Biological Conservation 160 (2013) 105–113

Contents lists available at SciVerse ScienceDirect

Biological Conservation

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

Boat anchoring impacts coastal populations of the pen shell, the largest bivalve in the Mediterranean

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ARTICLE INFO

Article history:
Received 1 July 2012
Received in revised form 7 January 2013
Accepted 16 January 2013
Available online 28 February 2013

Keywords:
Pinna nobilis
Habitat
Population structure
Hierarchical models
Bayesian analysis
Data augmentation
Capture–recapture
Population size
Individual covariate

ABSTRACT

The decline of important coastal habitats, like seagrass meadows, is likely to influence populations of associated species, like the noble pen shell, *Pinna nobilis*. Here we used a Bayesian formulation of individual covariate models to derive a reliable estimate of populations of *P. nobilis* in shallow, and thus usually most impacted, areas around the island of Majorca, Balearic Islands, Spain. At six evaluated sites we find quite distinct densities ranging from 1.4 to 10.0 individuals/100 m^2. These differences in density could not be explained by habitat factors like shoot density and meadow cover, nor did dislodgement by storms (evaluated by maximum wind speeds at the sites) seem to play an important role. However, noble pen shell density was related to anchoring as at sites where anchoring was not permitted the average density was 7.9 individuals/100 m^2 while in sites where ships anchored the density was on average 1.7 individuals/100 m^2. As for the conservation of *Posidonia oceanica* meadows, for the associated population of *P. nobilis* it would be of utmost importance to reduce anchoring pressure as a conservation measure for these endangered and protected bivalves.

1. Introduction

Coastal marine biodiversity is expected to decrease as a consequence of the biotic and abiotic changes resulting from anthropogenic activities (Hendriks et al., 2006; Jordà et al., 2012; Vaquer-Sunyer and Duarte, 2008; Waycott et al., 2009). Yet, despite a general consensus on this scenario, the current state of many benthic populations and the factors threatening their persistence are still poorly understood (Irish and Norse, 1996; Kochin and Levin, 2003; Lawler et al., 2006). Consequences of this knowledge gap are major uncertainties concerning adequate managerial strategies to address the emerging conservation problems (Norse and Crowder, 2005) for benthic populations in littoral areas. Marine communities in coastal areas are characterized by the presence of 'ecosystem engineers', species able to modify the physical and geochemical conditions in their environment, facilitating the life of other organisms in the community (Bouma et al., 2009; Jones et al., 1994). The reduction of ecosystem engineers is likely to create an extinction cascade difficult to evaluate (Coleman and Williams, 2002; Gutiérrez and Jones, 2008; Gutiérrez et al., 2012; Ormerod, 2003). The most important engineer species in the Mediterranean Sea are corals, bivalves and seagrasses. Seagrass, particularly *Posidonia oceanica*, meadows directly modify the nature and complexity of sediment composition and contribute to increase water clarity (Duarte, 2000; Gutiérrez et al., 2012; Hendriks et al., 2010). However, *Posidonia* meadows are declining (Marbà and Duarte, 2010; Marba et al., 2005) in parallel to mounting impacts of human activities in Mediterranean coastal ecosystems (e.g. Vaquer-Sunyer and Duarte, 2008). The decline in *Posidonia* meadows, resulting from compounded local and global effects, is so dramatic as to severely impact these ecosystems or even possibly drive them to functional extinction before the end of this century (Jordà et al., 2012). This will impact the populations of species associated with *Posidonia*, some of them of particular conservation importance.

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0006-3207/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biocon.2013.01.012

The species associated with *P. oceanica* which status is most compromised is arguably the noble pen shell, *Pinna nobilis*, the largest bivalve of the Mediterranean Sea. The noble pen shell is threatened by ocean acidification, habitat loss and/or direct human disturbance like recreational or commercial fishing, their use for decorative purposes, and incidental mortality by trawling and anchoring (Richardson et al., 1999; Katsanevakis, 2007a; Katsanevakis, 2009; Rabaoui et al., 2007). Typical reported values of noble pen shell densities within the Mediterranean basin are in the range of a few (1–10) individuals per 100 m^2 (Moreteau and Vicente, 1982; Vicente et al., 1980; Zavodnik et al., 1991). Its populations are in decline, and the species is listed as endangered and protected under the European Council Directive 92/43/EEC (EEC, 1992). The noble pen shell is particularly vulnerable to anchoring impacts, associated with the increasing use of Mediterranean coastal areas (Milazzo et al., 2004). The noble pen shell is typically associated with meadows of the seagrass *P. oceanica*. Even though there are populations of noble pen shells that are not associated to seagrass meadows (Addis et al., 2009; Katsanevakis, 2005, 2007b), this is an exception and normally populations are closely linked to seagrass habitats. Seagrass provides shelter for small animals from storms that can dislodge them (Garcia-March et al., 2007; Hendriks et al., 2011), increases food supply for filter feeders by reducing current flow and trapping particles (Hendriks et al., 2008; Peterson et al., 1984) and provides shelter from predators. Additionally, since it is illegal (EC 1626/94) to use bottom trawls, seines or similar nets above seagrass habitats in the Mediterranean, association with this habitat effectively protects against commercial fishery. In littoral areas used for recreational tourism, many meadows have been impacted by anchoring and pollution from recreational boating, which is insufficiently regulated around the islands (Procaccini et al., 2003; Sánchez-Camacho, 2003). Seagrass habitats are sensitive to damage from dragging anchors (Backhurst and Cole, 2000; Ceccherelli et al., 2007; Duarte, 2002; Walker et al., 1989). The noble pen shell has relatively fragile shells, stands upright in the seagrass meadows, and protrudes up to 70 cm above the sediments, and can be damaged directly by the anchor track. The persistence of noble pen shell populations is dependent on anthropogenic impacts, but also on habitats properties. However, the latter are poorly understood.

Our first objective was to derive an estimate for the population density of *P. nobilis* around the Balearic Islands and investigate whether habitat characteristics or physical forcing are determining the spatial differences in population density and structure. Capture-mark-recapture (CMR) models, based on multiple observations of marked individuals, can be used to estimate animal abundance (Seber, 1982; Williams et al., 2002). CMR models include a set of parameters to account for the observational process, such as detection failures (Schwarz and Anderson, 2001; Williams et al., 2002), expected to be a problem for organisms living in seagrass meadows. Traditional models rely on the hypotheses that all individuals are equally likely to be captured. If not corrected, unequal catchability leads to biased estimates of the animal abundance (Pollock et al., 1990). Hendriks et al. (2012) found that the probability of detection of noble pen shells in Posidonia meadows is positively associated with shell size, but that this association is similar across sites. In contrast, we expect population density and structure to vary spatially. Royle (2009) have showed how size-dependent recapture can be incorporated into models for population abundance using data augmentation techniques (Kéry and Schaub, 2012; Royle and Dorazio, 2008). Here we extended the model to stratified data and simultaneously analyzed the CMR data from five different sites. We then test whether site dependent differences were influenced by site-specific anchoring pressures or by the physical characteristic of the habitat. This information can be used to focus conservation efforts for the population of endangered bivalves in coastal areas.

2. Methods

2.1. Study area

We conducted a survey along the coastline of Majorca, Baleares, Spain at six sites, Magalluf (39°30.1′N, 2°32.36′E), Cala ́dOr (39°22.164′N, 3°13.887′E), Pollença (39°53.792′N, 3°05.523′E), Es Cargol (39°16.394′N, 3°2.476′E), Sta. Maria (39°9.00′N, 2°56.96′) and Es Castell (39°9.12′N, 2°55.48′); Fig. 1). The six sites had a uniform depth between 5 and 6 m but contrasting anchoring pressure and physical characteristics. Magalluf is an area with important tourist development with associated pollution (Medina, 2004)

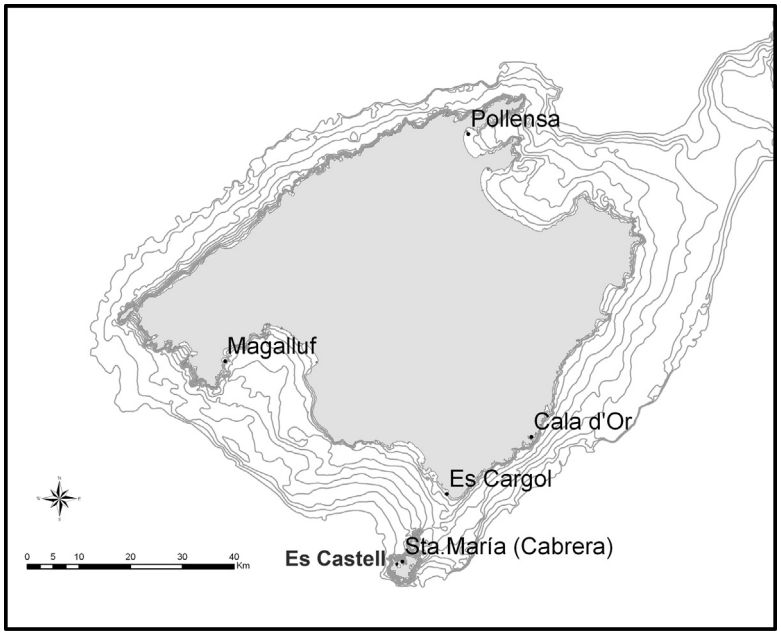

Fig. 1. Map with the locations of the sites where surveys were conducted around the island of Majorca, Balearic Islands, Spain.