Marine Pollution Bulletin 76 (2013) 203–213

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Assessing the impact of fishing in shallow rocky reefs: A multivariate approach to ecosystem management

Carlos Sangil [a,*], Laura Martín-García [b], Sabrina Clemente [b]

[a] Smithsonian Tropical Research Institute, Smithsonian Institution, 0843-03092 Ancon, Panama City, Panama
[b] Departamento de Biología Animal, Universidad de La Laguna, Tenerife, Canary Islands, 38206 La Laguna, Spain

ARTICLE INFO

Keywords:
Diadema africana
Trophic cascades
Conservation status
Zoning impacts
Canary Islands
NE Atlantic Ocean

ABSTRACT

In this paper we develop a tool to assess the impact of fishing on ecosystem functioning in shallow rocky reefs. The relationships between biological parameters (fishes, sea urchins, seaweeds), and fishing activities (fish traps, boats, land-based fishing, spearfishing) were tested in La Palma island (Canary Islands). Data from fishing activities and biological parameters were analyzed using principal component analyses. We produced two models using the first component of these analyses. This component was interpreted as a new variable that described the fishing pressure and the conservation status at each studied site. Subsequently the scores on the first axis were mapped using universal kriging methods and the models obtained were extrapolated across the whole island to display the expected fishing pressure and conservation status more widely. The fishing pressure and conservation status models were spatially related; zones where fishing pressure was high coincided with zones in the unhealthiest ecological state.

1. Introduction

Human activities are causing widespread extirpation of species in the marine environment (Dulvy et al., 2004) and a dramatic decline in the relative abundances of remaining species (Jakson et al., 2001; Myers and Worm, 2003; Pandolfi et al., 2003). These alterations to diversity can disrupt the structure of marine communities and the ecological functions those assemblages perform (Hughes et al., 2003). In subtropical and temperate subtidal rocky reef systems, trophic cascades are defined as predatory interactions involving three or more trophic levels, where primary carnivores indirectly increase seaweed abundance by removing herbivores (Menge, 1995). In many systems throughout the oceans, fisheries-related declines in predators have resulted in larger numbers of herbivores, creating so called barrens where grazing activity is intense, upright seaweed beds are reduced and crustose seaweeds dominate instead (Wharton and Man, 1981; Estes and Duggins, 1995; Sala et al., 1998; Shears and Babcock, 2002). Sea urchins are major grazers; where they are found at high density they can trigger the transition from upright seaweed beds to barrens and thus influence rocky reef biodiversity and functioning (McClanahan and Safir, 1990; Sala et al., 1998; Hernández et al., 2008b). The equilibrium between trophic levels is fragile and the relationship has only remained balanced in 'pristine' locations and some marine protected areas (Friedlander et al., 2010). Low levels of inshore fishing can be sufficient to cause significant decreases in the key predator populations, increase sea urchin density and indirectly effect coastal marine community organization (Sala et al., 1998; Pinnegar et al., 2000; Shears and Badcok, 2003; Guidetti, 2006; Clemente et al., 2011).

It is critical to identify the relationships between potentially damaging human activities (such as fishing) and the abundance of species at different trophic levels in order to understand system organization and ensure future marine conservation and management policies are effective (McClanahan, 1995; Clemente et al., 2010). However, community structure is known to depend not only on the incidence of fishing but also on the environmental context (Michelli et al., 2005; Shears et al., 2008; Clemente et al., 2011). Regional and even local-scale environmental variability should not be overlooked as a factor affecting the equilibrium between trophic levels in benthic marine communities, especially in systems that are markedly variable at small scales (Hernández et al., 2008b; Clemente et al., 2011). A good understanding of these key ecological processes and the consideration of all involved variables is therefore needed for planning and implementing spatial management (Almany et al., 2009).

Devising marine management plans depends on the availability of maps displaying punctual biological survey data. These maps can be constructed using geographical information systems (GIS) coupled with geostatistical modeling to extrapolate the data across

* Corresponding author. Tel.: +34 636 558 266.
E-mail addresses: casangil@ull.es (C. Sangil), lmargar@ull.es (L. Martín-García), msclemen@ull.es (S. Clemente).

0025-326X/$ - see front matter
http://dx.doi.org/10.1016/j.marpolbul.2013.08.041

large areas and create a ‘layer’ of information (Miller et al., 2007; Hengl et al., 2009). Generally, biological maps only display unique values for a key species or group (e.g. a family or single trophic group). Though simple, this information is sufficient to identify subzones within a study area and can provide a basic tool to inform environmental monitoring decisions (Jordan et al., 2005; Leleu et al., 2012; Martin et al., 2012). However, biological data from the maps can be used in a more sophisticated way links between trophic levels can be included to investigate ecosystem functioning and conservation status. Based on trophic relationships established in specific shallow rocky reefs around La Palma island (Canary Islands, NE Atlantic Ocean), we are able to present tools that test ecosystem functioning and fishing pressure via modeling across the entire insular territory. In the Canary Islands, the abundance of seaweeds and generation of extensive barrens is controlled mostly by the voracious grazing activity of *Diadema africana* sea urchins, the principal ecological engineers of shallow rocky bottoms and is able to remove all upright species (Hernández et al., 2008b; Sangil et al., 2011b). Only a few species of fish have been found to prey upon *D. africana* with adequate intensity to influence population densities in the Canary Islands (Clemente et al., 2010) and studies suggest that the removal of these predatory fish by fishing may have community-wide effects on rocky reef ecosystems (Clemente et al., 2010, 2011). Although *D. africana* occurs throughout the entire Archipelago, there is clear spatial variability in their abundance between islands and between sites on the same island related to human fishing activities (Hernández et al., 2008b; Clemente et al., 2011). Each island within the Canarian Archipelago consists of an independent large volcanic structure. The shallow subtidal platforms around each island are not continuous except between the islands of Lanzarote and Fuerteventura (Carracedo et al., 2001) and as a result each island has its own independent shallow benthic populations. Since no adult inter-island migration takes place, the population size of each organism on each island depends more heavily on the availability of habitat and the impacts of activities such as fishing (Sangil et al., 2013). For centuries, fishing has been a major activity around the coast of La Palma and most of the pressure has been focused at shallow depths between 0–50 m. In this limited fringe, commercial (100–125 individuals and 60 fishing boats) and sport fishing (5000 people: including land-based fishermen, spearfishermen and over 700 boats) coexist. Sport fishing is regulated in terms of fishing gear (only hooks may be used) and capture. Commercials do not have catch limits and use traps and nets as well as hooks (Sangil et al., 2013). However, La Palma also has a marine protected area where both sport and commercial fishing activities are regulated. Spearfishermen can only fish in four areas (see Fig. 1). In the present study, relationships between members of the three key trophic levels (primary producers, herbivores, predators of herbivores), other biological parameters and fishing activities have been examined by multivariate analyses and GIS for the first time in the Canarian Archipelago. The study is proposed as a means of providing a valid indicator of fishing pressure across the island and is potentially of use in planning future conservation strategies.

2. Methods

2.1. Study area

La Palma is the most north-westerly of the Canary Islands, located in the eastern subtropical Atlantic (Fig. 1). The island has a land surface of 706 km^2 and a coastline 180 km long (Carracedo et al., 2001). The subtidal platform (0–50 m depth) is relatively small at just 86.96 km^2. To the north of the island the platform is wider due to the greater geological age of that area. To the south the bottoms are steeply sloping and highly complex and the platform is narrow. The waters around La Palma are subtropical and for that reason nutrient levels and primary productivity are low (Martín-García et al., 2011). For most of the year the coast is subject to NNE-NE winds which cause moderate waves. During autumn and winter strong NNW-NW waves are common (Braun and Molina, 1988). Areas of water around the islands that are exposed to these winds and waves are known to be slightly cooler and richer in nutrients than less exposed areas (Martín-García et al., 2011).

Around La Palma there are several protected areas: a marine reserve (La Palma MPA) located southwest of La Palma; and two Special Areas of Conservation (SACs) belonging to the Natura 2000 Network (EU Directive, 92/43/EEC). The SACs are called Costa de Garafía and Franja Marina de Fuencaliente, and the area of the latter overlaps with the marine reserve (Fig. 1). La Palma MPA is divided between two zones: a reserve area and a no-take area, each zone restricts different activities. In the reserve area commercial fishing from boats with hooks and land-based fishing with rods are permitted whereas in the no take area all fishing activities are forbidden.

2.2. Collection of data

2.2.1. Fishing activities

We obtained data from fish traps, boat fishing, land-based fishing and spearfishing. The number and GPS position of fish traps, deployed attached to surface buoys, were recorded during boat-based surveys around the island's coastline. The mean number of boats, land-base fishermen and spearfishermen were estimated from tours in land. Land-based observation points were selected around the coastline (Fig. 1). Surveying was conducted twice per month for a year; each month, one survey was carried out on a working day and the second on a holiday or weekend day. Observations of boats, land-based fishermen and spearfishermen were made using binoculars, and their positions were recorded on paper maps. Fishing boats were only included in the survey when they were stationary and fishing and all sailboats were excluded. All data were entered into a GIS database. Due to sometimes recreational boats could not be separated from commercial, both were considered together.

2.2.2. Biological parameters

Fieldwork was conducted on SCUBA diving at 51 sites around the island in 2009 (Fig. 1). The sites, each sampled once, were located on rocky reefs between depths of 5 and 20 m. Fish assemblages were sampled *in situ* using a stationary visual count method to record the number and estimated size of relevant fishes (Bortone et al., 1989). We followed the point-count method, where the observer takes a position at the centre of 100 m^2 circle (nine per site, total $n = 459$). Only certain fish were included in the study: *D. africana* predators (*Diplodus cervinus*, *Diplodus sargus*, *Balistes capriscus*, *Bodianus scrofa*, *Canthidermis sufflamen*, *Chilomycterus atringa*) which have been appointed as keystone species needed to preserve the functioning of sublittoral rocky systems (Clemente et al., 2010); groupers (*Epinephelus marginatus*, *Mycteroperca fusca*, *Serranus atricauda*), highly vulnerable species to intense fishing (Tuya et al., 2006); and the parrotfish *Sparisoma cretense* which is a highly prized fishing resource in both local recreational and commercial fisheries across the region, known as an indicator of fishery stock status and ecosystem service defined as the availability of locally important fishing resources (Clemente et al., 2010). Fish biomass was calculated based on species specific size-biomass relationships (Froese and Pauly, 2012). Herbivore density was estimated by counting the numbers of the sea urchin *D. africana* using the belt transect method described in Hernández et al. (2008b).