Marine Environmental Research 130 (2017) 282–292

Contents lists available at ScienceDirect

Marine Environmental Research

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

Long-term assessment of recruitment, early stages and population dynamics of the endangered Mediterranean fan mussel *Pinna nobilis* in the Columbretes Islands (NW Mediterranean)

Diego K. Kersting [a, b, *], José R. García-March [c]

[a] Departament de Biologia Evolutiva, Ecologia i Ciències Ambientals, Facultat de Biologia, Universitat de Barcelona, Barcelona, Spain
[b] Working Group on Geobiology and Anthropocene Research, Institute of Geological Sciences, Freie Universität Berlin, Berlin, Germany
[c] IMEDMAR-UCV, Institute of Environment and Marine Science Research, Universidad Católica de Valencia SVM, Calpe, Alicante, Spain

ARTICLE INFO

Article history:
Received 15 June 2017
Received in revised form
13 August 2017
Accepted 19 August 2017
Available online 19 August 2017

Keywords:
Pinna nobilis
Pinna rudis
Recruitment
Growth
Larval collectors
Population dynamics

ABSTRACT

A long-term experimental approach was undertaken to assess viability and resilience of the endangered Mediterranean fan mussel *Pinna nobilis*. Artificial and natural recruitment, mortality, population traits and juvenile growth were assessed in seasonal and annual surveys. In the Columbretes Islands, *P. nobilis* thrives in differing substrate types, from coarse sand to boulders, in *Cymodocea nodosa* meadows and among rhodoliths, and is always found sharing habitat with the less abundant sibling species *P. rudis*. In artificial collectors larval settlement occurred over a several months period, concentrating its peak in September and resulting from two separated spawning events. Recruitment in the collectors showed high inter-annual variability and was independent of depth, but positively correlated with seasonal water temperature increase in June. Natural recruitment of *P. nobilis* was low and showed little variability, evidencing the existence of intense post-settlement processes. Adult mortality was also low, thus leading to slow population dynamics and to the species' vulnerability to catastrophic events. Population size structure suggests the existence of a refuge size above 45 cm shell length. The fast growth during the first years of life would help shortening this vulnerability period. Altogether, essential information and tools for the species' conservation are provided, which will be critical in the current context of mass mortalities affecting *P. nobilis*.

1. Introduction

Recruitment, juvenile survival and growth, are critical in determining adult population structure and thus, knowledge on these traits is essential to assess population dynamics and viability in marine species (Caley et al., 1996; Roughgarden et al., 1985). Particularly, in endangered species the study of life-history traits becomes critical to accurately assess their status and develop appropriate protection tools (Powles et al., 2000). Altogether, the study of population dynamics and life-history traits is considered a priority under the focus of conservation biology (Soulé and Kohm, 1989).

The Mediterranean endemic fan mussel *Pinna nobilis* is one of the largest bivalves of the world and the largest in the Mediterranean Sea (Zavodnik et al., 1991). It occurs in coastal areas, between 0.5 and 60 m depth, mainly on soft sediments colonized by seagrass meadows (Basso et al., 2015b), but also on other type of substrata such as bare sand (Katsanevakis, 2007; Rabaoui et al., 2007; Richardson et al., 1999), mud (Richardson et al., 1999), rhodolith beds (García-March and Kersting, 2006), pebbly bottoms (Richardson et al., 1999; Zavodnik, 1967) or among boulders (García-March and Kersting, 2006). Density values in *P. nobilis* populations are around 1 individual 100 m^{-2} (Coppa et al., 2010; García-March et al., 2007a; Guallart and Templado, 2012; Siletic and Peharda, 2003), however higher densities have been reported in many areas (Basso et al., 2015b; Prado et al., 2014).

Populations of this long-lived species have been greatly reduced during the past decades as a result of human activities (Hendriks et al., 2013; Katsanevakis, 2007; Rabaoui et al., 2007; Richardson et al., 1999). Consequently, *P. nobilis* has been included in the European list of species for which specific conservation strategies

* Corresponding author. Departament de Biologia Evolutiva, Ecologia i Ciències Ambientals, Facultat de Biologia, Universitat de Barcelona, Barcelona, Spain.
E-mail address: diegokersting@gmail.com (D.K. Kersting).

http://dx.doi.org/10.1016/j.marenvres.2017.08.007
0141-1136/

should be implemented (ANNEX II, Barcelona Convention) and surveillance of the conservation status undertaken (ANNEX IV, Habitats Directive).

Reproduction of the fan mussel has been reported to occur between June and August (De Gaulejac, 1995). Despite larval stages have not been studied in detail, larval period has been estimated to last a maximum of 10 days (Butler et al., 1993; De Gaulejac and Vicente, 1990). Larval settlement has been observed to occur in a wide seasonal range, from late summer (Cabanellas-Reboredo et al., 2009) to autumn and winter (Richardson et al., 2004). Recruitment has been described to be patchy (Butler et al., 1993) and to occur mostly in soft-bottom areas covered by seagrass meadows and bare sand bottoms (Katsanevakis, 2007; Zavodnik et al., 1991).

Growth rates have been assessed both through direct measurements (Acarli et al., 2011; García-March et al., 2007a; Moreteau and Vicente, 1982) and indirect approaches (Galinou-Mitsoudi et al., 2006; García-March et al., 2011a; Katsanevakis, 2007; Richardson et al., 2004, 1999; Siletic and Peharda, 2003), being described as some of the highest in bivalves (Richardson et al., 2004).

There is, however, a knowledge gap on the early stages of *P. nobilis* (Basso et al., 2015b) and little attention has been paid to the growth of recently settled juveniles. In laboratory, juveniles have been used to study potential effects related to climate change and acidification (Basso et al., 2015a), as well as to monitor growth over short periods of time (13 days) (Hendriks et al., 2012). While in open waters, Kožul et al. (2012) and Hendriks et al. (2012) assessed juvenile growth in cages in the Adriatic and Western Mediterranean Sea, during periods of 1 year and 6 months, respectively.

Experimental approaches to the study of larval settlement and recruitment based on the deployment of artificial structures (settlement or larval collectors), are widespread in marine invertebrate research (e.g. Cabanellas-Reboredo et al., 2009; Hereu et al., 2004; Mundy, 2000). These artificial structures can be used to estimate total recruitment, i.e. excluding early post-settlement processes such as predation, when using collectors that provide refuge from predators.

In the present study, early stages of the Mediterranean endemic bivalve *P. nobilis* were assessed using long-term, *in situ* experimental approaches and were compared with data from this bivalve populations in the same area. It must be highlighted that studies on age and growth in this species have been recently recommended to obtain more information on its resilience (Basso et al., 2015b). Furthermore, the urge of knowledge on these issues has drastically increased in the context of the worrying recent mass mortality that is affecting the species in the Western Mediterranean Sea (Vázquez-Luis et al., 2017). The mass mortality, most probably caused by a Haplosporidian-like parasite, has drastically decimated *P. nobilis* populations over hundreds of kilometres in central and southern Spanish Mediterranean coasts (including the Balearic Islands) and there is a high probability that the infection is still in a spreading phase (Vázquez-Luis et al., 2017).

2. Materials and methods

2.1. Study site

The Columbretes Islands emerge in open waters at 30 nautical miles off the coast of Castelló (Spain, NW Mediterranean) surrounded by water depths of 80–90 m. The archipelago is formed by four main islet groups (Illa Grossa, Ferrera, Foradada and Carallot) and is encircled by a 5500 ha marine reserve established in 1990 by the Spanish Ministry of Agriculture, Food, Fisheries and Environment.

2.2. Inter-annual larval collectors

Recruitment of *P. nobilis* was assessed using larval collectors installed in four locations inside no take zones of the Columbretes Islands Marine Reserve during 9 annual recruitment periods from 2003 to 2011 (Fig. 1). Larval collectors consisted of plastic mesh bags (8 l volume and 0.8 cm mesh-size) filled with tangled nylon fishing net. The bags were attached to a main rope that was fixed to a concrete mooring and kept vertical by a submerged buoy. Mesh collectors were attached to the main rope at 1.5 m intervals between 5.5 and 13 m depth (Fig. 2a). Larval collectors were installed in the Illa Grossa inlet (Mancolibre), in the Western side of the Illa Grossa islet (Rossí), and near the islets of Foradada and Carallot (Fig. 1). Three of these four sites host dense *P. nobilis* populations (Illa Grossa inlet, Foradada and Carallot) in different types of substrata (*Cymodocea nodosa* meadows, boulders and maërl beds), while the species is practically absent in the fourth site (Rossí) (García-March and Kersting, 2006).

Larval collectors were moored annually in early-summer (June) and removed in mid-autumn (November) from 2003 to 2011. The collector in the Carallot islet was lost in 2003, therefore, data for this location during that year is missing in the series.

Once removed, the bags were immediately opened and all *P. nobilis* recruits were carefully collected from the nylon mesh (Fig. 2b, c, d, e). Individuals recorded in the collectors were considered as recruits, because they had survived to a specific size after settlement (Rodriguez et al., 1993). Observation of *P. nobilis* recruits was undertaken with the naked eye, allowing the detection of recruits of sizes down to 0.3 cm of antero-posterior length. Measurements of the antero-posterior length and width of each juvenile were made in aquaria at the laboratory of the marine reserve.

Bhattacharya (1967) method was used to assess the number of cohorts in each recruitment season. This method allows the decomposition of length-frequency distributions into a series of Gaussian components through iterative computations of regression lines (e.g. Casale et al., 2011; Close et al., 2010). Mean size and standard deviations of each Gaussian component representing a strong mode were estimated.

A generalized linear mixed model (GLMM) with a Poisson error

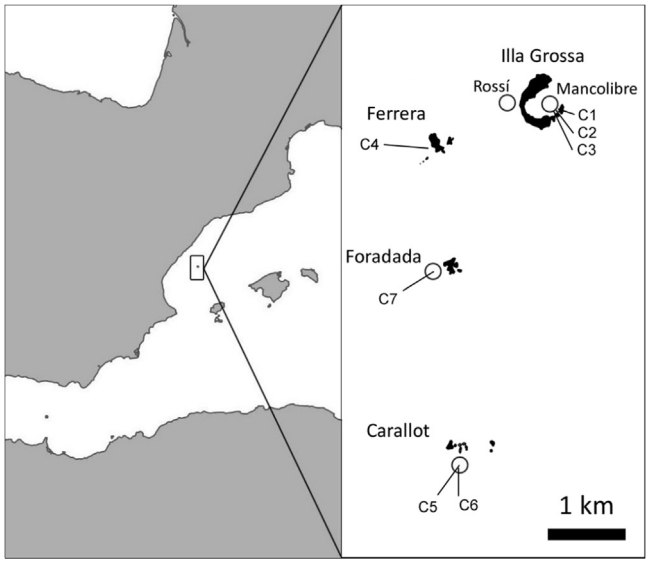

Fig. 1. Columbretes Islands, locations were larval collectors were installed throughout the studied period (circles) and monitoring stations (C1 to C7).