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Temporal Shifts of *Posidonia oceanica* and *Corallium rubrum* in Cap de Creus (NE Spain): Recreational SCUBA diver's perception of change

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Abstract

Temporal trends of the main Mediterranean benthic coastal marine habitats point to an overall decline of their extent and health status. We assessed recreational scuba divers' perceptions of the temporal change abundance of two key Mediterranean ecosystem engineering species in the Cap de Creus Marine Protected Area: the red coral *Corallium rubrum* (an octocoral, component of coralligenous assemblages) and *Posidonia oceanica* (a seagrass, forming meadow formations on soft bottoms). We conducted semi-structured interviews and a target survey to recreational scuba divers of the area. Scuba divers reported decreasing abundance for *C. rubrum,* but not for *Posidonia oceanica* meadows during the last four decades. Qualitatively comparable ecological data for the area are only available for the last two decades and suggest stability in the abundance of both species. We explain the mismatch between data sources regarding *C. rubrum* arguing that, while ecological data mainly focus on no-take areas inside Cap de Creus, divers mainly visit areas where red coral colonies are unprotected. For *P. oceanica*, stability over the last two decades is indicated both in ecological data and in divers' responses, suggesting that this habitat did not suffer major decline during the study period. The results of this study are overall limited by a low replication. However, it highlights local expert knowledge (i.e., recreational divers' knowledge) as an untapped source of observations that could contribute to increase information of the historical ecological trends of these key species.

Keywords: Catalan Sea; Coastal marine habitats; Ecological trends; Environmental change; Marine Historical Ecology; Local Ecological Knowledge; Marine Protected Area.

Introduction

The Mediterranean Sea, and especially the NW coastal region, is considered a biodiversity hotspot (Lejeusne *et al.*, 2010; Coll *et al.*, 2012), with *Posidonia oceanica* Delile 1813 meadows and coralligenous reefs being important hosts of numerous species (Boudouresque, 2004; Ballesteros, 2006; Boudouresque *et al.*, 2017). A key species in coralligenous habitats is the octocoral *Corallium rubrum* (Linnaeus, 1758; red coral), an ecosystem-engineering cnidarian that increases the complexity of the habitat, serving as refuge for several species (Picciano *et al.*, 2007; Tsounis *et al.*, 2010; Mallo *et al.*, 2019; Rossi & Rizzo, 2020). Benthic habitats have been substantially affected for centuries mainly by human activities, with their degradation being more evident during the last four-five decades, particularly in certain areas (Kiparissis *et al.*, 2011; Rossi, 2019; Hassoun *et al.*, 2022).

Analysis of temporal trends of benthic habitats shows that the coastal marine Mediterranean region has faced large anthropogenic impacts that influence the abundance and distribution of the benthic ecosystems (Claudet & Fraschetti, 2010), even in Marine Protected Areas (MPA; Claudet *et al.*, 2020). One of the most effective and direct ways to assess the abundance of coastal marine habitats is through scientific scuba diving (Cattaneo-Vietti & Mojetta, 2021). However, when logistics are difficult and funding limited, recreational scuba diving can be an alternative source of information providing reports and/or photographic information about the abundance of singular species. In fact, the aggregated reports of many visitors can provide a complete qualitative map through scuba diving centres or free diving (e.g., Bramanti *et al.* 2011; Marrocco *et al.*, 2019). To date, recreational scuba diving has been used for monitoring the Mediterranean coralligenous reefs (e.g., Gerovasileiou *et al.*, 2016; Turicchia *et al.*, 2021), specifically *C. rubrum* (Bramanti *et al.*, 2011). Also, *P. oceanica* meadows have had a specific monitoring in this sense (e.g., de Virgilio *et al.*, 2020). Few studies have also relied on these methods to reflect on changes over time by tapping on the memory of divers' past immersions (e.g., Jiménez-López, 2012 in Medes Islands MPA). Initiatives now exist that bring together volunteers, scientists, and local communities to monitor, analyze, and document the health of marine and coastal environments (e.g., "Observadores del Mar", https://observadoresdelmar.es/).

This study examines scuba divers' perceptions of temporal changes in the abundance of *P. oceanica* and *C. rubrum* in the Cap de Creus MPA (NE Spain) and the main drivers causing these changes. Observations referring to the past are key to understand temporal ecosystems transformation and how ecosystem functioning has been modified during the last decades to centuries (Gatti *et al.* 2015; Thurstan *et al.*, 2017; Rossi, 2019). In the case of the red coral, these changes have been dramatic especially in the NW Mediterranean Sea, where it is considered that the octocoral population passed from a "tree forest" to a "grassland" (Cattaneo-Vietti *et al.*, 2016; Mallo *et al.*, 2019; Rossi, 2019). *P. oceanica* also declined considerably in the Mediterranean basin (Marbà *et al.*, 2014; Telesca *et al.*, 2015), although in the last decades an important part of them is found to be stable, or even in recovery mode (de los Santos *et al.*, 2019). Our work focusses on changes during the past four decades in an emblematic coastal area of the NW Mediterranean Sea.

Material and Methods

We collected data in three municipalities (Port de la Selva, Cadaqués, and Roses) around the Cap de Creus Marine Protected Area (MPA), NE Spain. The marine reserve was established in 1998, and its dominant marine habitats include seagrass meadows on sandy bottoms (most between 2 and 25 meters depth), where *P. oceanica* dominates, and coralligenous reefs (most between 20 and 70 meters depth) on rocky bottoms (Sardà *et al.*, 2012). We conducted semi-structured interviews (Newcomer *et al.*, 2015) with managers of scuba diving centres (December 2017 and July 2018) and a survey to recreational scuba divers (July and August 2019). Semi-structured interviews allowed us to collect detailed data from the most experienced sea observers in the area, while the survey allowed us to reach a larger sample due to the less time-consuming approach. The research protocol was approved by the Ethics Committee on Animal and Human Experimentation of the Autonomous University of Barcelona (CEEAH 4792).

We showed managers of the scuba diving centres a map of Cap de Creus and photo-cards of different levels of abundance of *C. rubrum* and *P. oceanica*: "High", "Medium", "Low", and "Absent" (Fig. S1). Respondents had to interpret the level of abundance of both species in various sites of Cap de Creus and for different decades (i.e., since they started diving in the area to date). When interviewees reported having observed different abundances of a species in a particular area, we asked them to estimate the average abundance at each point in time. We asked interviewees to report information only for areas they knew well. When an interviewee reported a change of abundance in a species of an area from a decade to another, we further asked their opinion about the possible driver(s) of such change.

Surveys were addressed to scuba divers who had dived in the area for at least a decade (n = 32). Before responding to the survey, we asked whether they were aware of *C. rubrum* and *P. oceanica* during their dives. If the answer was positive, they had to provide a qualitative estimate of the overall species abundance within the qualitative categories "High", "Medium", "Low", "Absent". The question was asked for all the different places that the diver visited and for each decade they had dived in the study area. To reduce variation, we provided visual references for each category. Finally, we also asked survey participants to foresee the species' abundance by 2050. The question aimed to assess which future environmental changes are expected by the respondents based on their past and present experiences (Fig. S2).

In both methodologies, we displayed the frequency distribution of the answers for all decades and calculated their median values. Also, for both methodologies, we noted answers' overall and decadal variations, coded as "Increase" (e.g., when in the 1990s is "Medium" and in the 2000s "High"), "Stable", or "Decrease". This information allowed us to compare categorization between respondents. We acknowledge that the data collection methods do not reflect the complexity of the factors that determine a species' health status, as our data reflects the perceived abundance of two engineering species in the study area. Informants might have used subjective interpretation of the four categories of abundance (High, Medium, Low, Absent). We tried to minimize this bias by providing visual references, although we cannot discard that, for example, some respondents might value more the size of big corals and others their density.

Results

Semi-structured interviews to five managers from scuba diving centres resulted in 20 reports for *C. rubrum* and 22 for *P. oceanica* (Table S1). A report was defined as an assessment of the abundance of the species for an area (i.e., a card placement on the map; Fig. S1). Interviewees' reports never covered the entire Cap de Creus MPA, but usually focused around the area closer to their diving centre. In some cases, respondents noted a decadal shift in species and identified the factors driving it, but they felt the change was not significant enough to alter the card category.

The number of semi-structured interview reports was lower for the past than for more contemporary times, with a higher number of reports for recent years (2017-18), and only a few in the 1970s. The frequency distribution and the decadal medians suggest an overall perception of decrease of species abundance (Fig. 1a; Table 1). That is especially notable for *C. rubrum*, which had a dominance of "Medium" and/or "High" in the 1980s and 1990s, but a dominance of the "Low" category nowadays. The largest perceived decrease in *C. rubrum* occurred from the 1990s to the 2000s. Despite a slight overall decrease, with some reports of "Low" and "Absent" since the 2010s, *P. oceanica* is perceived to have remained stable with dominance of the "High" category across decades (Fig. 1a; Table 1).

Thirty-two scuba divers answered the survey (Table S2). Almost all of them reported to be aware of the status of *C. rubrum* and *P. oceanica* during their dives (30 of *C. rubrum*, 31 of *P. oceanica*). As for interviews, the number of reports was lower for past than for recent years, with

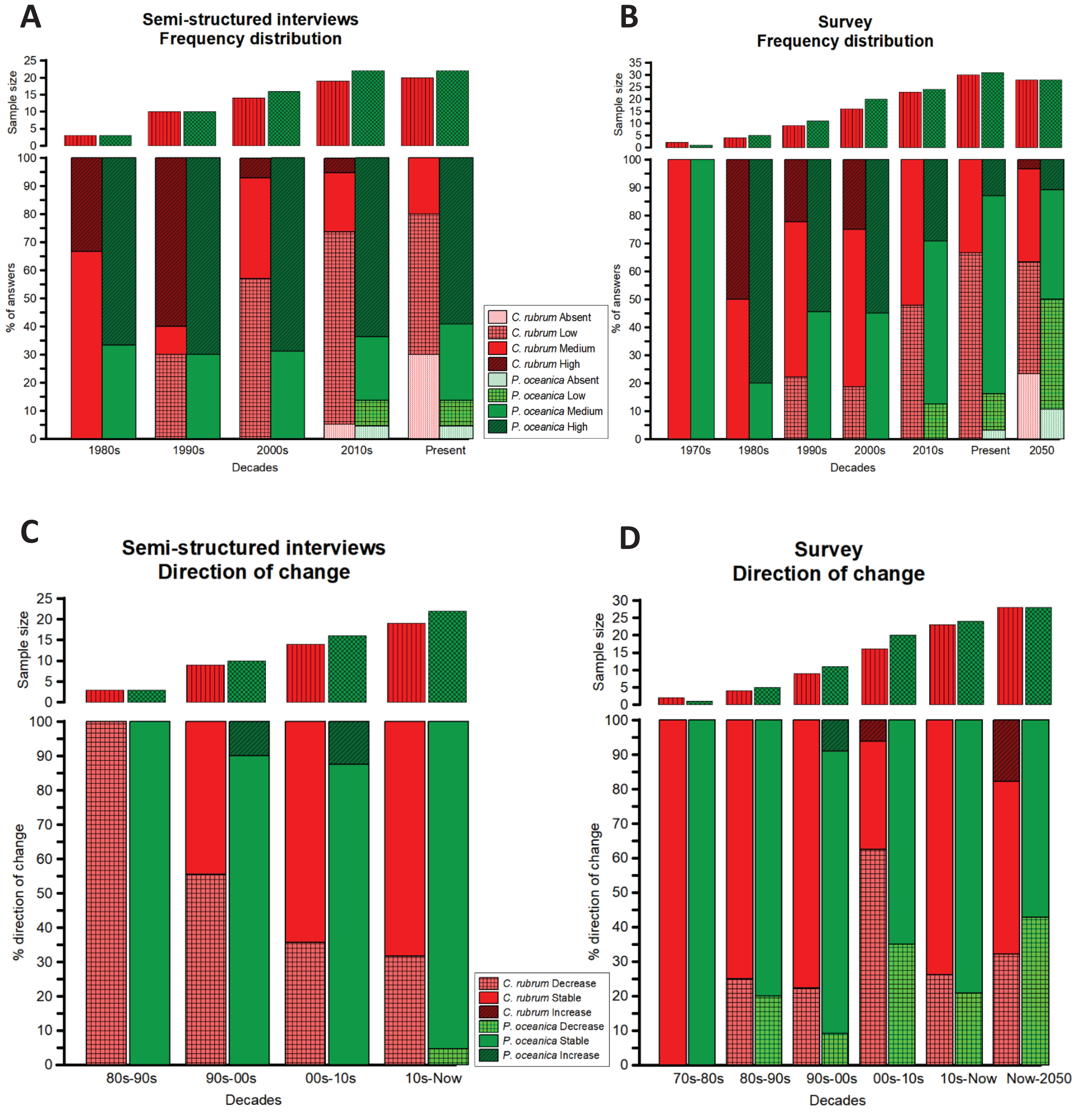

Fig. 1: **(A, C)** Semi-structured interview results. **(B, D)** Survey results. Upper bars above each graph represent the number of reports for each species (red and vertical lines *C. rubrum*, green and crossed lines *P. oceanica*). **(A, B)** Frequency distribution (in %) per decade for each category of *Corallium rubrum* (red color range) and *Posidonia oceanica* (green color range). Diagonal lines and dark color represent "High", solid color "Medium", squared pattern and light color "Low", and dotted bars with white background "Absent". **(C, D)** The direction of change in respondents' answers for each decade (in %). Diagonal lines and dark color represent "Increase", solid color represent "Stable", "Decrease" in squared pattern and light color.

Table 1. Decadal median values of the qualitative categories ("High", "Medium", "Low", "Absent") for both species (*Corallium rubrum*, *Posidonia oceanica*) in both methodologies (semi-structured interviews, survey). See Figure 1 for sample sizes.

Decade	1970s	1980s	1990s	2000s	2010s	Present	2050
Semi-structured interviews							
C. rubrum		Medium	High	Low	Low	Low	
P. oceanica		High	High	High	High	High	
Survey							
C. rubrum	Medium	Medium & High	Medium	Medium	Medium	Low	Low
P. oceanica	Medium	High	High	High	Medium	Medium	Low & Medium

most respondents having dived in recent years (2019), only a few having dived in the 1980s, and two in the 1970s. Survey results suggest an overall decreasing trend in the abundance of the two studied species (Fig. 1b; Table 1). *C. rubrum* progressively shifted from a dominance of "Medium" reports in the farther decades towards an increase of "Low" and a decrease of "High" reports in recent decades. Compared to semi-structured interviews, responses to the survey showed a more pronounced decrease through time in *P. oceanica.* Thus, survey results indicate a shift from the dominance of "High" reports in the farther decades (except for the low sample sized 1970s) towards a dominance of "Medium" reports in the present, with the first appearance of "Low" in the 2010s (Fig. 1b; Table 1). Finally, respondents considered that both species, but particularly *P. oceanica*, will continue to show a decreasing trend by 2050.

We focus now on individual decadal variations (i.e., "Decrease", "Stable", or "Increase"; Fig. 1c, d). In the semi-structured interviews, we did not obtain any report of increase for *C. rubrum* (Fig. 1c). Reports of the decrease of the species dominated until the 2000s, while the stable population reports dominated in the period 2000-2019. In contrast, in the survey we observed a dominance of stable – not decreasing – reports (except in 2000s-2010s). The three possibilities (stable, increase, decrease) are well represented in answers referring to the potential status of red coral by 2050 (Fig. 1d). For *P. oceanica*, reports of a stable population dominated in semi-structured interviews (Fig. 1c). The same trend was found with survey results (Fig. 1d), although survey respondents provided further reports of decrease, especially from the 2000s. Respondents had a divided prediction of the potential status of *P. oceanica* by 2050 between stable and decreasing trends. Unlike with *C. rubrum*, none of the respondents thought *P. oceanica* will increase in abundance by 2050.

Finally, according to responses from semi-structured interviews, the decreasing abundance of *C. rubrum* is driven by overharvesting (reported by 4 respondents), poaching (3), and a lack of vigilance of the MPA, which was considered an underlying driver of the others (2; Table S1). In contrast, perceived drivers of the decreasing abundance of *P. oceanica* are boat anchoring (3), pollution (1; only in the 1980s-1990s), and lack of vigilance of the MPA (1). Respondents who perceived a decadal increase in *P. oceanica* attributed it to increased public awareness (2) and the vigilance of the MPA (1).

Discussion

Three main findings result from our work. First, respondents clearly reported decreasing abundance of *Corallium rubrum*, with a dominance of reports of "Low" abundance in the present. Second, the reported trend for *Posidonia oceanica* was less clear, with a dominance of reports of "stable" abundance within decades. Third, it seems that, in general, the coralligenous community is perceived to be much more affected than the seagrass meadows, although several drivers of benthos transformation are present in the study area. Before discussing these results, we present some limitations of our methodology. First, our study has a low sample size, especially for the 1970s and 1980s decades. Participants reporting on the oldest decades are particularly significant, as their long-term perspective and expertise allows identifying possible trends in species abundance. However, the low sample size does not allow us to conduct multivariate analysis to identify covariates (e.g., age, occupation, sex, place of residence) that could shape the answers of some of our respondents. Second, our sample specifically targeted recreational divers, thus excluding other users and observers of the sea floor habitats, such as commercial divers, spear fishers, or snorkelers. A more diverse sample would reduce potential biases originating from similar backgrounds in respondents. In the text, therefore, we refer to abundance. We did not assess the number of observations per decade of any scuba diver, hence, an experienced diver with many dives has the same weight on the answers than an occasional diver. Finally, our method is subject to memory bias and change blindness, which potentially affect responses in unknown magnitude and direction. Future research should consider these limitations and expand sample size and diversity, aiming to obtain more statistically solid results.

Our results indicated a perceived decreasing trend of *Corallium rubrum* in the study area. Comparable empirical results of red coral morphometric parameters, which would provide information of their abundance, are not common in Cap de Creus and available records cover only the last two decades (Table S3; Tsounis *et al.*, 2006; Vielmini *et al.*, 2010; Bramanti *et al.*, 2014; Linares *et al.*, 2018). Moreover, the scant previous abundance data of *C. rubrum* in this area are not representative of the natural population as they are commercial catches, which are usually biased towards larger specimens (García-Rodríguez & Massò, 1986a, b). Ecological data reporting red coral population structure in Cap de Creus from the 2000s onwards suggest no significant changes in abundance, although the trend remains uncertain due to substantial variation within the data (Mallo *et al.*, 2019). Such trend is in line with calculations of the decadal variations based on informants' reports, although it contrasts with the frequency distribution of survey responses, which suggest a declining trend over the same decades. We argue that our respondents possibly identified a true decrease in abundance of red coral from the 2000s onwards in the overall Cap de Creus region. We base our argument on the fact that the available scientific data from the last decades, reporting an increasing trend, correspond to no-take zones within the MPA (Mallo *et al.*, 2019). In contrast, other areas of Cap de Creus have no harvesting restriction for which they might have suffered harvesting and poaching episodes, as suggested by respondents and also reported in the literature (Garrabou *et al.*, 2017). A similar situation happens in the Medes Islands (a Catalan MPA where since 1983 is forbidden to extract red coral), where recreational scuba divers reported a decrease of red coral abundance outside the no-take zones, while within such zones they reported that red coral was improving (Jiménez-López, 2012).

A less clear trend was indicated for *P. oceanica* abundance in the presented results, much in line with reports from existing empirical data. From 1962 onwards, trends in *P. oceanica* abundance started being monitored, and from the 1990s the species began to be notably studied (Marbà *et al.*, 2014; Dunic *et al.*, 2021). Scientific data on *P. oceanica* abundance in Cap de Creus is largely available for the 2010s, with records also for the 2000s (Romero *et al.*, 2016; 2020). These data show that, despite the overall decrease in absolute numbers, in the 2010s there is a relatively large percentage of studied meadows with a steady or even increasing state. For example, Marbà *et al.* (2014) found 38% of the studied meadows were steady or increasing in areal extent, 18% in shallow limit, 11% in deep limit, 50% in cover percentage, and 57% in absolute density. Other studies also show that, in Cap de Creus, *P. oceanica* shoot density and cover have been stable from 2008 until 2020 (Romero *et al*., 2020). Consequently, both empirical data and recreational scuba divers reports' similarly report a stable trends of *P. oceanica* during the last two decades, although scuba divers' reports of "Absent", "Low" and "Medium" abundance start increasing since the 2010s. Two potential reasons for this include increased boat anchoring on seagrass, likely due to a rising number of boats, and the broader coverage and longer observation periods of divers, which enabled them to detect seagrass degradation not captured in previous studies.

Scuba divers' projections of future trends of both species by 2050 were not optimistic: reports of "Stable" abundance dominate, with a minority of reports of "Increase" abundance for red coral. It is possible that our respondents expect a future decrease of these species in the area related to the well-known effects that climate change can have on *C. rubrum* (e.g., Garrabou *et al.*, 2009; Bramanti *et al.*, 2013; Galli *et al.*, 2016) and *P. oceanica* (e.g., Marbà *et al.*, 2014; Pergent *et al.*, 2014). Overall, the past and projected decrease of emblematic and endemic species like red coral will most probably negatively impact local economies. The presence of these species in a healthy state attracts scuba diving tourism and directly or indirectly modulate the resources for other species supporting the overall ecosystem functioning (Duffus & Dearden, 1990; Bramanti *et al.*, 2011). This fact is exemplified in the neighbouring Medes Islands MPA, where recreational scuba divers perceived a decrease in the attractiveness of the coralligenous areas because of climate change impact on different species, reducing their willingness to pay for the experience while expecting economic losses in the region (Rodrigues *et al.*, 2015).

Recreational divers' perception, as reported in this study, indicates diverse drivers affecting the two studied species, which could explain the different trends found. Qualitative information reporting a heavy exploitation of *C. rubrum* in the Costa Brava region dates back in time (Mallo *et al.,* 2019). Different sources emphasize either how abundant red coral was in the past, how easy it was to obtain, or the continuous extraction it suffered (e.g., Maluquer, 1917; Audivert, 1971; Pons, 1989; Rossi, 2019; Mallo *et al.*, 2019). Our respondents confirmed these quantitative observations. In addition, managers of scuba diving centres reported that the main pressure currently impacting *P. oceanica* in Cap de Creus is boat anchoring (and the structures built for it). According to our informants, reduction of boat anchoring, both through better MPA vigilance and increased awareness, are the underlying causes of the decadal increase in *P. oceanica* abundance. Despite these reports, scientific studies have found no significant impact of boat anchoring on *P. oceanica* (Romero et *al.*, 2020).

Our study highlights recreational scuba divers' reports as complementary to available ecological data which, albeit being more precise, only span over the last two decades and, especially for *C. rubrum*, are limited to no-take zones. Thus, information from recreational divers may reveal trends that would otherwise be neglected and can help scientists gain insight to the perceived futures of these habitats. Our findings thus encourage the use of projects involving long-time scuba divers to understand trends in marine habitats' health, especially since scuba divers are the largest group of volunteers in marine Citizen Science projects (Hermoso *et al.*, 2020). This kind of studies can cover extensive areas with lower sampling costs than conventional methods and stimulate social participation on conservative actions while bridging the gap between science and society (Bramanti *et al.,* 2011; Marrocco *et al.*, 2019; Zorrilla-Pujana *et al.*, 2020).

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Supplementary Data

The following supplementary information is available online for the article:

Fig. S1: Example of an answer of the semi-qualitative interviews realized to scuba diving centres owners or managers.
Fig. S2: English version of the questionnaire.
Table S1. Semi-structured interviews responses (n = 5). Absent = 0, Low = 1, Medium = 2, High = 3. The drivers of change mentioned by the interviewees are found in the last column, regardless of their involvement in a category change.
Table S2. Survey responses. The years on the top columns represent the decades, except 2019 that represents the time of the interview. Obs. = Have you seen and observed any red coral/*Posidonia oceanica* during your dives in this area? Y = Yes, N = No. 3 = High, 2 = Medium, 1 = Low, 0 = Absent. N/A = No answer. You can find the sociodemographic data of our respondents below the table.
Table S3. On the left, *Corallium rubrum* values of its most studied parameters and number of colonies sampled for obtaining them. On the right, the yearly averages and their respective standard deviations of those parameters. This material is modified from Figure 4 and S4 Table in Mallo *et al.* (2019), *PLoS One*.