First attempts towards the restoration of gorgonian populations on the Mediterranean continental shelf

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Abstract

1. In the Mediterranean Sea, gorgonians are among the main habitat-forming species of benthic communities on the continental shelf and slope, playing an important ecological role in coral gardens.
2. In areas where bottom trawling is restricted, gorgonians represent one of the main fractions of trammel net bycatch. Since gorgonians are long-lived and slow-growing species, impacts derived from fishing activities can have far-reaching and long-lasting effects, jeopardizing their long-term viability. Thus, mitigation and ecological restoration initiatives focusing on gorgonian populations on the continental shelf are necessary to enhance and speed up their natural recovery.
3. Bycatch gorgonians from artisanal fishermen were transplanted into artificial structures, which were then deployed at 85 m depth on the outer continental shelf of the marine protected area of Cap de Creus (north-west Mediterranean Sea, Spain). After 1 year, high survival rates of transplanted colonies (87.5%) were recorded with a hybrid remotely operated vehicle.
4. This pilot study shows, for the first time, the survival potential of bycatch gorgonians once returned to their habitat on the continental shelf, and suggests the potential success of future scaled-up restoration activities.

KEYWORDS

benthos, conservation evaluation, coral, fishing, new techniques, recovery

1 | INTRODUCTION

Unsustainable and destructive fishing activities have been identified as one of the most pervasive threats to marine benthic ecosystems occurring on continental shelves and slopes (~60–1,000 m depth), as these areas endure the bulk of commercial fishing activity (Hall-Spencer, Allain, & Fossa, 2002; Watling & Norse, 1998). Consequently, the vast majority of benthic communities inhabiting these depths have been degraded for decades (Hall, 2002). A large amount of the fishing

bycatch (the untargeted catch occurring unintentionally in a fishery) of sessile macrofauna comprises coral, gorgonian, and sponge species dwelling on the continental shelf and slope, as they are easily entangled in trammel nets, longlines, and pots due to their branching morphology and erect structure (Althaus et al., 2009; Bo, Bava, et al., 2014; Durán Muñoz et al., 2011; Sampaio et al., 2012; Wareham & Edinger, 2007). Additionally, these benthic species are also highly exposed to partial mechanical damage (i.e. breakage and tissue abrasion) from the direct impact of fishing activities (Althaus et al., 2009;

Mytilineou et al., 2014; Sampaio et al., 2012) and smothering by sediment suspended by bottom-trawling fishing (Grant, Matveev, Kahn, & Leys, 2018). The loss of this benthic habitat-forming species can result in overall loss of the associated biodiversity and is comparable to the impact of forest clear-cutting on terrestrial ecosystems (Watling & Norse, 1998).

Corals, gorgonians, and sponges are among the main engineering species (*sensu* Jones, Lawton, & Shachak, 1994) in marine ecosystems, where they play an important structural and functional role (Gili & Coma, 1998; Wildish & Kristmanson, 1997). They form complex three-dimensional structures that generate spatial heterogeneity and provide suitable habitat for hundreds of associated species, many of which are of economic importance (Henry & Roberts, 2007; Krieger & Wing, 2002). Moreover, by capturing plankton and suspended particulate organic matter they influence benthic–pelagic coupling processes and biogeochemical cycles (Gili & Coma, 1998). In the Mediterranean Sea, coral gardens dominated by gorgonians are among the main structuring communities in benthic ecosystems on the continental shelf and slope (Angiolillo & Canese, 2018; Bo et al., 2012; Gori et al., 2017). Currently, coral garden distribution on the continental shelf is mostly restricted to areas where bottom trawling does not occur due to the rough topography of the sea bottom (Bo et al., 2015; Fabri et al., 2014; Grinyó et al., 2016). However, since commercial fish species are often associated with these communities, they are largely exploited by artisanal fishermen using trammel nets and longlines (Deidun et al., 2015; Mytilineou et al., 2014). The entire removal or partial damage of coral and gorgonian colonies caused by fishing gears can have far-reaching and long-lasting effects, undermining the long-term viability of their populations (Bo, Cerrano, et al., 2014; Bo et al., 2015), since they are long-lived, slow-growing species, with delayed sexual maturity and limited recruitment success (Coma, Ribes, Zabala, & Gili, 1998; Garrabou & Harmelin, 2002; Linares, Doak, Coma, Díaz, & Zabala, 2007).

Natural recovery of these communities may take centuries, if possible at all (Dayton, 2003). In order to enhance their recovery, active intervention to aid the regeneration of these communities is highly desirable (Rinkevich, 2005). Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed by human activities, bringing it back as close as possible to its undisturbed state (Society for Ecological Restoration International Science & Policy Working Group Restoration [SER], 2004). At present, the practice of ecological restoration is receiving increasing attention worldwide as it offers the opportunity to reverse much of the environmental anthropogenic damage caused by mismanagement of natural resources (Falk, Palmer, & Zedler, 2006). Although marine restoration practices are widespread, mainly in shallow tropical environments (e.g. Precht & Robbart, 2006; Rinkevich, 2005; Young, Schopmeyer, & Lirman, 2012), active restoration initiatives focusing on degraded deeper benthic ecosystems are still extremely uncommon (Brooke, Koenig, & Shepard, 2006; Dahl, 2013).

The adverse impact of fishing to vulnerable marine ecosystems, such as cold-water coral (CWC) reefs and coral gardens (OSPAR Commission, 2010) and the need to conserve them, have become a

global concern (Angiolillo & Canese, 2018; Davies, Roberts, & Hall-Spencer, 2007). Owing to the low resilience of coral garden species, they display high vulnerability to disturbance from human activities (Montero-Serra, Linares, Doak, Ledoux, & Garrabou, 2018; Roberts & Hirshfield, 2004), which has prompted a growing interest in protection and restoration initiatives aimed at mitigating their further degradation and enhancing their recovery (Angiolillo & Canese, 2018). Currently, a few deep-sea active restoration initiatives have mainly focused on transplantation of CWC species, such as *Oculina varicosa* off the south-eastern coast of Florida (Brooke et al., 2006) and *Lophelia pertusa* in Sweden (Dahl, 2013). Nevertheless, restoration techniques for coral gardens on the continental shelf and deeper environments have not yet been validated.

The main goal of this study was to evaluate, for the first time, the feasibility of recovering and returning to their natural environment bycatch gorgonians from the Mediterranean continental shelf in order to the mitigate fishing impact. Bycatch gorgonians collected from artisanal fishermen were transplanted onto artificial structures, deployed at the continental shelf (85 m depth) in a marine protected area, and monitored using a hybrid remotely operated vehicle (ROV). This pilot action could be applicable to deeper ecosystems that require similar technical logistics and is a first essential step in assessing the feasibility of future large-scale ecological restoration of CWC gardens.

2 | METHODS

2.1 | Gorgonian collection and maintenance

Colonies of the gorgonian *Eunicella cavolini* (Koch, 1887) were obtained from artisanal fishermen's bycatch from Cap de Creus (north-western Mediterranean Sea, 42°19.12'N; 03°19.34'E), at a depth range from 70 to 100 m, during three fishing sorties in June and one in August 2015. Fishermen picked up gorgonians entangled in trammel nets and kept them in containers filled with surface sea water (~20–23°C). Once back on land (1–2 hr after collection), gorgonians were transported to the experimental aquarium facilities of the Institute of Marine Sciences (ICM-CSIC) in Barcelona (within 3–4 hr after the initial pick up), while seawater temperature was kept at $14 \pm 1.0^\circ\text{C}$ at all times. A total of 120 gorgonians were held in 100 L tanks with continuous seawater flow, filtered through a 50 µm sand filter (Olariaga, Gori, Orejas, & Gili, 2009), fed frozen *Cyclops* three times a week, and kept at $14 \pm 1.0^\circ\text{C}$ in the dark, thus simulating Cap de Creus continental shelf's natural conditions. The size of the collected colonies ranged from 6.7 to 22.4 cm (12.3 ± 4.6 cm, mean $\pm$ SD), and they were held under the aforementioned conditions between a few days and a maximum of 2 months.

2.2 | Transplant on artificial structures and deployment on the sea bottom

From June 27 to 30, 2015, 80 gorgonians were transplanted onto two stainless steel structures (40 gorgonians onto each; outer diameter:

2 m; inner diameter: 1.5 m), with a base grid ($10 \times 10 \text{ cm}^2$) surrounded by four concrete plates and a central 1 m vertical axis holding an acoustic reflector (30 cm in diameter) supported by four stainless steel bars (12 mm in diameter) (Figure 1). Forty conical supports for the gorgonians (80 mm high, 20 mm diameter) were placed on the grid. The inside of the supports was filled by polyester fibreglass resin and, once dry, 8 mm boreholes were made in order to attach the gorgonians colonies with epoxy putty (Corafix). Each structure weighed 137 kg in the air. Initially, the structures were deployed at 6 m depth north of the marine protected area of Cap de Creus, where gorgonians (entire colonies) were attached to the supports by scuba divers. Each structure was then raised up to below the water surface by means of a buoy and transported by boat at a slow and constant speed ($\sim 0.5 \text{ kn}$) towards the continental shelf, where they were deployed at 85 m depth (structure 1: $42^\circ 20.06' \text{N}$; $03^\circ 18.67' \text{E}$; structure 2: $42^\circ 20.05' \text{N}$; $03^\circ 18.67' \text{E}$). Since an additional 40 gorgonian colonies were collected as bycatch in fishing events in August, they were transplanted later on a third structure on October 23–24, 2015, and deployed on October 25, 2015, nearby the first two structures (structure 3: $42^\circ 20.05' \text{N}$; $03^\circ 18.64' \text{E}$) following exactly the same procedure. The density value of colonies transplanted onto each structure corresponds to $\sim 15 \text{ colonies/m}^2$, and was selected based on data about

Mediterranean gorgonian assemblages dwelling at 40–300 m depth ($10\text{--}20 \text{ colonies/m}^2$; Bo et al., 2009; Grinyó et al., 2016).

2.3 | Monitoring of transplanted colonies

The structures were monitored through three consecutive surveys using the Girona 500 autonomous underwater vehicle, equipped with the Bumblebee stereo camera, working as a hybrid ROV (Carreras et al., 2016). Surveys were conducted on July 21, 2015 (21 days after deployment for structures 1 and 2), December 12, 2015 (6 months after deployment for structures 1 and 2; 47 days for structure 3), and September 2, 2016 (14 months after deployment for structures 1 and 2; 10 months for structure 3). During each survey, the hybrid ROV used sonar to locate the acoustic reflector and approach each structure. The images, with a resolution of $1,024 \times 768 \text{ px}^2$, were subsequently collected by encircling each of the structures, while maintaining the gorgonians in the centre of the view. The robot maintained an approximately constant distance of 2 m between the camera and the centre of the structure, enabling observations of the gorgonians from various directions with sufficient image quality to allow successful assessment of their survivorship. Gorgonian survival was assessed by individually observing if each transplanted colony was still in place and alive (with no evidence of necrotic tissue).

The three-dimensional (3D) reconstructions of the three structures deployed on the continental shelf with transplanted gorgonians (Figure 2 and Supporting Information) were made using an optical 3D reconstruction procedure, as described in Hernández et al. (2016). The final models are obtained through a series of steps, starting with the simultaneous optimization of the pose of the camera (at each moment of the image acquisition) and the sparse geometry of the structure, followed by densification of the geometrical representation, surface estimation, and texture mapping.

3 | RESULTS

Several of the gorgonians collected from fishermen showed partial breakage and a little evidence of tissue abrasion. Even so, they all recovered and survived while being maintained in aquaria at ICM-CSIC prior to redeployment at sea. On structures 1 and 2,

FIGURE 1 Schematic figure of the stainless steel structures used in this study

FIGURE 2 Three-dimensional (3D) reconstruction of the three structures deployed on the continental shelf with transplanted gorgonians. The 3D visualization of structure 1 can be found in Supporting Information. The 3D computer model was obtained from images acquired by the hybrid remotely operated vehicle while circling the structures, using the 3D reconstruction pipeline described in Hernández et al. (2016)

FIGURE 3 Survival rate of transplanted gorgonians for each structure during the study period. Solid line corresponds to structure 1, dashed line to Structure 2, and dotted line to structure 3. Pictures correspond to structure 1 during the consecutive surveys

98.8 ± 1.8% (mean ± SD) of the transplanted gorgonians were still in place at the time of the first survey (21 days after deployment), and they all were still surviving after 6 months at the time of the second survey. On structure 3, 85% of the transplanted gorgonians were still in place at the time of the second survey (47 days after deployment). Finally, approximately 1 year after deployment (14 months for structures 1 and 2, and 10 months for structure 3) 87.5 ± 9.0% (mean ± SD) of the gorgonians were still in place and alive on the three structures (Figure 3).

4 | DISCUSSION

This pilot study has assessed, for the first time, the feasibility of successfully returning bycatch gorgonians recovered from artisanal fishery to their natural environment on the Mediterranean continental shelf. Initial results showed that, in spite of some *E. cavolini* colonies suffering partial breakage, tissue abrasion, or both, all colonies survived while being maintained in aquaria. This survival may be attributable to the species' high healing rate (0.085 mm of tissue recovery-per day; Fava, Bavestrello, Valisano, & Cerrano, 2010). In contrast, other common Mediterranean gorgonians, such as the red gorgonian *Paramuricea clavata* (which is also frequently collected by artisanal fishermen in Cap de Creus), show low survival rates when recovered from bycatch and are maintained in aquaria, with a rapid degradation of living tissues and high colony mortality (M. Montseny, personal observation). These observations highlight the importance of understanding the biological and ecological characteristics of each species before engaging in any restoration initiative (Montero-Serra, Garrabou, et al., 2018), and points at *E. cavolini* as a suitable gorgonian species for restoration projects in the Mediterranean continental shelf.

Monitoring of structures shortly after their deployment (21 days or 47 days, depending on the structure) suggested that initial loss of gorgonians was mainly due to colony detachment during the structure deployment on the continental shelf (Figure 3). Although natural mortality cannot strictly be excluded, the high survival rate following initial losses (Figure 3), which is in accordance with previous gorgonian transplantations in Mediterranean shallower habitats (Fava et al., 2010; Linares, Coma, & Zabala, 2008), suggests that the initial successful securement of a colony to the substrate is critical to its long-term survival with a relatively minor effect of stress due to transplantation (Linares et al., 2008). Gorgonian transplants in the present study showed high survival (almost 85%) approximately 1 year after deployment, in line with the high survival observed for *Corallium rubrum* 4 years after transplantation (about 99.1%) (Montero-Serra, Garrabou, et al., 2018), and much higher when compared with transplanted *Eunicella singularis* (35–45% survival after 1 year), *Eunicella verrucosa* (30% survival after 1 year) and *Paramuricea clavata* (35–50% survival after 1 year) (Fava et al., 2010; Linares et al., 2008; Montero-Serra, Garrabou, et al., 2018).

In shallow Mediterranean environments, survival of transplanted gorgonians can be compromised by several environmental parameters generally associated with seasonal fluctuations, such as high water turbulence, high irradiance, algal competition (Linares et al., 2008; Weinberg, 1979), and thermal stress (Fava et al., 2010). Long-term survival of *E. cavolini* transplants on the continental shelf may thus be partially explained by the higher stability of environmental factors in deeper habitats (below ~40 m depth) (Garrabou, Ballesteros, & Zabala, 2002; Grinyó et al., 2018). Indeed, the outcomes from shallow restoration studies in tropical ecosystems with high environmental stability are in accordance with the high gorgonian survivorship detected in the present study (Edwards & Gomez, 2007; Guzmán, 1991). However, tropical corals encompass species with contrasting

life history traits, including fast- and slow-growing species (Darling, Alvarez-Filip, Oliver, Mcclanahan, & Côté, 2012), which make tropical transplant survival rates highly variable (43–95% during the first year) (Lindahl, 2003; Yap, Alino, & Gomez, 1992; Young et al., 2012). Thus, the high survival rate detected in this study is consistent with the notion that slow-growing species require little initial transplantation effort, since they show high survival rates after transplantation in comparison with fast-growing species, but the period required to fully re-establish habitat complexity will tend to be far longer (Montero-Serra, Garrabou, et al., 2018).

In comparison with shallow-water restoration studies, there are only a few instances of ecological restoration attempts in deeper habitats. The first such attempt to restore a deep-sea coral ecosystem was conducted with the CWC *Oculina varicosa* in Florida, where restoration modules were deployed at 70–100 m depth with colonies transplanted that showed moderate survival rates (50–60%) after 1 year (Brooke et al., 2006). In Sweden, a restoration action focused on the CWC *Lophelia pertusa* recorded high survival of the transplants (76%), which increased in size by 36% after more than 3 years (Dahl, 2013; Jonsson et al., 2015). Similarly, an in situ growth study showed high survival (over 90% polyp survival) and active colony growth of *L. pertusa* fragments deployed during 1 year at ~500 m depth in the northern Gulf of Mexico (Brooke & Young, 2009).

These first pilot studies (including the present one) demonstrate the feasibility of the active restoration of CWC reefs and coral gardens, which should encourage future initiatives aimed at recovering, preserving, and sustainably managing these vulnerable marine ecosystems. However, ecological restoration of intermediate depths and deep-sea habitats involves considerable constraints due to the difficult access, requiring the use of advanced underwater technology entailing high economic cost. Deep-sea restoration cost per hectare has been estimated at two to three orders of magnitude higher than for shallow marine ecosystems (Van Dover et al., 2014). Future availability of accessible cost-effective underwater technology (such as relatively low-cost autonomous underwater vehicles for monitoring) will be paramount for the wide application and upscaling of coral and gorgonian restoration at depths below conventional or technical scuba diving limits.

The ultimate goal of restoration initiatives should be to achieve the recovery of the structure and ecological functioning of affected ecosystems (McDonald, Gann, Jonson, & Dixon, 2016; SER, 2004). For coral gardens, restoration of sessile engineering species can drastically alter the abiotic system state and trigger a consequent response in the biotic state (Byers et al., 2006), such as that transplanted gorgonians not only provide habitat structure but also enhance the recovery of associated biodiversity and positively influence ecosystem functioning (Geist & Hawkins, 2016). Overall, although restoration is often a long-term investment and its potential results are still highly uncertain (Suding, 2011; Van Dover et al., 2014), the results of this pilot project highlight the feasibility of using bycatch gorgonians recovered from artisanal fisheries to mitigate the fishing-related degradation by restoring coral gardens on the Mediterranean continental shelf. This is an essential first step that leads to future large-scale and cost-effective

restoration actions of coral gardens located on the continental shelves or in even deeper environments. In contrast to most restoration practices using coral transplants obtained from fragmentation of donor colonies (Brooke et al., 2006; Dahl, 2013), restoration based on bycatch gorgonians would minimize damage to other colonies or populations. Nevertheless, to be effective, these restoration actions should be accompanied by a reduction of fishing impacts in the restored areas, by partial closures, or by improving fishing techniques.

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REFERENCES

- Althaus, F., Williams, A., Schlacher, T. A., Kloser, R., Green, M. A., Barker, B. A., ... Schlacher-Hoenlinger, M. A. (2009). Impacts of bottom trawling on deep-coral ecosystems of seamounts are long-lasting. *Marine Ecology Progress Series*, 397, 279–294. <https://doi.org/10.3354/meps08248>
- Angiolillo, M., & Canese, S. (2018). Deep gorgonians and corals of the Mediterranean Sea. In C. Duque (Ed.), *Corals in a changing world* (pp. 29–49). Rijeka, Croatia: IntechOpen. <https://doi.org/10.5772/intechopen.69686>
- Bo, M., Bava, S., Canese, S., Angiolillo, M., Cattaneo-Vietti, R., & Bavestrello, G. (2014). Fishing impact on deep Mediterranean rocky habitats as revealed by ROV investigation. *Biological Conservation*, 171, 167–176. <http://doi.org/10.1016/j.biocon.2014.01.011>
- Bo, M., Bavestrello, G., Angiolillo, M., Calcagnile, L., Canese, S., Cannas, R., ... Cau, A. (2015). Persistence of pristine deep-sea coral gardens in the Mediterranean Sea (SW Sardinia). *PLoS ONE*, 10, e0119393. <https://doi.org/10.1371/journal.pone.0119393>
- Bo, M., Bavestrello, G., Canese, S., Giusti, M., Salvati, E., Angiolillo, M., & Greco, S. (2009). Characteristics of a black coral meadow in twilight

- zone of central Mediterranean Sea. *Marine Ecology Progress Series*, 397, 53–61. <https://doi.org/10.3354/meps08185>
- Bo, M., Canese, S., Spaggiari, C., Pusceddu, A., Bertolino, M., Angiolillo, M., ... Bavestrello, G. (2012). Deep coral oases in the south Tyrrhenian Sea. *PLoS ONE*, 7, e49870. <https://doi.org/10.1371/journal.pone.0049870>
- Bo, M., Cerrano, C., Canese, S., Salvati, E., Angiolillo, M., Santangelo, G., & Bavestrello, G. (2014). The coral assemblages of an off-shore deep Mediterranean rocky bank (NW Sicily, Italy). *Marine Ecology*, 35, 332–342. <https://doi.org/10.1111/maec.12089>
- Brooke, S., Koenig, C. C., & Shepard, A. N. (2006). *Oculina* Banks Restoration Project: Description and preliminary assessment. *Proceedings of the Gulf and Caribbean Fisheries Institute*, 57, 607–620.
- Brooke, S., & Young, C. M. (2009). In situ measurement of survival and growth of *Lophelia pertusa* in the northern Gulf of Mexico. *Marine Ecology Progress Series*, 397, 153–161. <https://doi.org/10.3354/meps08344>
- Byers, J. E., Cuddington, K., Jones, C. G., Talley, T. S., Hastings, A., Lambrinos, J. G., ... Wilson, W. G. (2006). Using ecosystem engineers to restore ecological systems. *Trends in Ecology and Evolution*, 21, 493–500. <http://doi.org/10.1016/j.tree.2006.06.002>
- Carreras, M., Gori, A., Mallios, A., Palomeras, N., Linares, C., Ribas, D., ... Ridao, P. (2016). Seabed monitoring with Girona 500 AUV working as HROV. In *7th international workshop on marine technology: MARTECH 2016. Instrumentation viewpoint* (pp. 65–66). Vilanova i la Geltrú, Spain: SARTI.
- Coma, R., Ribes, M., Zabala, M., & Gili, J. M. (1998). Growth and production in a modular marine invertebrate. *Estuarine, Coastal and Shelf Science*, 47, 459–470. <https://doi.org/10.1006/ecss.1998.0375>
- Dahl, M. (2013). Conservation genetics of *Lophelia pertusa* (PhD thesis). University of Gothenburg, Gothenburg, Sweden.
- Darling, E. S., Alvarez-Filip, L., Oliver, T. A., Mcclanahan, T. R., & Côté, I. M. (2012). Evaluating life-history strategies of reef corals from species traits. *Ecology Letters*, 15, 1378–1386. <https://doi.org/10.1111/j.1461-0248.2012.01861.x>
- Davies, A. J., Roberts, J. M., & Hall-Spencer, J. (2007). Preserving deep-sea natural heritage: Emerging issues in offshore conservation and management. *Biological Conservation*, 138, 299–312. <https://doi.org/10.1016/j.biocon.2007.05.011>
- Dayton, P. K. (2003). The importance of the natural sciences to conservation. *The American Naturalist*, 162, 1–13. <https://doi.org/10.1086/376572>
- Deidun, A., Andaloro, F., Bavestrello, G., Canese, S., Consoli, P., Micallef, A., ... Bo, M. (2015). First characterisation of a *Leiopathes glaberrima* (Cnidaria: Anthozoa: Antipatharia) forest in Maltese exploited fishing grounds. *Italian Journal of Zoology*, 82, 271–280.
- Durán Muñoz, P., Murillo, F. J., Sayago-Gil, M., Serrano, A., Laporta, M., Otero, I., & Gómez, C. (2011). Effects of deep-sea bottom longlining on the Hattton Bank fish communities and benthic ecosystem, north-east Atlantic. *Journal of the Marine Biological Association of the United Kingdom*, 91, 939–952. <https://doi.org/10.1017/S0025315410001773>
- Edwards, A. J., & Gomez, E. D. (2007). *Reef restoration. Concepts and guidelines: making sensible management choices in the face of uncertainty*. St Lucia, QLD, Australia: Coral Reef Targeted Research & Capacity Building for Management Program.
- Fabri, M. C., Pedel, L., Beuck, L., Galgani, F., Hebbeln, D., & Freiwald, A. (2014). Megafauna of vulnerable marine ecosystems in French Mediterranean submarine canyons: Spatial distribution and anthropogenic impacts. *Deep-Sea Research Part II: Topical Studies in Oceanography*, 104, 184–207. <https://doi.org/10.1016/j.dsr2.2013.06.016>
- Falk, D. A., Palmer, M. A., & Zedler, J. B. (2006). *Foundations of restoration ecology*. Washington, DC: Island Press.
- Fava, F., Bavestrello, G., Valisano, L., & Cerrano, C. (2010). Survival, growth and regeneration in explants of four temperate gorgonian species in the Mediterranean Sea. *Italian Journal of Zoology*, 77, 44–52. <https://doi.org/10.1080/11250000902769680>
- Garrabou, J., Ballesteros, E., & Zabala, M. (2002). Structure and dynamics of north-western Mediterranean rocky benthic communities along a depth gradient. *Estuarine, Coastal and Shelf Science*, 55, 493–508. <https://doi.org/10.1006/ecss.2001.0920>
- Garrabou, J., & 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. *Journal of Animal Ecology*, 71, 966–978. <https://doi.org/10.1046/j.1365-2656.2002.00661.x>
- Geist, J., & Hawkins, S. J. (2016). Habitat recovery and restoration in aquatic ecosystems: Current progress and future challenges. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 26, 942–962. <https://doi.org/10.1002/aqc.2702>
- Gili, J. M., & Coma, R. (1998). Benthic suspension feeders: Their paramount role in littoral marine food webs. *Trends in Ecology and Evolution*, 13, 316–321. [https://doi.org/10.1016/S0169-5347\(98\)01365-2](https://doi.org/10.1016/S0169-5347(98)01365-2)
- Gori, A., Bavestrello, G., Grinyó, J., Dominguez-Carrió, C., Ambroso, S., & Bo, M. (2017). Animal forests in deep coastal bottoms and continental shelf of the Mediterranean Sea. In S. Rossi, L. Bramanti, A. Gori, & C. Orejas (Eds.), *Marine animal forests. The ecology of benthic biodiversity hotspots* (pp. 1–26). Cham, Switzerland: Springer International Publishing.
- Grant, N., Matveev, E., Kahn, A. S., & Leys, S. P. (2018). Suspended sediment causes feeding current arrests in situ in the glass sponge *Aphrocallistes vastus*. *Marine Environmental Research*, 137, 111–120. <https://doi.org/10.1016/j.marenvres.2018.02.020>
- Grinyó, J., Gori, A., Ambroso, S., Purroy, A., Calatayud, C., Dominguez-Carrió, C., ... Gili, J. M. (2016). Diversity, distribution and population size structure of deep Mediterranean gorgonian assemblages (Menorca Channel, Western Mediterranean Sea). *Progress in Oceanography*, 145, 42–56. <https://doi.org/10.1016/j.pocean.2016.05.001>
- Grinyó, J., Gori, A., López-González, P. J., Santín, A., Baena, P., & Gili, J. M. (2018). Morphological features of the gorgonian *Paramuricea macrospina* on the continental shelf and shelf edge (Menorca Channel, Western Mediterranean Sea). *Marine Biology Research*, 14, 30–40. <https://doi.org/10.1080/17451000.2017.1375118>
- Guzmán, H. (1991). Restoration of coral reefs in Pacific Costa Rica. *Conservation Biology*, 5, 189–195. <https://doi.org/10.1111/j.1523-1739.1991.tb00123.x>
- Hall, S. J. (2002). The continental shelf benthic ecosystem: Current status, agents for change and future prospects. *Environmental Conservation*, 29, 350–374.
- Hall-Spencer, J., Allain, V., & Fossa, J. H. (2002). Trawling damage to Northeast Atlantic ancient coral reefs. *Proceedings of the Royal Society B: Biological Sciences*, 269, 507–511. <https://doi.org/10.1098/rspb.2001.1910>
- Henry, L. A., & Roberts, J. M. (2007). Biodiversity and ecological composition of macrobenthos on cold-water coral mounds and adjacent off-mound habitat in the bathyal Porcupine Seabight, NE Atlantic. *Deep-Sea Research Part I: Oceanographic Research Papers*, 54, 654–672. <https://doi.org/10.1016/j.dsr.2007.01.005>
- Hernández, J. D., Istenič, K., Gracias, N., Palomeras, N., Campos, R., Vidal, E., ... Carreras, M. (2016). Autonomous underwater navigation and optical mapping in unknown natural environments. *Sensors (Switzerland)*, 16, 1174. <https://doi.org/10.3390/s16081174>

- Jones, C. G., Lawton, J. H., & Shachak, M. (1994). Organisms as ecosystems engineers. *Nordic Society Oikos*, 69, 373–386. <https://doi.org/10.2307/3545850>
- Jonsson, L., Dahl, M., Strömberg, S., Lindegarth, M., André, C., & Lundälv, T. (2015). In situ measurement of survival and growth of genotyped transplanted fragments of the cold-water coral *Lophelia pertusa*. Presentation. In *Restaurering i marin miljö*. Gothenburg, Sweden.
- Krieger, K. J., & Wing, B. L. (2002). Megafauna associations with deepwater corals (*Primnoa* spp.) in the Gulf of Alaska. *Hydrobiologia*, 471, 83–90. <http://doi.org/10.1023/A:1016597119297>
- Linares, C., Coma, R., & Zabala, M. (2008). Restoration of threatened red gorgonian populations: An experimental and modelling approach. *Biological Conservation*, 141, 427–437. <http://doi.org/10.1016/j.biocon.2007.10.012>
- Linares, C., Doak, D. F., Coma, R., Díaz, D., & Zabala, M. (2007). Life history and population viability of a long-lived marine invertebrate: The octocoral *Paramuricea clavata*. *Ecology*, 88, 918–928. <https://doi.org/10.1890/05-1931>
- Lindahl, U. (2003). Coral reef rehabilitation through transplantation of staghorn corals: Effects of artificial stabilization and mechanical damages. *Coral Reefs*, 22, 217–223. <https://doi.org/10.1007/s00338-003-0305-6>
- McDonald, T., Gann, G. D., Jonson, J., & Dixon, K. W. (2016). *International standards for the practice of ecological restoration—including principles and key concepts*. Washington, DC: Society for Ecological Restoration.
- Montero-Serra, I., Garrabou, J., Doak, D. F., Figuerola, L., Hereu, B., Ledoux, J. B., & Linares, C. (2018). Accounting for life-history strategies and timescales in marine restoration. *Conservation Letters*, 11, 1–9. <https://doi.org/10.1111/conl.12341>
- Montero-Serra, I., Linares, C., Doak, D. F., Ledoux, J. B., & Garrabou, J. (2018). Strong linkages between depth, longevity and demographic stability across marine sessile species. *Proceedings of the Royal Society B*, 285, 20172688. <https://doi.org/10.1098/rspb.2017.2688>
- Mytilineou, C., Smith, C. J., Anastasopoulou, A., Papadopoulou, K. N., Christidis, G., Bekas, P., ... Dokos, J. (2014). New cold-water coral occurrences in the eastern Ionian Sea: Results from experimental long line fishing. *Deep-Sea Research Part II: Topical Studies in Oceanography*, 99, 146–157. <https://doi.org/10.1016/j.dsr2.2013.07.007>
- Olariaga, A., Gori, A., Orejas, C., & Gili, J. M. (2009). Development of an autonomous aquarium system for maintaining deep corals. *Oceanography*, 22, 44–45. <https://doi.org/10.5670/oceanog.2009.04>
- OSPAR Commission. (2010). *Background document for coral gardens*. Biodiversity Series Publication Number: 486. London, UK: OSPAR Commission.
- Precht, W. F., & Robbart, M. (2006). Coral reef restoration: The rehabilitation of an ecosystem under siege. In W. F. Precht (Ed.), *Coral reef restoration handbook*. Boca Raton, FL: CRC Press. <https://doi.org/10.1201/9781420003796.ch1>
- Rinkevich, B. (2005). Conservation of coral reefs through active restoration measures: Recent approaches and last decade progress. *Environmental Science and Technology*, 39, 4333–4342. <https://doi.org/10.1021/es0482583>
- Roberts, S., & Hirshfield, M. (2004). Deep sea corals: Out of sight, but no longer out of mind. *Frontiers in Ecology and the Environment*, 2, 123–130. [https://doi.org/10.1890/1540-9295\(2004\)002\[0123:DCO OSB\]2.0.CO;2](https://doi.org/10.1890/1540-9295(2004)002[0123:DCO OSB]2.0.CO;2)
- Sampaio, I., Braga-Henriques, A., Pham, C., Ocaña, O., De Matos, V., Morato, T., & Porteiro, F. M. (2012). Cold-water corals landed by bottom longline fisheries in the Azores (north-eastern Atlantic). *Journal of the Marine Biological Association of the United Kingdom*, 92, 1547–1555. <https://doi.org/10.1017/S0025315412000045>
- Society for Ecological Restoration International Science & Policy Working Group (2004). *The SER international primer on ecological restoration*. Tucson, AZ: Society for Ecological Restoration International.
- Suding, K. N. (2011). Toward an era of restoration in ecology: Successes, failures, and opportunities ahead. *Annual Review of Ecology, Evolution, and Systematics*, 42, 465–487. <https://doi.org/10.1146/annurev-ecolsys-102710-145115>
- Van Dover, C. L., Aronson, J., Pendleton, L., Smith, S., Arnaud-Haond, S., Moreno-Mateos, D., ... Warner, R. (2014). Ecological restoration in the deep sea: Desiderata. *Marine Policy*, 44, 98–106. <https://doi.org/10.1016/j.marpol.2013.07.006>
- Wareham, V. E., & Edinger, E. N. (2007). Distribution of deep-sea corals in the Newfoundland and Labrador region, Northwest Atlantic Ocean. *Bulletin of Marine Science*, 81, 289–313. Q9
- Watling, L., & Norse, E. A. (1998). Disturbance of the seabed by mobile fishing gear: A comparison to forest clearcutting. *Conservation Biology*, 12, 1180–1197. <https://doi.org/10.1046/j.1523-1739.1998.0120061180.x>
- Weinberg, S. (1979). Transplantation experiments with Mediterranean gorgonians. *Bijdragen tot de Dierkunde*, 49, 31–41. Q10
- Wildish, D., & Kristmanson, D. (1997). *Benthic suspension feeders and flow*. Cambridge, UK: Cambridge University Press. <https://doi.org/10.1017/CBO9780511529894>
- Yap, H. T., Alino, P. M., & Gomez, E. D. (1992). Trends in growth and mortality of three coral species (Anthozoa: Scleractinia), including effects of transplantation. *Marine Ecology Progress Series*, 83, 91–101. <https://doi.org/10.3354/meps083091>
- Young, C., Schopmeyer, S., & Lirman, D. (2012). A review of reef restoration and coral propagation using the threatened genus *Acropora* in the Caribbean and western Atlantic. *Bulletin of Marine Science*, 88, 1075–1098. <https://doi.org/10.5343/bms.2011.1143>

SUPPORTING INFORMATION

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