

From youth to death of old age: the 50-year story of a *Pinna nobilis* fan mussel population at Port-Cros Island (Port-Cros National Park, Provence, Mediterranean Sea)

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Abstract. A population of the fan mussel *Pinna nobilis* Linnaeus, 1758 (molluscan, Bivalvia) has been studied since 1969 at Port-Cros Island (Port-Cros National Park, Provence, France, Mediterranean Sea). This population dwelt on a substrate constituted of dead rhizomes of the seagrass *Posidonia oceanica* ("dead matte") covered by coarse sand, between 10 and 38 m depth. 122 individuals were studied (census and biometry) within the framework of a long term monitoring programme. The population probably originated in a single cohort that settled ~ 5 years before 1969. Since the first survey, no juvenile was observed in the studied area. The mortality rate peaked between 1978 and 1984, when individuals were 15-20 years old. In 2009, the two last living individuals were observed. They died between 2009 and 2014, at an age between ~45 and 50 years. The putative longevity of the species is therefore far above the 10-20 years previously assumed. The total shell length of the last two survivors was 73 cm and 75 cm, respectively.

Keywords: *Pinna nobilis*, long-term monitoring, longevity, Port-Cros National Park, Mediterranean.

Résumé. De la jeunesse à la mort de vieillesse : 50 ans d'histoire d'une population de *Pinna nobilis* à Port-Cros (Parc national de Port-Cros, Provence, Méditerranée).

Une population de la grande nacre de Méditerranée *Pinna nobilis* Linnaeus, 1758 (mollusque, bivalve) été étudiée depuis 1969 au Nord de l'île de Port-Cros (Parc national de Port-Cros), près de la baie de La Palud. Cette population vivait sur des mattes mortes de la magnoliophyte marine *Posidonia oceanica* recouvertes de sable grossier, entre 10 et 38 m de profondeur. 122 individus y ont été recensés, repérés individuellement (au moyen d'un piquet et d'une plaque) et mesurés (biométrie), dans le cadre d'un programme de suivi à long terme. La population semble provenir d'une même cohorte dont le recrutement a eu lieu quelques années (peut-être 5 selon le modèle de croissance) avant 1969. Au cours de la période étudiée (1969-2014), aucun recrutement n'a été observé au sein de la population, bien que des recrutements se soient produits au voisinage, à faible profondeur (entre 2 et

10 m). La population a décliné au cours du temps, avec un pic de mortalité entre 1978 et 1984, quand les individus étaient probablement âgés de 15-20 ans. En 2009, les deux derniers individus vivants ont été observés ; ils mesuraient (longueur totale de la coquille) 73 et 75 cm ; la croissance de la coquille avait cessé environ 20 ans auparavant. Ces deux individus sont morts entre 2009 et 2014, à un âge d'environ 45-50 ans. L'espérance de vie de *P. nobilis*, établie à Port-Cros, est très supérieure à ce que l'on supposait (10 à 20 ans), d'après les données de la littérature.

Mots-clés : *Pinna nobilis*, suivi de longue durée, longévité, Parc national de Port-Cros, Méditerranée.

Resumen. De la juventud a la muerte por vejez: 50 años de historia de una población de *Pinna nobilis* en Port-Cros (Parque Nacional de Port-Cros, Provenza, Mediterráneo).

Una población de la gran nacla mediterránea *Pinna nobilis* Linnaeus, 1758 (molusco, bivalvo) ha sido estudiada desde 1969 al norte de la isla de Port-Cros (Parque Nacional de Port-Cros), junto a la bahía de La Palud. Esta población vivía sobre fondos de mata muerta de la magnoliofita marina *Posidonia oceanica* y arena gruesa entre 10 y 38 metros de profundidad. Un total de 122 individuos fueron censados, marcados individualmente (por medio de una piqueta y una placa) y medidos (biometría), dentro del programa de seguimiento a largo plazo. La población parece proceder de una misma cohorte cuyo reclutamiento tuvo lugar algunos años (puede que 5 según el modelo de crecimiento) antes de 1969. Durante el periodo de estudio (1969-2014), no se ha observado ningún reclutamiento en dicha población aunque si se produjeran en áreas vecinas poco profundas (entre 2 y 10 m). La población ha visto reducida sus cifras de densidad a lo largo del tiempo, con un "pico" de mortalidad entre 1978 y 1984, cuando los individuos contaban con edades comprendidas entre 15-20 años. En 2009, se observaron los dos últimos ejemplares vivos; medían entre 73 y 75 cm (longitud total de la valva); el crecimiento de las valvas se había detenido 20 años antes. Estos dos últimos individuos murieron entre 2009 y 2014 a la edad aproximada de 45-50 años. La esperanza de vida de *P. nobilis* en Port-Cros es, por tanto, muy superior a la supuesta para dicha especie (10 a 20 años) según la literatura.

Palabras clave: *Pinna nobilis*, seguimiento ecológico, longevidad, Parque Nacional de Port-Cros, Mediterráneo.

Introduction

The fan mussel *Pinna nobilis* Linnaeus, 1758 is the largest bivalve of the Mediterranean Sea, to which it is endemic. It reaches a size of up to 120 cm (Vicente and Moreteau, 1991; Zavodnik *et al.*, 1991; Vicente and De Gaulejac, 1993) and lives in soft-sediment areas (Katsanevakis, 2005) and beds of the seagrasses *Posidonia oceanica* (Linnaeus) Delile and *Cymodocea nodosa* (Ucria) Ascherson (Vicente *et al.*, 1980; Zavodnik *et al.*, 1991; Vicente and De Gaulejac, 1993; Richardson *et al.*, 1999; Šiletić and Peharda, 2003; García-March, 2006; García-March and Vicente, 2006), at depths ranging from 0.5 to 60 m depth (Butler *et al.*, 1993; Templado *et al.*, 2004).

Exploitation for commercial and food uses in the past, destruction by trawling and anchoring, environmental pollution and regression of the seagrass meadows, have resulted in a dramatic decline of populations of *P. nobilis* (Vicente, 1991). The species is now protected by national legislation (France) and international conventions such as

the Habitats Directive (92/43/EEC) and Barcelona Convention (Vicente and Moreteau, 1991; Vicente and De Gaulejac, 1993; García-March and Vicente, 2006; Katsanevakis *et al.*, 2011). Thirty years ago, densities of individuals were relatively low, particularly on the French coasts, about 1 individual/100 m² (Vicente *et al.*, 1980; Moreteau and Vicente, 1982). At present, at least within Marine Protected Areas (MPAs), population densities show higher values (Trigos *et al.*, 2013). In the Scandola MPA (Corsica), mean densities of about 14 individuals/100 m² can be observed (Vicente, 2010). In some other MPAs, the density is even higher, up to 20 individuals/100 m² at Mljet National Park (Croatia) and Columbretes Marine Reserve (Spain) (Zavadnik *et al.*, 1991; Templado 2001, Šiletić and Peharda 2003; García-March *et al.*, 2007). In the Port-Cros National Park, mean densities range from 1.4 to 8.0 individuals/100m² (Medioni and Vicente, 2001; Vicente, 2009).

The Scientific Council (Boudouresque *et al.*, 2013), the scientific department and the managers of Port-Cros National Park (PCNP; Barcelo and Boudouresque, 2012) have carried out a monitoring survey of *Pinna nobilis* populations of the Port-Cros Archipelago since 1969, and more particularly of the so-called “Champ de La Palud” population. This population was discovered by Captain Philippe Taillez and mine clearance expert divers of the French Navy who carried out the first survey in 1969. Between 10 m and 38 m depth, 122 *P. nobilis* individuals, probably resulting from a single recruitment event, were identified by a numbered plate, adjacent to each individual, and measured during each field survey (Vicente *et al.*, 1980). The only available data regarding the life-span of this species are based on growth modelling and on the posterior adductor muscle scar (PAMS) (Moreteau and Vicente, 1980, 1982; García March and Ferrer Ferrer, 1995; Garcia March and Márquez Aliaga, 2007). Some works have estimated, on the basis of the records of the PAMS, that *P. nobilis* can live for more than 20 years (Galinou-Mitsoudi *et al.*, 2006; García-March *et al.*, 2011). However, despite these studies, there is still a considerable gap in our knowledge of the life expectancy of the species. Here, we describe the fate of a population of *P. nobilis*, based upon a 45 year long-term monitoring program (from 1969 to 2014), which also enables us to assess its lifespan under non-disturbed conditions.

Methods

The studied population of *P. nobilis* is located on the north coast of Port-Cros Island (Port-Cros Archipelago, PNPC, eastern Provence, France, northwestern Mediterranean Sea), between Rascas Islet and La Palud Cape (Fig. 1). The bottom is constituted of dead *Posidonia oceanica* rhizomes (“dead matte”), the remains of a former seagrass

meadow, covered by coarse sand (Belsher *et al.*, 2005; Astruch *et al.*, 2012). The surface area occupied by this population is ca. 0.6 ha and it is located between 10 and 38 m depth.

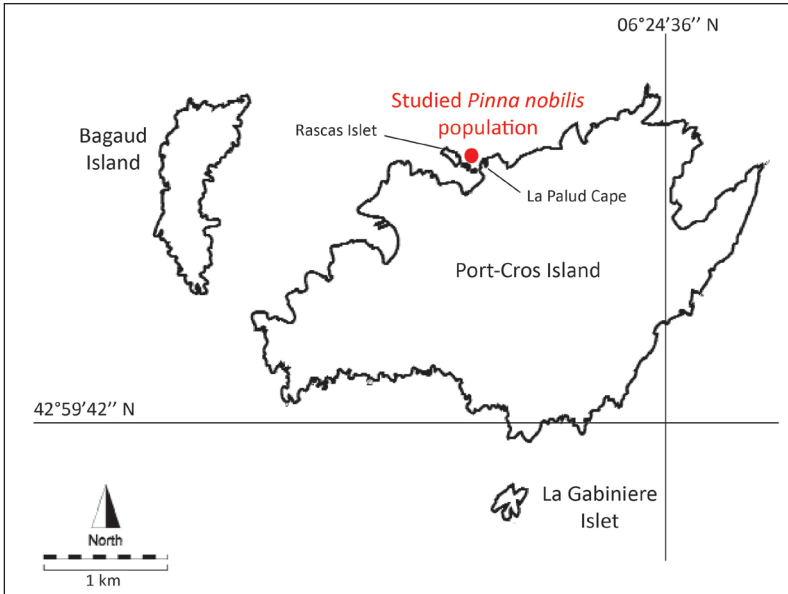


Figure 1. Location of the studied population of *Pinna nobilis*, within the Port-Cros Archipelago (Port-Cros National Park).

Since the first monitoring campaign, in 1969, the observed individuals were counted in order to follow the evolution over time of the population, the possible arrival of recruits and the individual mortality. Individuals were easily observable because shells jut out the bare substratum. Fourteen further censuses were performed in 1978, 1980, 1981, 1982, 1983, 1984, 1985, 1994, 2001, 2002, 2004, 2006, 2009, 2014.

From 1975, each individual of *P. nobilis* was identified by a numbered plate, adjacent to the individual; biometric data were recorded in order to estimate the total shell height and growth rate. Using the method described by Moreteau and Vicente (1980), *P. nobilis* individuals were measured *in situ* to avoid unnecessary removal and disturbances. The shell length above the sediment (L_s ; in cm) and the width at sediment level (w_c ; in cm) were recorded (Fig. 2). The total shell length (L_t ; in cm) was estimated using the following equation applied to the field data (García March and Ferrer Ferrer, 1995): $L_t = (1.79 \times w_c + 0.5 \pm 0.2) + L_s$. The combined use of two shell size parameters (L_s and w_c) eliminates potential problems with the total shell length calculation

that might occur as a result of differences in shell morphology or burial depth (Moreteau, 2003). Although this formula was originally used for the calculation of *P. nobilis* total shell length from a different area (Moraira, Spain), it was considered suitable for the study population.

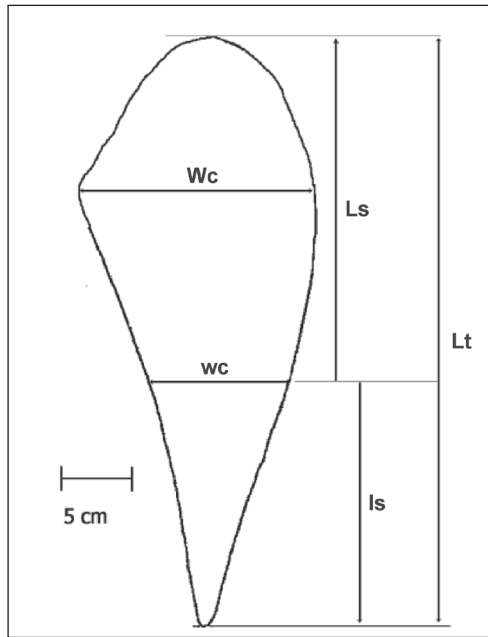


Figure 2. Biometric parameters of *Pinna nobilis*: Wc maximum shell width, wc shell width at sediment level, Ls unburied shell length, ls buried shell length and Lt total shell length.

The rate of mortality between successive censuses was assessed. By comparing the abundance of *P. nobilis* between two censuses, we can establish a coefficient of mortality (z) following the formulas (García-March *et al.*, 2006): $n_2/n_1 = e^{-z(t_2-t_1)}$, with $z = [\ln(n_2/n_1)]/(t_2-t_1)$, n_2 and n_1 number of individuals at time t_2 and t_1 , respectively.

Moreteau and Vicente (1982) have drawn up, from the *P. nobilis* population studied, a size-age growth curve based on Von Bertalanffy's model. Of course, epibionts ("macroalgae", sponges, bryozoans, etc.) fixed on shells weaken the individuals and can affect growth (Moreteau and Vicente, 1980). Specimens with a total shell length (L_t) ≤ 20 cm were considered as juveniles according to literature data (Combelles *et al.*, 1986; Butler *et al.*, 1993; Richardson *et al.*, 1999).

Results

Abundance and mortality

Forty five years of monitoring have enabled us to study a *P. nobilis* population that was possibly of recent settlement when discovered (in 1969), but was in no way juvenile since the individual size was over 20 cm (Lt), though not accurately measured at that time. In 1969, at the time of discovery and of the first monitoring survey, the population was possibly 5 years old, according to the size-age growth models. 122 individuals were recorded, that is a density of 1.97 individuals/100 m² (Fig. 3). The mortality rate was very high between 1978 and 1984, high between 1984 and 1994 and low when individuals were relatively young and very old (Fig. 4). Finally, at the end of the last decade (year 2009), only two individuals were recorded. The last survey carried out in 2014 confirmed the total disappearance of the population: only one empty shell was found.

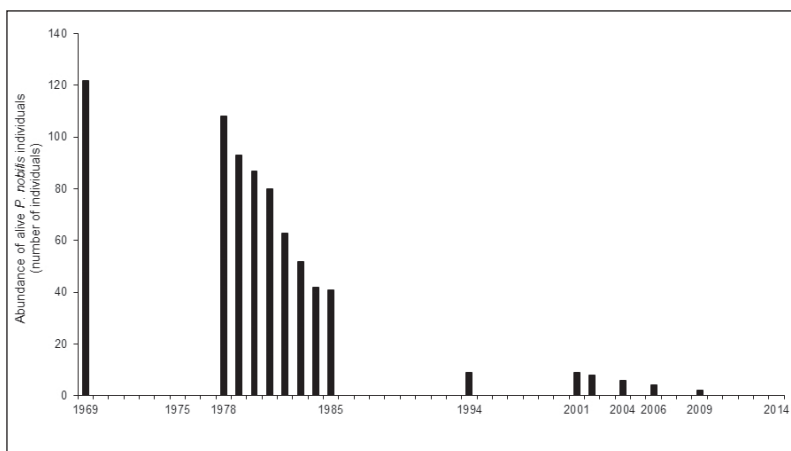


Figure 3. Abundance of alive *Pinna nobilis* in the studied population, between 1969 and 2014.

During this period of more than four decades, no recruitment occurred within the studied population. Recruitment was only observed in the vicinity of the area, near the beach of La Palud Bay, between 2 and 10 m depth, within a *Posidonia oceanica* seagrass meadow.

Biometry

In 2014 only the empty shell of individual n°56 was found. The direct measurement of the total shell length (Lt) enabled us to check the quality of the indirect length estimation. Through measurements of shell length above the sediment (Ls) and the width at sediment level (wc) made in 2009, the total shell length was estimated at 73.9 ± 2 cm.

In 2014, the total length measured was 73 cm. Its growth was close to zero between these two dates. Estimated values of L_t in this study can therefore be considered as valid.

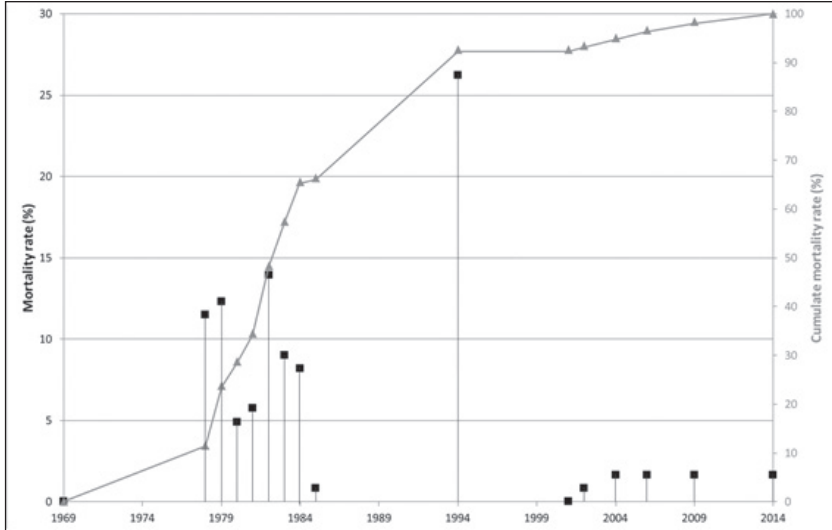


Figure 4. Mortality rate, since the previous census (squares) and cumulated (triangles) of the *Pinna nobilis* population at the study site between 1969 and 2014.

The smallest measured individual was 42.2 cm in length (L_t) (in 1990), while the largest was 88.2 cm in length (in 1977). Over the course of the study period, the mean length L_t was relatively stable, between 62 cm and 75 cm (Fig. 5). This can be a bias due to the fact that the set of measured individuals was not identical from one monitoring campaign to the next. Another possibility is that the length of *P. nobilis* quickly reaches a plateau, roughly after the first ten years, then more or less stops growing.

The two oldest individuals, which were still alive in 2009, are n°56 (measured since 1980) and n°160 (measured since 1985). For the former, we noted an increase in total length until 1997 (20 cm in 17 years), and for the latter an increase until 1990 (12 cm in 5 years) (Fig. 6). This observation suggests that the growth is still noticeable in individuals aged up to ~30 years, then stops, and that the stability of the shell length (Fig. 6) would be an artefact, as hypothesized above.

Discussion and conclusion

Although the data published on the density of populations of *P. nobilis* are rare, trends can be obtained from the literature (Tabl. I). Generally, the density is low compared with the other marine bivalves

living on loose substrata. Vicente *et al.* (1980) and Combelles *et al.* (1986), who have analyzed data from Port-Cros Island (Provence) and Scandola (Corsica) MPAs in the 1980s, reported a mean density of 1 individual/100 m². In Vouliagmeni Lagoon (Greece), in 2004 and in Embiez Archipelago (near Toulon, Provence, France), in 2006, both unprotected areas, densities ranged from 0 to 1.5 individuals/100 m², according to the studied sites (Katsanevakis, 2005 and Vicente, unpublished data, respectively). Since the 1990s, *P. nobilis* has been protected by French legislation and by international conventions and population densities are on the increase everywhere, in particular in the Port-Cros National Park. There, the mean density rosed from 1 individual/100 m² in the 1980s to 8 in some sectors of the island 30 years later. In the no-take zone (NTZ) of Scandola MPA, the increase in density is even greater: between 1986 and 2000, density was multiplied by 6, and between 1986 and 2012 by 14. In Larvotto MPA (Monaco), Hignette (1982) only observed a few individuals while in 2011 the density was very high, with about 400 individuals mapped (De Vaugelas, *pers. comm.*). However at Porquerolles Island, close to the Port-Cros Island MPA, which has been included within a Natura 2000 site since 1996 (but regulations only enforced in 2007), *P. nobilis* density is lower with a maximum of 2.3 individuals/100 m². Around Embiez Archipelago, another Natura 2000 site since 2011, *P. nobilis* density is 1.9 individuals/100 m² (Trigos *et al.*, 2013). The implementation of a marine protected area for decades, with no (or reduced) anchoring and no trawling, human activities that result in breakage of the shells, and the absence of poaching by divers, appears favourable to thriving populations of *P. nobilis*.

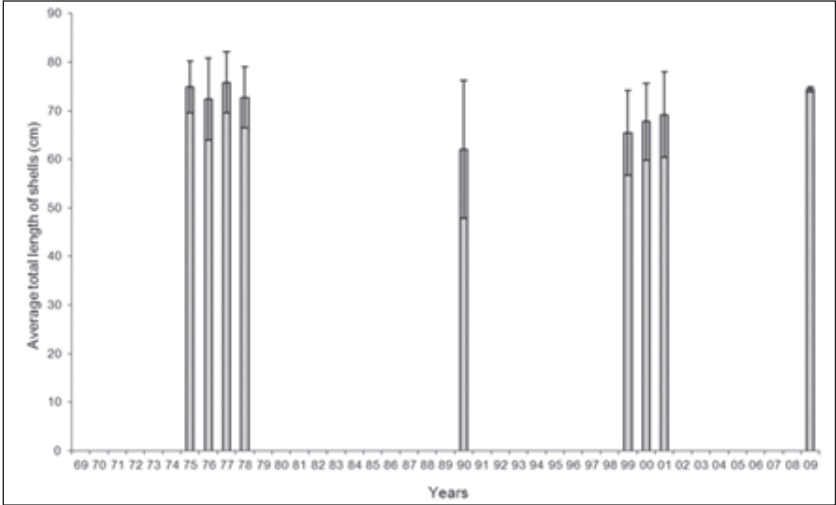


Figure 5. Average total length (Lt) estimated for the study population of *Pinna nobilis* between 1975 and 2009. Note that the set of measured individuals was not identical from one monitoring campaign to the next. Bars = standard deviation.

Since the first survey, 45 years ago, no juvenile was observed in the studied area. However, larval supply does exist as juvenile individuals were observed in shallow waters near the studied area. Only the 122 individuals observed in the first survey (in 1969) were studied. This population seems to have originated in a single cohort that settled a few years (five?) before 1969. The populations of *P. nobilis* follow normally patchy patterns of distribution (Combelles *et al.*, 1986; Butler *et al.*, 1993). These metapopulations are often distributed according to substrate characteristics or the presence of *P. oceanica* meadows (Combelles *et al.*, 1986). Suitable habitats are obviously present in the study area, so that the absence of recruitment over the 45 years of the survey cannot be explained by the absence of suitable habitats.

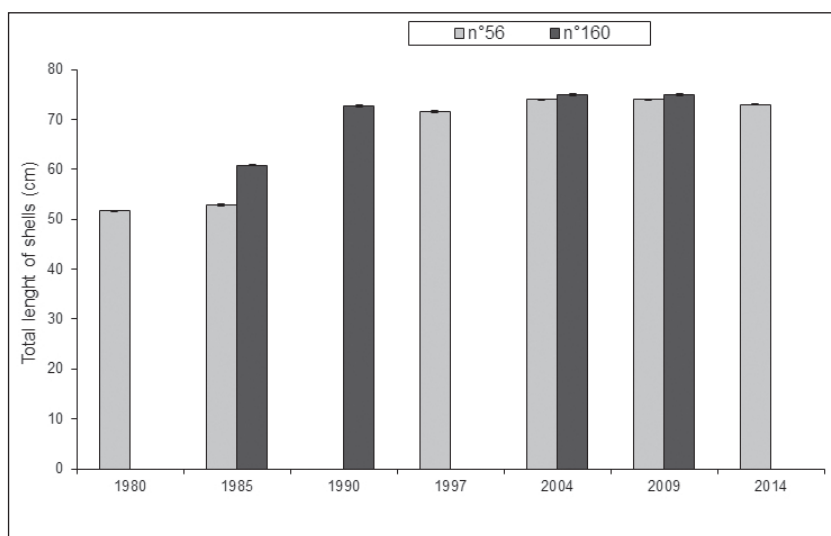


Figure 6. Total length (Lt) of the two oldest individuals of *Pinna nobilis* (n°56 and n°160) at the study site, between 1980 and 2014. Bars = standard deviation.

Table I. Density of *Pinna nobilis* observed at various locations. MPA: Marine Protected Area. NTZ: No-Take Zone. Data are arranged in a chronological order; ind. = individuals

Locations	Mean density (ind./100 m ²)	References
Port-Cros Island (Port-Cros National Park, MPA), Provence, France	1	Vicente <i>et al.</i> , 1980; Combelles <i>et al.</i> , 1986
Scandola marine reserve (MPA), Corsica	1	Combelles <i>et al.</i> , 1986
Croatia, Adriatic Sea	9	Zavodnik <i>et al.</i> , 1991
Chafarinas Islands, Spain, Northern Africa	3.2	Guallart, 2000
Scandola marine reserve (MPA, NTZ), Corsica	6	Charrier <i>et al.</i> , 2000
Mijet National Park (MPA), Croatia, Adriatic Sea	2 to 20	Šiletić and Peharda, 2003

Locations	Mean density (ind./100 m ²)	References
Murcia, Almeria and Balearic Islands, Spain	10	García-March, 2003
Vouliagmeni Lagoon, Greece	1.1	Katsanevakis, 2005
Columbretes marine reserve (MPA), Castellón, Comunitat valenciana, Spain	1.5	García-March and Kersting, 2006
El Carallot, Castellón, Comunitat valenciana, Spain	16	
Mar Grande of Taranto, Ionian Sea, Italy	10 to 70	Centoducati <i>et al.</i> , 2007
Souda Bay, Crete Island, Greece	20	Katsanevakis and Thessalou-Lagaki, 2009
Port-Cros Island (Port-Cros National Park, MPA), Provence, France	2 to 8	Vicente, 2009
Porquerolles Island, Provence, France	0.2 to 2.3	
Scandola marine reserve (MPA, NTZ), Corsica	14	Vicente, 2010
Tunisia (east and southeast coast)	1.5	Rabaoui <i>et al.</i> , 2010
Pass between Bagaud and Port-Cros Islands (Port-Cros National Park, MPA), Provence, France	6 to 13	Rouanet <i>et al.</i> , 2012
Embiez Island, Six-Fours-les-Plages, Provence, France	1.9	Trigos <i>et al.</i> , 2013
Javea, Alicante, Spain	<1	García-March, pers. comm.
Moraira, Alicante, Spain	1 to 12	García-March, pers. comm.

MPAs allow observation of large individuals of *P. nobilis*. The largest individual observed was 88.2 ± 0.2 cm in length, i.e. one of the biggest fan mussels recorded in the Mediterranean Sea. Similar sizes were reported in Mare Grande of Taranto (Ionian Sea, Italy), with an estimated shell length of 87.9 cm (Centoducati *et al.*, 2007). In Vouliagmeni Lake (Greece), Katsanevakis (2005) recorded one individual of 75.1 cm length. Smaller specimens were listed in Moraira Bay (Spain) and in Croatia, with fan mussels measuring 65 cm and 59.9 cm length respectively (Richardson *et al.*, 2004; García March *et al.*, 2007). However, all these individuals are still far short of the one reported by Zavodnik *et al.* (1991), which reached 120 cm in length.

According to the size-age diagram of Moreteau and Vicente (1982), the 122 individuals observed during the first monitoring (1969) were then ~5 years-old. In 2014, all individuals were dead. The two last living individuals were observed in 2009 and they died between 2009 and 2014. The longevity of these fan mussels was therefore ~45-50 years. The first individual (No. 56) had a total shell length (Lt) of 73 cm, and the second (No. 160) an estimate total shell length of 74.9 ± 2 cm (Fig. 7). Hitherto, the longevity of *P. nobilis* was estimated

to be 9-12 years (Richardson *et al.*, 2004) or around 20 years (Butler *et al.*, 1993). Our results show that it is much more long-lived than previously assumed.

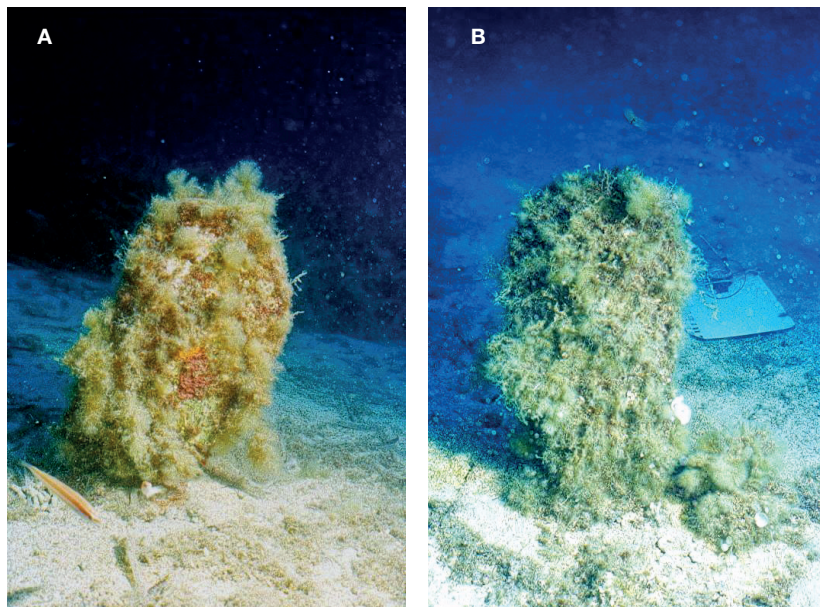


Figure 7. Photos of the 2 last survivors of the studied population of *P. nobilis*, ~45 years old at that time (in 2009); they died between 2009 and 2014. The shells are strongly covered by epibionts. A: individual No. 56. B: individual No. 160 (© N. Vicente).

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