesa, M. C., Cannas, R., Cau, A., Pedoni, C., Pesci, P., and Cau, A. (2013). Deep-water red coral from the island of Sardinia (north-western Mediterranean): a local example of sustainable management. *Mar. Freshw. Res.* 64, 706–715.
- Food and Agriculture Organization (1995). *Code of Conduct for Responsible Fisheries Rome*. Rome: FAO.
- Food and Agriculture Organization (2009). *Fisheries Advisory Panel Offers Recommendations on CITES Proposals*. Rome: Food and Agriculture Organization.
- Food and Agriculture Organization (2010). *Update on the 15th CITES Conference For Parties 13–25 March 2010, Doha, Qatar. Committee on fisheries sub-Committee On Fish Trade. Twelfth Session, Buenos Aires, Argentina, 26–30 April 2010*. Rome: Food and Agriculture Organization.

- Food and Agriculture Organization (2019a). *General Fisheries Commission for the Mediterranean. Report of the Twenty-First Session of the Scientific Advisory Committee on Fisheries, Cairo, Egypt, 24–27 June 2019 / Commission générale des Pêches Pour La Méditerranée. Rapport de la vingt-et-unième Session du Comité Scientifique Consultative Des Pêches. Le Caire, Égypte, 24–27 juin 2019*. FAO Fisheries and Aquaculture Report/FAO Rapport Sur Les Pêches et l'aquaculture No. 1290. Rome: FAO.
- Food and Agriculture Organization (2019b). *International Symposium on Fisheries Sustainability: Strengthening the Science-Policy Nexus*. Rome: FAO.
- Furlong, W. J., and Martin, P. M. (2000). "Observer deployment in the fishery and regulatory self-enforcement. in: microbehavior and macroresults," in *Proceedings of the Tenth Biennial Conference of the International Institute of Fisheries Economics and Trade, July 10–14, 2000, Compiled by Richard S. Johnston and Ann L. Shriver. International Institute of Fisheries Economics and Trade (IIFET), Corvallis, 2001, Corvallis*.
- Garrabou, J., and Harmelin, J. G. (2002). A 20-year study on life-history traits of a harvested long-lived temperate coral in the NW Mediterranean: insights into conservation and management needs. *J. Anim. Ecol.* 71, 966–978. doi: 10.1046/j.1365-2656.2002.00661.x
- Garrabou, J., Sala, E., Linares, C., Ledoux, J. B., Montero-Serra, I., Dominici, J. M., et al. (2017). Re-shifting the ecological baseline for the overexploited Mediterranean red coral. *Sci. Rep.* 7:42404.
- GFCM (2010). *General Fisheries Commission for the Mediterranean, Scientific Advisory Committee (SAC). Thirteenth Session Marseille, France, 7–11 February 2011 Report of the Transversal workshop on red coral Alghero*. Sardinia: GFCM.
- GFCM (2011). Recommendation GFCM/35/2011/2 on the Exploitation Of Red Coral In The GFCM Area Of Application. Available online at: <http://www.fao.org/3/a-ax376e.pdf> (accessed October 24, 2019).
- GFCM (2012). Recommendation GFCM/36/2012/1 on Further Measures For The Exploitation Of Red Coral in the GFCM Area Of Application. Available online at: <http://www.fao.org/3/a-ax387e.pdf> (accessed October 24, 2019).
- GFCM (2016). Recommendation GFCM/40/2016/7 Concerning The Authorization Of The Use Of Remotely Operated Vehicles Within The Framework Of National Scientific Research Programmes On Red Coral. Available online at: <http://www.fao.org/3/a-i6700e.pdf> (accessed October 24, 2019).
- GFCM (2017a). *General Fisheries Commission for the Mediterranean, Scientific Advisory Committee (SAC). Report of THE WORKSHOP ON RED CORAL (WKREDCORAL)*. Gammarth: GFCM.
- GFCM (2017b). Recommendation GFCM/41/2017/5 on the Establishment Of A Regional Adaptive Management Plan For The Exploitation Of Red Coral In The Mediterranean Sea. Available online at: <http://www.fao.org/3/I8500EN/i8500en.pdf> (accessed October 24, 2019).
- GFCM (2019). Recommendation GFCM/43/2019/4 on a Management Plan For The Sustainable Exploitation Of Red Coral In The Mediterranean Sea. Available online at: <http://www.fao.org/3/ca4047en/ca4047en.pdf> (accessed March 11, 2020).
- Gilman, E., Weijerman, M., and Suuronen, P. (2017). Ecological data from observer programmes underpin ecosystem-based fisheries management. *ICES J. Mar. Sci.* 74, 1481–1495. doi: 10.1093/icesjms/fsx032
- Gray, C. A., and Kennelly, S. J. (2017). Evaluation of observer-and industry-based catch data in a recreational charter fishery. *Fish. Manag. Ecol.* 24, 126–138. doi: 10.1111/fme.12210
- Knittweis, L., Aguilar, R., Alvarez, H., Borg, J. A., Evans, J., Garcia, S., et al. (2016). New depth record of the precious red coral *Corallium rubrum* for the Mediterranean. *Rapp. Comm. Int. Mer. Méditerranée*. 41:463.
- Mangi, S. C., Dolder, P. J., Catchpole, T. L., Rodmell, D., and de Rozarieux, N. (2015). Approaches to fully documented fisheries: practical issues and stakeholder perceptions. *Fish Fish.* 16, 426–452. doi: 10.1111/faf.12065
- Montero-Serra, I., Linares, C., García, M., Pancaldi, F., Frleta-Valiç, M., Ledoux, J. B., et al. (2015). Harvesting effects, recovery mechanisms, and management strategies for a long-lived and structural precious coral. *PLoS One* 10:e0117250. doi: 10.1371/journal.pone.0117250
- Porter, R. D. (2010). Fisheries observers as enforcement assets: lessons from the North Pacific. *Mar. Policy* 34, 583–589. doi: 10.1016/j.marpol.2009.11.005
- R Core Team (2016). *R: A Language and Environment for Statistical Computing*. R Found Stat Comput Vienna, Austria. Available online at: <http://www.R-project.org>.
- Rossi, S., Tsounis, G., Orejas, C., Padrón, T., Gili, J. M., Bramanti, L., et al. (2008). Survey of deep-dwelling red coral (*Corallium rubrum*) populations at Cap de Creus (NW Mediterranean). *Mar. Biol.* 154, 533–545. doi: 10.1007/s00227-008-0947-6
- Santangelo, G., Abbiati, M., Giannini, F., and Cicogna, F. (1993). Red coral fishing trends in the western Mediterranean Sea during the period 1981–1991. *Sci. Mar.* 57, 139–143.
- Santangelo, G., and Bramanti, L. (2010). Quantifying the decline in *Corallium rubrum* populations. *Mar. Ecol. Prog. Ser.* 418, 295–297. doi: 10.3354/meps08897
- Santangelo, G., Bramanti, L., and Iannelli, M. (2007). Population dynamics and conservation biology of the over-exploited Mediterranean red coral. *J. Theor. Biol.* 244, 416–423. doi: 10.1016/j.jtbi.2006.08.027
- Schewe, R. L., and Dutton, C. (2018). NOAA fishery observers and vietnamese american fishers in the southeastern US. *Mar. Policy* 96, 145–151. doi: 10.1016/j.marpol.2018.08.006
- Taviani, M., Friewald, A., Beuck, L., Angeletti, L., Remia, A., Vertino, A., et al. (2010). "The deepest known occurrence of the precious red coral *Corallium rubrum* (L. 1758) in the Mediterranean Sea," in *Proceedings of the International Workshop on Red Coral Science, Management, and Trade: Lessons from the Mediterranean, Naples*.
- Tescione, G. (1973). *The Italians and Their Coral Fishing*. Naples: Fausto Fiorino.
- Tsounis, G., Rossi, S., Bramanti, L., and Santangelo, G. (2013). Management hurdles for sustainable harvesting of *Corallium rubrum*. *Mar. Policy* 39, 361–364. doi: 10.1016/j.marpol.2012.12.010
- Tsounis, G., Rossi, S., Gili, J. M., and Arntz, W. E. (2007). Red coral fishery at the Costa Brava (NW Mediterranean): case study of an overharvested precious coral. *Ecosystems* 10, 975–986. doi: 10.1007/s10021-007-9072-5
- Tsounis, G., Rossi, S., Grigg, R., Santangelo, G., Bramanti, L., and Gili, J. M. (2010). The exploitation and conservation of precious corals. *Oceanogr. Mar. Biol. Ann. Rev.* 48, 161–212. doi: 10.1201/ebk1439821169-3
- Uhlmann, S. S., van Helmond, A. T., Kemp Stefánsdóttir, E., Sigurðardóttir, S., Haralabous, J., Bellido, J. M., et al. (2014). Discarded fish in European waters: general patterns and contrasts. *ICES J. Mar. Sci.* 71, 1235–1245. doi: 10.1093/icesjms/fst030
- Western Pacific Regional Management Council (WPCouncil) (2007). *Fishery Management Plan For The Precious Coral Fisheries Of The Western Pacific Region*. Honolulu: WP Council.

**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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