



## Effect of recreational diving on Patagonian rocky reefs



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### ABSTRACT

Tourism has grown considerably in the last decades, promoting activities such as recreational SCUBA diving that may affect marine benthic communities. In Puerto Madryn, Patagonia Argentina, sub-aquatic tourism areas (STA) receive about 7,000 divers per year. Diving is concentrated on a few small rocky reefs and 50% of the dives occur in summer. In this work, we evaluated the effect of recreational diving activities on benthic communities and determined whether diving causes a press (long-term) or a pulse (short-term) response. We quantified the percentage cover of benthic organisms and compared benthic assemblage structure and composition between two sites with contrasting usage by divers, 'highly disturbed' and 'moderately disturbed' sites, and two 'control' sites with similar physical characteristics but no diving activity, twice before and after the diving peak in summer. We found differences in benthic assemblage structure (identity and relative abundance of taxa) and composition (identity only) among diving sites and controls. These differences were consistent before and after the peak of diving in summer, suggesting that recreational diving may produce a press impact on overall benthic assemblage structure and composition in these STA. At the moderately disturbed site, however, covers of specific taxa, such as some key habitat-forming or highly abundant species, usually differed from those in controls only immediately after summer, after which they began to resemble controls, suggesting a pulse impact. Thus, STA in Golfo Nuevo seem to respond differently to disturbances of diving depending on the usage of the sites. This information is necessary to develop sound management strategies in order to preserve local biodiversity.

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## 1. Introduction

Human disturbances on formerly remote habitats are diverse and include activities such as hunting, fishing and the collection of organisms for recreational or commercial purposes (Vitousek et al., 1997; Castilla, 1999; Cloern, 2001; Crutzen, 2006). The increased use of natural habitats may lead to a decline in the resources and/or services that attracted people. Among the various human disturbances that can lead to changes in natural systems are tourism and the activities derived from it (Miller, 1993; Hall, 2001; Davenport and Davenport, 2006). Tourism has grown significantly in the last

decades and, as a consequence, marine benthic communities have been affected by boating, trampling, snorkelling and SCUBA diving (Addesi, 1994; Garrabou et al., 1998; Eckrich and Holmquist, 2000; Minchinton and Fels, 2013). In particular, SCUBA diving is amongst the fastest growing pastimes in the world, with ca 1 million new recreational divers being trained each year (Van Treeck and Schumacher, 1998; Zakai and Chadwick-Furman, 2002; Hasler and Ott, 2008). Participants are drawn to the most attractive diving sites, some of which are located in marine protected areas (Milazzo et al., 2004; Davenport and Davenport, 2006; Smith et al., 2008). Divers, however, can affect natural habitats through direct physical damage and can also interfere with ecological processes, including reproduction and growth of species, as well as trophic interactions (Zakai et al., 2000; Chabanet et al., 2005; Luna et al., 2009). Moreover, most studies on potential impacts of diving are done in tropical systems, while temperate systems have been largely

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overlooked.

In Patagonia Argentina, one of the main tourist attractions is Península Valdés (42°30' S, 64°00' W), a natural reserve created in 1983 and recognized as World Natural Heritage by the UNESCO in 1999. Puerto Madryn is the closest city to Península Valdés; therefore, tourism is one of the major activities of the city, which receives *ca* 250,000 tourists per year (Secretaría de Turismo 2014). Puerto Madryn has been among the top diving destinations in Patagonia since the late 50s, attracting several thousands of divers per year from all over the world (Sanabra, 2002; Torrejón et al., 2012). There are 14 sites within Golfo Nuevo bay, where Puerto Madryn is located, that are utilized as 'sub-aquatic tourism areas' ('STA'). STA are areas of ecological interest for sustainable tourism development and conservation. These areas are chosen because of desirable characteristics such as clear waters, shallow rocky reefs (<25 m depth), proximity to the city, impressive underwater scenery and high biodiversity. The local government is currently developing policies to formally create and regulate STA; however, these policies have not been finalized nor implemented yet.

STA usually have a predominantly flat topography with soft bottoms from which rocks outcrop forming rocky reefs (Ciocco, 1988; Galván, 2008; Irigoyen, 2010). These reefs extend from a few to several hundred square-meters and their cracks and ledges are used by a wide variety of fish species (Ciocco, 1988; Galván, 2008; Irigoyen, 2010). As in other temperate reefs, surfaces are mainly colonized by algae and sessile invertebrates such as mussels, anemones and ascidians (Osman, 1977; James and Underwood, 1994; Baynes, 1999; Piriz et al., 2003; Irigoyen et al., 2011). Water temperature in Golfo Nuevo ranges between 9 and 16 °C (Dellatorre et al., 2012); hence, divers typically use 7 mm neoprene wetsuits and large amounts of weight to control buoyancy. As a result, inexperienced divers often touch or even hit the organisms present on the rocky reefs, unintentionally damaging fragile benthic flora and fauna and creating patches of bare rock. Disturbance of the seabed and the creation of bare rock patches can, in turn, facilitate invaders, such as the invasive kelp *Undaria pinnatifida*, which has a negative effect on native algae, dramatically reducing its richness and diversity (Casas et al., 2004; Raffo and Irigoyen, 2011). In addition, local dive instructors frequently touch animals, feed fishes with benthic organisms collected on-site (e.g. mussels) and guide divers into tight spaces, all with the intention of enhancing the overall diving experience (Bravo, 2013). This diver–reef interaction, together with the great amount of divers over small areas (Bravo, 2013) could result in the deterioration of benthic communities in the STA of Puerto Madryn.

Bender et al. (1984) defined two types of human disturbances: 'pulse' and 'press'. Pulse disturbances are short-term, intense episodes of disturbances that are then removed. Press disturbances, instead, are chronic and persistent. For a conservation perspective, rehabilitation or reduction of the effects of pulse disturbances may be relatively easy compared with press disturbances, because the cause of the potential impact ends relatively fast (Bender et al., 1984; Underwood, 1992; 1994). Pulse disturbances can, however, elicit either a pulse or a press response on organisms (and vice versa; Glasby and Underwood, 1996). Most diving activities in Puerto Madryn occur during summer, with 50% of the dives occurring in January and February, while the rest is spread equally year round (Bravo, 2013). Diving may therefore be considered a pulse disturbance as most diving occurs in a particular time of the year, although at a larger temporal scale it may be considered a press disturbance as it has been repeatedly done every summer for decades. However, in terms of the type of response this disturbance may elicit on benthic assemblages, potential effects of diving may be short-term, with benthic community structure changing in response to diving during and after summer, but eventually

becoming similar to non-disturbed sites before the next diving season starts. Such short-term or acute disturbances have been classified as 'pulse' disturbances, with regards to the way affected organisms respond to them (Bender et al., 1984; Underwood, 1989). Alternatively, the effects of diving on benthic communities may be long-term, with effects on community structure lasting longer than the period between diving seasons. These long-term, chronic disturbances have been referred to as 'press' disturbances as they elicit chronic changes in the ecology of the organisms affected (Bender et al., 1984; Underwood, 1989). Understanding the type of response that recreational diving can exert on benthic communities in STA of Puerto Madryn will be useful to develop successful management strategies (Underwood, 1994; Glasby and Underwood, 1996).

There are no quantitative data available concerning the potential impacts of diving on local benthic communities. Our aim was to evaluate the effect of recreational diving activities on rocky reef benthic communities and to determine whether disturbance by diving causes a press or a pulse impact on the community as a whole and/or on specific taxa. Specifically, we predicted differences in the structure and composition of benthic assemblages between disturbed and control sites. If diving results in a press impact, we predicted a consistent difference in assemblage structure between disturbed and control sites before and after the diving season, given that disturbed sites have been used intensively for the past two decades (Bravo, 2013). If, however, diving results in a pulse impact, we predicted differences between disturbed and control sites only after the diving season. We compared the percentage cover of benthic organisms between two 'disturbed' sites, which are regularly used by divers, and two 'control' sites with similar physical characteristics but where almost no diving is done, twice before and after the diving peak in summer, and used multivariate analyses to determine potential effects at the assemblage level and univariate analyses for specific taxa.

## 2. Materials and methods

The study was performed at two disturbed sites, a 'highly disturbed' one that receives *ca* 1000 divers per summer season (42.779° S, 64.992° W), and a 'moderately disturbed' site (42.778° S, 64.988° W) that receives *ca* 500 divers per season, as well as at two 'control' sites (42.779° S, 64.959° W; 42.776° S, 64.958° W) visited by few divers only occasionally (Bravo, 2013). Sites were chosen based on the information obtained from records of the Puerto Madryn Tourism Office (Secretaría de Turismo 2014) and interviews with dive instructors and dive-centre owners (Bravo, 2013). All sites have similar reef depth (6 m), orientation, slope and substrate type. The disturbed sites are, however, closer to the coast (300 m) and to Puerto Madryn city (3 km; hence the greater usage by diving companies) than the control sites (1 km from the coast and 5 km from the city), but all sites are within 2 km from each other. Two sampling periods before (t1: November; t2: December 2011) and two after (t3: April; t4: May 2012) the season of highest number of divers (January–February; see Introduction) were chosen. A non-destructive sampling methodology was used to avoid removing living organisms and degrade natural sites. Ten 25 × 25 cm quadrats were photographed at each site and time using an underwater digital camera equipped with a frame suitable to take all images at the same distance from the substrate. Quadrats were at least 2 m apart. Photographs were analysed using the free software Coral Point Count with Excel extensions (CPCe v4.1; Kohler and Gill, 2006). One hundred equidistant points were placed over each image and the percentage cover of benthic organisms was quantified using a point-intercept method. All organisms were identified to the lowest taxonomic level possible (42% of taxa to species, 33%

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