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Is the local extinction of *Pinna nobilis* facilitating *Pinna rudis* recruitment?

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Abstract

Until the late 2010s, the spiny fan-mussel *Pinna rudis* shared its habitat in many Mediterranean sites with the Mediterranean endemic *Pinna nobilis*, which used to be dominant, but has recently become locally extinct in most of its distribution areas due to a widespread disease outbreak. In the Columbretes Islands Marine Reserve (NW Mediterranean), both species coexisted until 2017, when *P. nobilis* populations completely disappeared. In spring 2021, we revisited seven permanent plots covering 1,485 m^2 that had been previously monitored from 2005 to 2009. We found that although previous studies have described *P. rudis* populations as stable with low recruitment rates, recruitment increased after 2017 in comparison to 2005-2009. At least two cohorts of recruits (~3 and ~1 year in age, respectively) were found in the plots as well as in other areas throughout the Columbretes archipelago, colonizing areas previously occupied by *P. nobilis*. We hypothesize that *P. rudis* has benefited from the local extinction of *P. nobilis*, most probably as a result of reduced interspecific competition. The ecological role once played mainly by *P. nobilis* as the dominant species might now be played by *P. rudis*, whose populations could grow in the coming years.

Keywords: *Pinna rudis*; *Pinna nobilis*; recruitment; mortality; Mediterranean Sea.

Introduction

The spiny fan-mussel *Pinna rudis* (Linnaeus, 1758) is well distributed along the African Atlantic coasts, but shows a more restricted distribution in the Mediterranean Sea, where it occurs mostly in the southwest, with fewer records of it along the northern and eastern coasts (Poppe & Goto, 1993; Barea *et al*., 2008; Gvozdenović *et al*., 2019). *Pinna rudis* has been generally described as preferring rocky substrata, although it can be also found in seagrass meadows and in detritic and rhodolith beds (Poppe & Gotto, 1993; Kersting & García-March, 2017). It is listed in Annex II of the Bern Convention as a strictly protected species and in Annex II of the Barcelona Convention as a threatened or endangered species.

Although little is known about the population dynamics of *P. rudis*, its populations have been described to be very stable and characterized by many adults but few juveniles (Nebot-Colomer *et al*., 2016; Kersting & García-March, 2017). Kersting & García-March (2017) assessed the population dynamics of *P. rudis* in several areas in the Columbretes Islands Marine Reserve (NW Mediterranean), observing that both mortality and recruitment remained nil over a period of five years (2005-2009).

The distributions of *P. rudis* and its sibling species *Pinna nobilis* overlapped in many Mediterranean sites, forming mixed populations that were largely dominated by *P. nobilis* (Vicente, 2010; Kersting & García-March, 2017; Gvozdenović *et al*., 2019). After the mass mortality event beginning in 2016 that pushed *P. nobilis* to the brink of extinction (Vázquez-Luis *et al*., 2017; Kersting *et al*., 2019; Katsanevakis *et al*., 2021), *P. rudis*, which has remained unaffected by these episodes (Catanese *et al*., 2018), is the only pinnid left in these once mixed populations.

Recently, alongside the decline in *P. nobilis* numbers, sightings and reports of *P. rudis* have increased on citizen science platforms and social media (e.g., Observadores del Mar, www.observadoresdelmar.es; Twitter, www.twitter.com). It has even been reported in Lake Faro (Sicily), where it had never been observed before (Donato *et al*., 2021).

Here, we present the results of revisiting seven permanent plots where the population dynamics of *P. nobilis* and *P. rudis* had been monitored from 2005 to 2009 in the Columbretes Islands Marine Reserve (NW Mediterranean, Kersting & García-March, 2017) to quantify changes in the dynamics of mortality and recruitment of *P. rudis* after the *P. nobilis* mass mortality event.

Material and Methods

Study site

The Columbretes Islands are a volcanic archipelago located at 30 nautical miles off the coast of Castelló (Spain, NW Mediterranean), encircled by a 5,500-ha marine reserve established in 1990.

Sampling

Seven permanent plots (total surveyed area of 1,485 m^2) at a depth range of 17-30 m and distributed throughout the Columbretes Islands Marine Reserve were revisited during the spring of 2021. These permanent plots were first established in 2005 and monitored until 2009 (Kersting & García-March, 2017). The plots have three types of habitats (*Cymodocea nodosa* meadows, rhodolith beds and rocky bottoms), where mixed populations of *P. nobilis* and *P. rudis* thrived in 2005-2009 (Kersting & García-March, 2017).

The plots were monitored using the methodology described in Kersting & García-March (2017), i.e., circle sampling where each pinnid found was measured (length and width above the sediment), tagged and positioned by recording the distance from the center of the circle and the orientation of the measuring tape. The area of the circles was thoroughly explored to evaluate mortality and recruitment. Total shell length (including the buried portion) was calculated using the equation proposed by Lopes *et al*. (2018) and the length-width relationship reported by Hernandis *et al*. (2021). All the individuals found were identified at the species level. It must be noted that *P. rudis* juveniles are easily distinguishable from *P. nobilis* juveniles once they reach a certain size (Kersting *et al*., 2020).

In addition, exploratory dives were performed in August 2021 to gather further information on the presence of *P. rudis* recruits at other sites within the marine reserve.

Results and Discussion

A total of 11 *P. rudis* individuals was recorded in the circles in 2021 (Table 1). Surprisingly, 10 of them were young specimens and only one was an adult already identified in the 2005-2009 period by Kersting & García-March (2017). Those authors reported neither recruitment nor mortality during their 5-year study, suggesting slow and stable population dynamics that depended highly on the survival of the adults. Similar population dynamics were reported by Nebot-Colomer *et al*. (2016), who found that *P. rudis* populations were characterized by many adults and few juveniles in the Cabrera National Park (Balearic Islands). However, this static scenario seems to have changed drastically since 2009 and most probably after 2017, when *P. nobilis* mortality occurred in the Columbretes Islands, about one year after the first report by Vázquez-Luis *et al*. (2017). In 2009, the last year that was monitored by Kersting & García-March (2017), 46 *P. nobilis* individuals were recorded inside the permanent plots. However, as expected, we did not find any *P. nobilis* individuals during the surveys. Although larval recruitment of this species has been recorded in larval collectors in the Columbretes Islands for several years after the mass mortality event (Kersting *et al*., 2020), we did not find any *P. nobilis* juveniles or recruits.

All the *P. rudis* juveniles recorded in the circles (n = 10) had similar sizes, i.e., ~20-25 cm in total length. We estimated an age of ~3 years for this size, according to the information provided by Nebot-Colomer *et al*. (2016) and Hernandis *et al*. (2021) as well as the juvenile growth data available from the sibling species *P. nobilis* (Kersting & García-March, 2017). This indicated that the *P. rudis* juveniles might have been recruited around 2017-2018. It must be noted that 2017 was an outstanding year for *P. nobilis* larval recruitment (Kersting *et al*., 2020), with García-March *et al*. (2020) reporting the same for *P. rudis*. Although no smaller juveniles were found in the surveyed circles, exploratory dives during the summer of 2021 showed that another successful recruitment event happened most probably in 2020, since many small juveniles (n > 10, 6-10 cm

Table 1. *Pinna rudis* number and density of individuals (per 100 m^2) (separated by/) within the population dynamics circles fixed in 2005 in the Columbretes Islands Marine Reserve. All individuals in 2021 except one in Carallot (*) are ~3 yr. old juveniles. [1] Data from 2005-2009 extracted from Kersting & García-March (2017).

Permanent plot	2005 [1]	2007 [1]	2009 [1]	2021
Mancolibre 1 (314 m^2)	1/0.3	1/0.3	1/0.3	**0**
Mancolibre 2 (201 m^2)	2/1	2/1	2/1	**1/0.5**
Mancolibre 3 (201 m^2)	0/0	0/0	0/0	**0**
Ferrera (254 m^2)	0/0	0/0	0/0	**1/0.4**
Foradada (201 m^2)	1/1.5	1/1.5	1/1.5	**0**
Carallot 1 (113 m^2)	3/2.7	3/2.7	3/2.7	**5/4.4**
Carallot 2 (201 m^2)	0/0	0/0	0/0	**4/2***

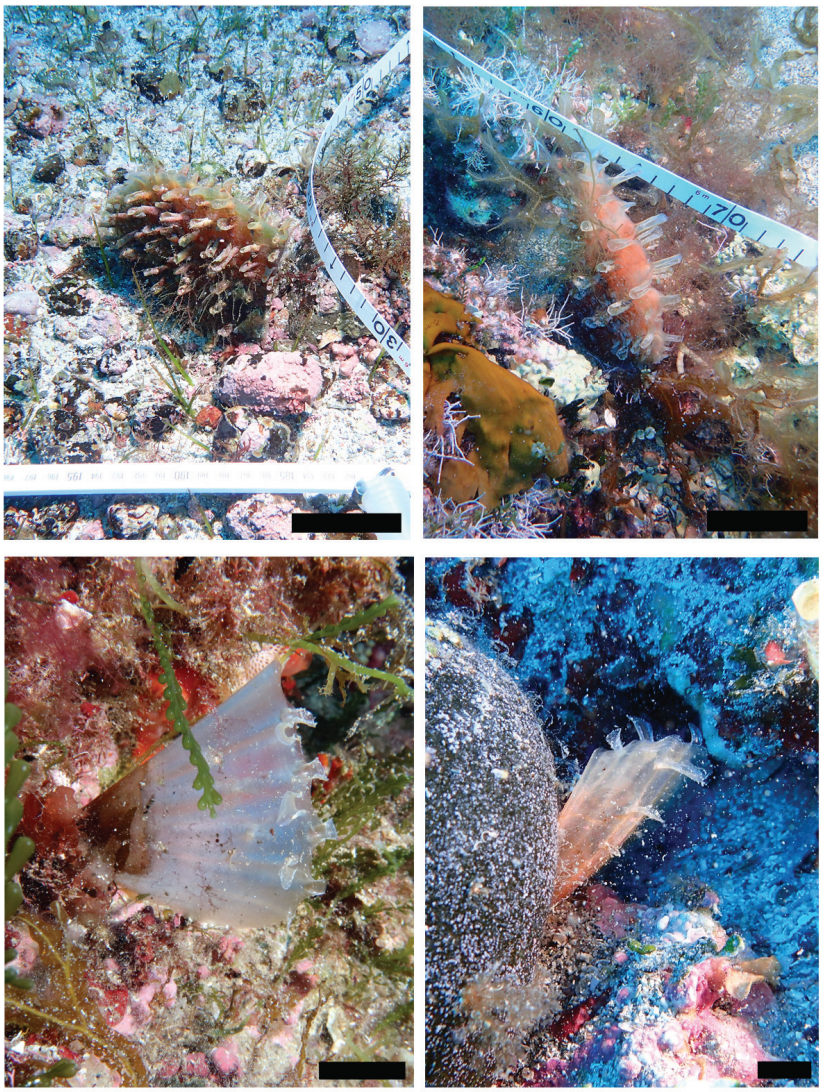

Fig. 1: *Pinna rudis* juveniles found inside the permanent plots (upper pictures, scale bar 5 cm) and younger juveniles found during the exploratory dives (lower pictures, scale bar 1 cm).

in total length, i.e., about 1 year in age; Fig. 1) were found between the depths of 8 m and 35 m.

The comparison of our results with the information provided by Kersting & García-March (2017) indicates that the success of *P. rudis* recruitment seems to have increased after the decline of *P. nobilis* in the Columbretes Islands in these once mixed populations. A similar situation was reported by Donato *et al*. (2021) at shallower depths in Lake Faro (Sicily), where *P. rudis* was not present before the *P. nobilis* mass mortality event. Sightings of *P. rudis* have also increased at other Mediterranean sites, such as the French coasts, including Corsica (Vicente, 2021), and in the Cabrera Archipelago National Park (Balearic Islands, Spain; E. Ballesteros, pers. obs.). It is also remarkable that only one of the 7 individuals found in the circles in 2009 was found alive in 2021. It has to be noted that *P. rudis* has remained unaffected by the disease that is causing *P. nobilis* decline. In fact, many *P. rudis* adults and juveniles were found in the Columbretes Islands during our exploratory dives. Therefore, we do not consider the disease to be a cause of this increased mortality. Moreover, although mortality rates have increased in relation to those reported for the 2005-2009 period, the current *P. rudis* density in the Columbretes Islands has increased compared to that of 2009 due to the recent successful recruitment episodes.

Although we do not have an explanation for the recent colonization success of *P. rudis* in the Columbretes Islands, the disappearance of the once dominant *P. nobilis* species could have increased the recruitment success of *P. rudis* through the drastic reduction of the larvae being filtered by the once abundant and large-sized *P. nobilis* individuals (a mid-sized *P. nobilis* specimen can filter up to 1,500-2,000 liters per day; Hernandis, 2021). However, little is known about the larval stage of *P. rudis* and the interspecific competition between these congeneric species, and other unknown factors are most probably involved. It must be also noted that *P. rudis* is a thermophilic species and its expansion could also be facilitated by the ongoing warming trends.

In conclusion, only three years after the local extinction of *P. nobilis* in the Columbretes Islands, the congeneric species *P. rudis* is notably increasing its density and colonizing the grounds left free by the disappearance of

P. nobilis. The current pinnid populations in the Columbretes Islands are composed of *P. rudis* and *P. rudis*-*P. nobilis* hybrids, i.e., disease-resistant individuals that share morphological traits of both species, and that have been also observed at other sites where both species coexisted (Vázquez-Luis *et al*., 2021). In this regard, it is also important to note that both pinnids are genetically close, potentially having a common origin. Therefore, their distributions could have been geographically split in the past before overlapping more recently (Lemer *et al*., 2014). The ecological role once played mainly by *P. nobilis* might now be played by *P. rudis*, whose populations could be expected to continue growing in the coming years.

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