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Toward a recovery of the pen shell *Pinna nobilis* in the French Mediterranean open sea?

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Abstract. As a result of the massive mortality event impacting *Pinna nobilis* populations throughout the Mediterranean since 2016, with a mortality rate estimated at as much as 100 % in the waters of the Port-Cros Archipelago Marine Protected Area (Port-Cros National Park, eastern Provence, France), living pen shell were found in August 2020 on the south side of the island. Initial monitoring identified 8 living young individuals in November 2020. These individuals were still alive in March 2021.

Keywords: *Pinna nobilis*, *Haplosporidium pinnae*, *Mycobacterium*, mass mortality event, recovery, north-western Mediterranean Sea.

Résumé. Vers une reconstitution des populations de grande nacre *Pinna nobilis* en Méditerranée française ? À la suite d'une mortalité massive des populations de grande nacre *Pinna nobilis* à travers toute la Méditerranée depuis l'automne 2016, et une estimation de leur mortalité dans les eaux de l'aire marine protégée de l'archipel de Port-Cros (Parc national de Port-Cros, Provence orientale, France) proche de 100 %, des grandes nacres vivantes ont été trouvées en août 2020 sur la face sud de l'île. Les premiers suivis ont permis d'identifier 8 jeunes individus vivants en novembre 2020. Ces individus étaient toujours vivants en mars 2021.

Mots-Clés : *Pinna nobilis*, *Haplosporidium pinnae*, *Mycobacterium*, mortalité massive, recolonisation, Méditerranée nord-ouest.

Introduction

The pen shell *Pinna nobilis* Linnaeus 1758, a bivalve endemic to the Mediterranean Sea, is since 1992 strictly protected in Europe by the European Habitat Directive (92/43/EEC - Annexe IV) as a species of community interest. Populations of this species have been on the decline on the French coast for many years, mainly due to anthropogenic impacts such as pollution, boat mooring, trawling and the artificialization of the coastline (Vicente *et al.*, 2016). Already considered as vulnerable species, a mass mortality event has been devastating the species

since late 2016. The mass mortality event began in north-eastern Spain (Costa Blanca, Balearic Islands) impacting individuals of all sizes and regardless of the depth. Since then, the disease has spread rapidly along the Mediterranean coasts. It has already affected the whole of the Mediterranean basin, along the coasts of France, Spain, Greece, Cyprus, Italy, North Africa (Cabanellas-Reboredo *et al.*, 2019) and the Adriatic Sea (Šarić *et al.*, 2020). At the end of 2019, the mortality of *Pinna nobilis* was estimated at up to 85 % in most locations in the Mediterranean Sea. In some coastal lagoons and estuaries, the mortality seems to have been less pervasive than in the open sea, and many surviving individuals have been reported, for example, in France, in Carteau Bay (GIS Posidonie, comm. pers. 2020), in Thau Lagoon (Foulquié *et al.*, 2020) and in the Corsican Diana Lagoon (Simide *et al.*, 2019), and in Spain (Ebro Delta, Prado *et al.*, 2019). In 2019, *Pinna nobilis* was listed as “Critically Endangered” on the IUCN Red List of threatened species (Kersting *et al.*, 2019). In 2020, in the Port-Cros National Park, the mortality was estimated as close to 100 % of individuals.

The mass mortality of the pen shell is due to a parasite, *Haplosporidium pinnae* Catanese *et al.*, 2018, a new species of Rhizaria, described in 2018 (Catanese *et al.*, 2018). Several recent studies confirmed the co-occurrence of several pathogens together with *H. pinnae*, in particular bacteria of the genus *Mycobacterium* Lehmann & Neumann (1896) (Carella *et al.*, 2020; Lattos *et al.*, 2019; Šarić *et al.*, 2020). In most cases, *Mycobacterium* bacteria occur naturally in bivalves and play a role in the degradation of dead organisms. They are therefore not necessarily the pathogens responsible for mortality.

Materials and methods

A field survey was carried out using SCUBA diving from 15 to 22 August 2020 around Port-Cros Island, and in particular in areas known for their historical populations of *Pinna nobilis*, and in November 13th 2020 in the area concerned by living *P. nobilis*. A survey of this area was carried out on March 27th 2021 to verify the survival of the pen shells. The unburied length (uL) of living pen shells was measured *in situ* to the nearest centimetre.

Results and discussion

The first three living individuals were discovered in August 2020 off the south coast of Port-Cros Island (eastern Provence, France). In November 2020, a field survey in the concerned area was carried out, and 8 living individuals were recorded (Fig. 1). The 8 living

pen shells were observed between 23 to 27 m depth distributed over an area of approximately 1 000 m² (Table I). In the same area, 42 dead pen shells were observed (Fig. 2). The bottom is constituted of detritic sediment together with bryozoans and shell debris and free-living calcified red algae (Corallinales). This community is characteristic of Mediterranean detritic soft sediment exposed to deep-sea current. The colonization by the invasive green alga *Caulerpa cylindracea* Sonder is extensive (Fig. 2).



Figure 1. Living pen shell *Pinna nobilis* in the concerned area off the south coast of Port-Cros Island, August 2020. © Sandrine Ruitton.

Table I. Unburied length (uL), total length (Lt) estimated using the equation of Gaulejac and Vicente (1990), and depth of the 8 living individuals of *Pinna nobilis* recorded on the south coast of Port-Cros Island in November 2020. N: number of the individuals.

N	uL (cm)	Estimated Lt (cm)	Depth (m)
1	20	45	24.7
2	9	21	24.1
3	8	19	25.1
4	12	28	25.4
5	14	32	27.1
6	20	45	23.0
7	10	24	27.0
8	8	19	25.0

The living *Pinna nobilis* ranged from 8 to 20 cm in length (unburied length uL, Table I) for a mean length of 13 cm (standard deviation: sd = 5). As *P. nobilis* lives with its anterior part buried vertically in sandy substrate, it is difficult to measure the exact total length of individuals. The total shell length (Lt; in cm) was estimated using the equation applied to the field data (Gaulejac and Vicente, 1990): $Lt = 2.186 * uL + 1,6508$, (Lt: total length; uL: unburied length).

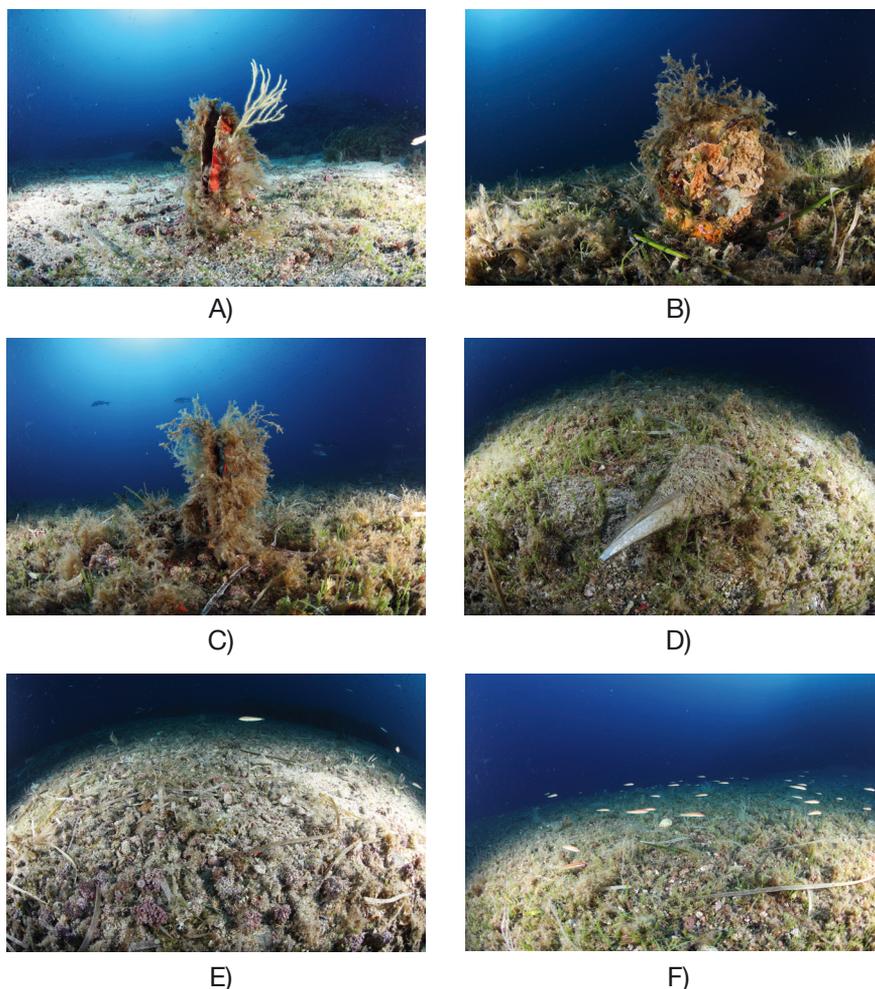


Figure 2. Dead *Pinna nobilis* colonized by a white gorgonian *Eunicella singularis* (Esper, 1791) (A), by encrusting bryozoans (B), by Phaeophyceae *Dictyopterus polypodioides* (A.P. De Candolle) J.V. Lamouroux (C), dead *P. nobilis* lying on the bottom (D), detritic bottom in the area concerned by living *P. nobilis* (E) and detritic bottom colonized by *Caulerpa cylindracea* (F). © Sandrine Ruitton, August 2020.

The equation of García-March and Ferrer Ferrer (1995) was not used in this study because the shell width at sediment level was not measured on all pen shells during the field survey. According to the model age / total length of Richardson *et al.* (1999) and Moreteau and Vicente (1982), the age of individuals is estimated at from 1 to 3 years and they probably settled in this area between summer 2017 and summer 2019.

At the end of March 2021 (27/03/2021), those individuals were still alive. Three individuals of small *Pinna rudis* Linnaeus, 1758, were also observed during the survey. On the French Mediterranean coasts, *P. rudis* is encountered sporadically at various sites, and does not constitute dense populations (Vicente, 2021).

Conclusion

The *Pinna nobilis* populations of the Port-Cros National Park have been studied since 1969 and in particular one population on the north coast of the island, the so-called 'Champ de La Palud' population (Rouanet *et al.*, 2015). This old population is described to have originated in a single cohort that settled in around 1965 and since that date, no other recruit has been found in this area. The two last individuals died between 2009 and 2014 at an estimated age of 45 to 50 years. Elsewhere in the Port-Cros National Park, the *Pinna nobilis* were quite abundant, and juveniles of the species were regularly observed. In a scientific report, Vicente *et al.* (2016) estimate the *Pinna nobilis* population of the *Posidonia oceanica* meadows around Port-Cros Island (110 ha) as about 12 490 to 19 471 individuals. The mass mortality event of *P. nobilis* is a disaster for the conservation of this long-living species and a blow to the managers of marine protected areas. The discovery of new living individuals offers real hope for the survival of the species and the recovery of the pen shell populations.

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