



Turning casualty into opportunity: fragmenting dislodged colonies is effective for restoring reefs of a Mediterranean endemic coral



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ABSTRACT

Within the framework of ecosystem-based management, restoration appears as a sensible option to counteract the global decline of coral reefs. Several techniques involving sexual and asexual coral propagules have been used for the restoration of reefs. Culturing of fragments has proved fruitful since it takes advantage of the capability of corals to asexually reproduce, providing a number of novel colonies that can be replanted. This method however, when using fragments detached from a colony, might be stressful for the wild donor. *Astroides calycularis* is an endemic and endangered Mediterranean scleractinian coral forming massive colonies mostly at shallow depth. It is subject to anthropogenic impact, particularly from damage due to accidental contacts by SCUBA divers, and it is expected to suffer from sea storms of increasing power under the projected climate change scenarios. Corals of opportunity (i.e. dislodged colonies found alive on the seabed) may be a useful resource for the restoration of *A. calycularis* reefs, given that the fragment-based transplant technique is effective for this species as it is for other massive corals. A one-year transplant experiment was carried out along an exposed rocky shore in NW Sicily (Mediterranean Sea) to test the feasibility of using fragments of corals of opportunity for restoration purposes. The transplants revealed high survival rates and higher number of new polyps than in control colonies. The original size of transplanted fragments did not influence their capability to bud new polyps and was not related to their survival rate. The applied technique provides the opportunity to restore rocky reefs, even the very shallow ones, through direct transplant of coral fragments, thus making reef restoration a feasible option in ecosystem-based management plans for this species.

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1. Introduction

Reefs built up by scleractinian corals are estimated to contribute with an astonishing 830,000 to the global species count being among the most diverse known habitats (Fisher et al., 2015). They also provide an array of goods (e.g., sea food, raw material for pharmaceuticals, organisms for aquarium trade, construction material, etc.) and ecological services (e.g., shoreline protection, maintenance of biodiversity and habitats, burial of CO₂, support of recreation and tourism) that make coral reefs ranking first among world habitats in terms of economic value per unit area (Moberg and Folke, 1999; de Groot et al., 2012).

Human impacts like pollution, fishing, coastal development, and climate change, are responsible for degradation of coral reefs in tropical areas, impairment of their recovery ability and ultimately loss of the goods and services they provide (Moberg and Folke, 1999; Pandolfi et al., 2003). Evidence indicates that in some tropical regions, coral reefs under low threat levels are exceptions and predictions warn that, without a global plan of conservation and management, the majority of reefs will undergo severe threat during the next few decades. Halting such threats requires an integrated approach at the ecosystem level focused on the management of sea-related human activities, and stakeholders may play a paramount role in this process (Moberg and Folke, 1999; Burke et al., 2011; Chavanich et al., 2015). For instance, diving on coral reefs is a major tourist attraction in many tropical locations, often providing substantial incomes to local communities. In some cases, part of such incomes is reinvested to support conservation programs in positive cycles (Burke et al., 2011). However, unman-

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aged or poorly managed recreational diving may represent a severe threat to coral reefs (Rinkevich, 1995). It is apparent that accidental contacts by SCUBA divers and snorkelers (kicking, kneeling, trampling, etc.) cause physical stress to corals with a strong correlation between the number of divers and that of damaged colonies (see Hasler and Ott, 2008, and references therein). However, the risk of contacts with corals falls significantly when tourists undergo educational training held by diving centres, as they are among the main stakeholders involved in coral reef conservation (Camp and Fraser, 2012; Branchini et al., 2015).

Restoration (*sensu* Edwards and Gomez, 2007) or rehabilitation (*sensu* Edwards, 2010) interventions may be necessary when coral reef degradation reaches levels that are hardly reversible using traditional management and conservation plans. In this regard, techniques involving the use of sexual as well as asexual propagules have been tested (Chavanich et al., 2015). Sexual propagules give the advantage of providing a restored reef with a higher genetic diversity. In this case, reefs are restored or rehabilitated by transplanting gravid colonies, from which the planulae produced *in situ* can settle and develop into new colonies or by inducing settlement in laboratory conditions on a proper substratum (tile, plastic support, dead colony etc.) that is then positioned on the damaged reef (Rinkevich, 1995). As far as asexual propagules are concerned, the transplant of entire or fragmented colonies has been successfully used to create a self-sustaining reef in an area where the original reef has been damaged. Cultivating fragments harvested from wild corals is functional to several purposes other than restoration, including the production of colonies for aquarium trade or research (Shafir et al., 2001, 2006a), thus reducing the burden on wild populations. However, wild donors may suffer from the removal of large fragments (Henry and Hart, 2005; Shafir et al., 2006a). To overcome this issue, the use of small (<1 cm) colony fragments (i.e. coral nubbins) has proved an efficient coral gardening technique to produce novel colonies within nursery areas in the wild which are then transplanted in damaged reef areas (Rinkevich 1995; Shafir et al., 2001, 2006b). Successful gardening experiences have been realised in tropical areas with branching species (e.g. *Acropora* spp.), while massive corals have been used less frequently. Among the latter, *Dipsastraea fava* (Forskål 1775) appeared to be a good candidate, although its survival performance (50%) was lower than in branching species (Shafir and Rinkevich, 2008). Medium-sized fragments (3.5 × 3.5 cm) of the massive coral *Porites lutea* Milne Edwards and Haime 1851 had an even lower survival rate of 23.3% that dropped further to 2.2% for smaller fragments (2.5 × 2.5 cm) (Thongtham and Chansang, 2008).

Outside tropical regions and more generally beyond 30° latitude, temperate corals and other calcifying organisms form complex 3-dimensional habitats like shallow-water coralligenous and vermetid reefs and deep/cold-water reefs, which harbour biodiversity hotspots similar to those of tropical coral reefs (Roberts et al., 2006). These biogenic reefs suffer from local (e.g., fishing, coastal development, pollution from land-based sources) and global (e.g., warming, acidification) pressures that are likely to surpass their ability to adapt and survive (Hoegh-Guldberg et al., 2007; Fabricius et al., 2011). In the Mediterranean Sea, the endemic dendrophylliid coral *Astroides calycularis* (Pallas 1766) is considered a reef forming species (European Commission, 2013) and covers up to 90% of some rocky areas in shallow waters (Goffredo et al., 2011a). Even though sparse colonies have been observed in the Adriatic Sea (Kružić et al., 2002; Grubelić et al., 2004), *A. calycularis* mostly occurs in the south-western part of the basin from the Gibraltar Strait to Sicily and the south-western coast of the Italian peninsula (Terrón-Sigler et al., 2016a; Musco et al. in press), where it is abundant from the surface to 15 m depth, although it can be observed down to 50 m. *A. calycularis* is an azooxanthellate species growing in both low and high light conditions, in caves and on vertical walls preferentially



Fig. 1. Massive colonies of *Astroides calycularis* at 2 m depth along the Zingaro coast (NW Sicily, Mediterranean Sea). Top: close-up picture. Bottom: a reef with reference measure (distance between the two red laser spots = 20 cm). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

exposed to intense hydrodynamics (Rossi, 1971; Cinelli et al., 1977; Zibrowius, 1995). The colonies have a massive-shaped morphology in shallow waters that are exposed to waves (Fig. 1), and a bush-shaped morphology at higher depths (Casado-Amezua et al., 2013). This species is gonochoric at colony level and brooder, and planulae are released from the tentacles from June to July (Goffredo et al., 2010; Casado-Amezua et al., 2013; Pellón and Badalamenti, 2016). The most frequent size class is generally from 3 to 4 mm as colonies tend to invest energy in increasing polyp size up to size at sexual maturity rather than in the growth of mature ones (Goffredo et al., 2010).

A. calycularis is considered a habitat former since its bioconstructions host a rich invertebrate fauna (Terrón-Sigler et al., 2014). It appears in the lists of strictly protected species of the Bern Convention (Annex II), endangered or threatened species of the Barcelona Convention (Annex II), and the CITES Convention. However, at present the species falls within the LC (Least Concern) category of the IUCN Italian Committee since it is spreading northwards in the Mediterranean Sea (Bianchi, 2007) and it does not appear to suffer from specific threats, although pollution and recreational diving may pose risks to its status (www.iucn.it). While studies aiming at a better understanding of the effects of pollutants on this species are needed, diving has already proved to cause serious damage to the colonies, especially in areas where its dense reefs attract SCUBA divers and snorkelers. In fact dislodged colonies on the seabed are

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