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THE RECRUITMENT OF THE ENDANGERED FAN MUSSEL *PINNA NOBILIS* (LINNAEUS, 1758) ON THE ROPES OF A MEDITERRANEAN MUSSEL LONG LINE FARM

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ABSTRACT The fan mussel *Pinna nobilis* (Linnaeus, 1758) is an endangered bivalve species and is endemic to the Mediterranean Sea. Juvenile animals have been found growing on mussels *Mytilus galloprovincialis* (Lamarck, 1819) long line aquaculture bounces and ropes within the Maliakos Gulf (Aegean Sea). Animals were sampled from the harvested mussel lines. The results show twelve juvenile *P. nobilis* per ton of harvested *M. galloprovincialis*.

KEY WORDS: fan mussel, *Pinna nobilis*, recruitment, biofouling, Mediterranean mussel aquaculture, *Mytilus galloprovincialis,* Maliakos Gulf, Aegean Sea

INTRODUCTION

The largest endemic Pteriomorphian bivalve in the Mediterranean Sea is *Pinna nobilis* (Linnaeus, 1758); growing up to 120 cm long (Zavodnik et al. 1991). Populations of *P. nobilis* have declined significantly within the last 30 y (Vicente & Moreteau 1991) because of consumption for food or ornaments and collaterally from trawling and boat anchoring (Galinou-Mitsoudi et al. 2006, Centoducati et al. 2007, Katsanevakis 2006, 2007, Katsanevakis et al. 2011, Katsanevakis & Thessalou-Legaki 2009, Vafidis et al. 2014). This species is protected by the Mediterranean Specially Protected Areas protocol (95/96 SPA ANNEX II) and under European legislation (92/43 EEC). Although there is intensive research regarding the population ecology and the species distribution around Mediterranean (Zavodnik 1967, Zavodnik et al. 1991, de Gaulejac & Vicente 1990, Butler et al. 1993, García-March & Ferrer 1995, Richardson et al. 1999, Siletic & Peharda 2003, Galinou-Mitsoudi et al. 2006, Centoducati et al. 2007, García-March et al. 2002, García-March & Vicente 2006, García-March et al. 2007a, b, Rabaoui et al. 2008, 2009, 2010, Katsares et al. 2008, Katsanevakis & Thessalou-Legaki 2009, Coppa et al. 2010, 2013, Vafidis et al. 2014), there is limited knowledge about zootechnical aspects of the animal such as feeding behavior (Cabanellas-Reboredo et al. 2009a, Davenport et al. 2011, Najdek et al. 2013, Trigos et al. 2014), reproduction (de Gaulejac et al. 1995a, b, Richardson et al. 2004), and the recruitment (Peharda & Vilibic 2008, Cabanellas-Reboredo et al. 2009b, Acarli et al. 2011a, Soria et al. 2014).

This study on the recruitment of *Pinna nobilis* on *Mytilus galloprovincialis* long line farming ropes within the Maliakos Gulf in Greece (Fig. 1) was undertaken with the aim of bringing to light empirical observations regarding the recruitment process of *P. nobilis* for the future protection of the species and possibilities for aquaculture.

The role of bivalve shellfish farming installations on the natural recruitment and restocking of wild endangered species/biofoulants, such as the fan mussel in the present case, is also discussed.

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MATERIALS AND METHODS

Study Area

The mussel farm installation is a single floating long line suspended culture system (Theodorou et al. 2015a) located in the southern part of the Maliakos Gulf (38° 51′39.82′′ N, 22° 41′45.54′′ E) in Central East Continental, Greece (Fig. 1). Maliakos is a natural semienclosed embayment in Central West Aegean Sea (belonging to the EU Natura 2000 Network) and harbors populations of various commercial exploitable bivalves including native oysters *Ostrea edulis* (Linnaeus, 1758), warty venus *Venus verrucosa* (Linnaeus, 1758), and Mediterranean mussel *Mytilus galloprovincialis* (Lamarck, 1819). During the last two decades, 10 long line farms were established in an effort to provide seafood in a sustainable way, giving an annual total mussel production of about 1,500–1,700 tonnes per year. Details about the environmental status and the local conditions of the mussel farm site used in the present study are given by Dimitriou et al. (2015) and Rodrigues et al. (2015).

Biological Material

The fan mussel *Pinna nobilis* (Linnaeus, 1758) population is an endemic species in Maliakos, with a well-established population, despite being that it is as an endangered species. This indicates the efficacy of protection from the human activities pressures and the "good environmental health" status of the area (James et al. 2010, Tagalis & Theodorou 2013, Theodorou et al. 2015b).

Experimental Method

Sampling

The specimens of *Pinna nobilis* were measured on board immediately, after the *Mytilus galloprovincialis* long lines were

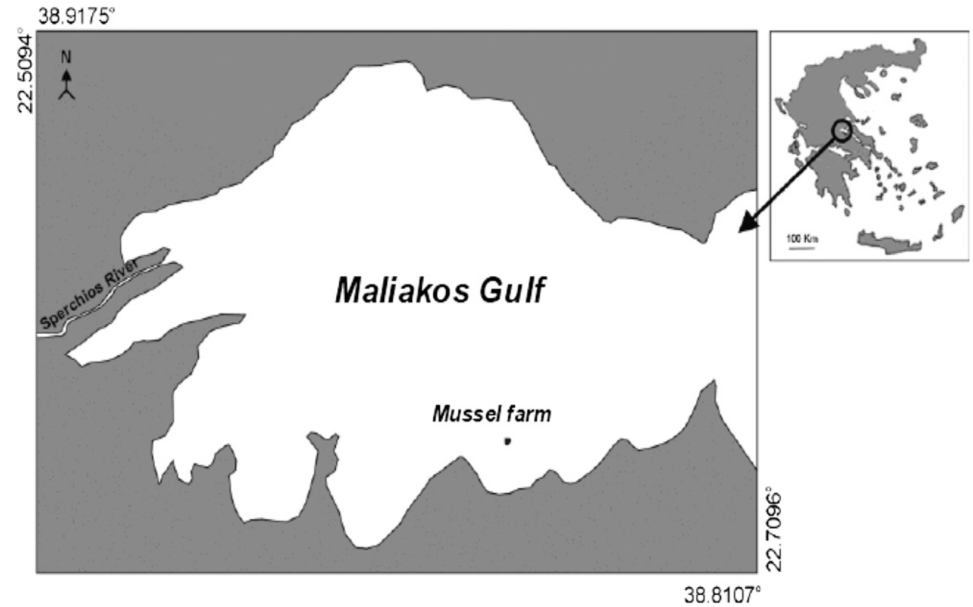

Figure 1. Mussel farm site in Maliakos Gulf (Aegean Sea, East Central Greece) where *Pinna nobilis* individuals were collected during the mussel harvesting process.

harvested during the summer–early autumn of 2009 (Fig. 2A, B). Measurements were taken using a Vernier Caliper with a resolution of 0.02 mm: the length (cm) and maximum width (cm) were recorded according to the guidelines of García-March et al. (2002) for the *Pinna in vivo* measurements. Shells were also rated as to whether they had been noticeably damaged in the process of harvesting and whether their regular morphology is slightly modified (after the typology demonstrated in Garcia-March & Vicente 2006) because of the space restrictions caused by close proximity to *M. galloprovincialis*. The samples were taken from a working mussel farming site and were harvested by chance from 100 m stretches of long line that had been developing for over 1 y. Samples were collected from three harvests of ~2 tonnes each of *M. galloprovincialis* (unsorted).

Data Analysis

A Microsoft Excel spreadsheet was drawn taking into the account the morphometric data of the harvested animals. Statistical comparisons between length and width were tested

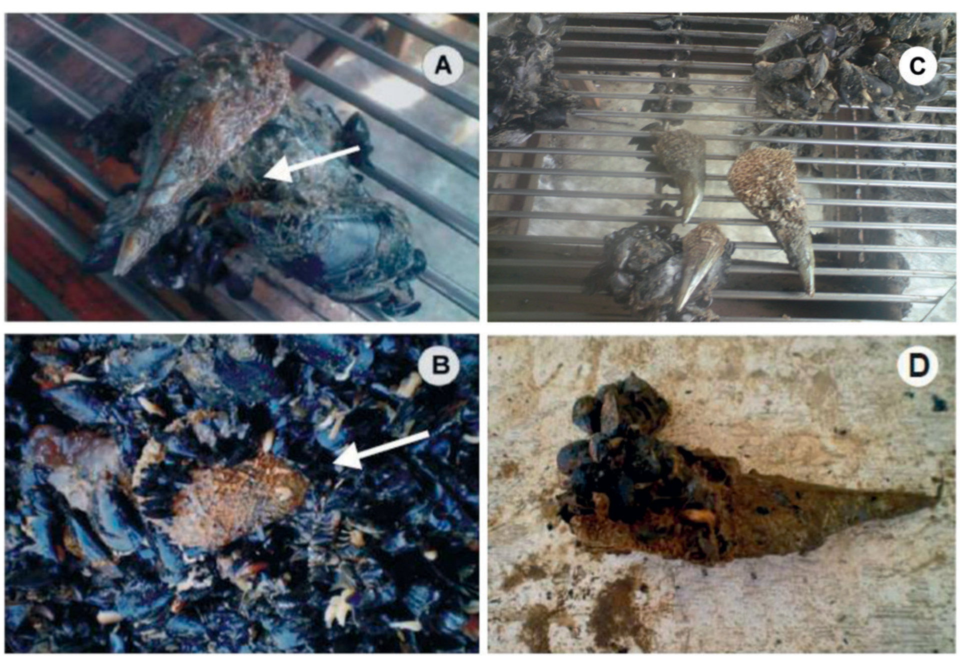

Figure 2. (A, B) Juveniles of *Pinna nobilis* with *Mytilus galloprovincialis* attached. (C, D) Various forms of *P. nobilis* juveniles: C–left, combed; C–right, straight wide; D, straight narrow.

through the application of one-way analysis of variance (ANOVA) using MiniTab statistical software.

RESULTS

A total of 72 animals were collected from the sample site. The three main typologies presented by García-March and Vicente (2006) were distinguished, in the harvested *Pinna nobilis* samples: (1) combed (Fig. 2C, left); (2) straight and wide (Fig. 2C, right); (3) straight and narrow (Fig. 2D).

The smallest individual measured 2.85 cm length and 0.94 cm width, the largest measured 19.36 cm length and 10.19 cm width; the average size being 13.45 ± 3.16 cm (length) and 6.21 cm ± 1.82 (width). ANOVA comparison between the length (cm) and width (cm) gave a result of $F = 5.64$ and $P < 0.05$, showing a significance between the length and the width if H_0 = no significance and where the α level is 0.05 (Fig. 3). Broken/malformed shells were included in the analysis.

DISCUSSION

In our samples, we found a shell shape variation among *Pinna* animals from the mussel socks (Fig. 2 C, D). This is not suprising, as it is also demonstrated in earlier observations by García-March and Vicente (2006), for individuals originated from the same population and from the same vathymetric range. During the life cycle of *Pinna nobilis* the shell formation shows a diverse morphological plasticity among animals of the same live stage (juveniles or adults) as well as in-between the juvenile and adult stage of the same individuals. In the juvenile stage, this may be related with the phenomenon of ecomorphosis as a result of the animal-substrate habits adaptation (Combelles et al. 1986).

The animals found within the examined mussel farm installation, are of special significance, as this shows that the natural propagation of *Pinna nobilis* is possible. Seventy-two animals of less than one-year old (<25 cm length, Richardson et al. 1999) were found over three separate harvestings of *Mytilus galloprovincialis* of around 2 tonnes per harvest, equating to around twelve juvenile *P. nobilis* per tonne of Mediterranean mussel. Whereas this figure is low, this species was untargeted and as such was by-catch from the main aquaculture industry. Aquaculture of *M. galloprovincialis* has a set timeline which is as follows (Fig. 4): May–July spat collectors obtain spats which are then put into small hanging nets; once large enough, between August and October, the spat are then resuspended in larger nets at least at once prior to start harvesting early summer (Theodorou et al. 2011, 2014). The significant date is the second renetting of the spats as it has been determined that early spat recruitment of *P. nobilis* takes place within the last week of August and the first week of September and can also be collected using a range of existing bivalve spat collection techniques (Cabanellas-Reboredo et al. 2009b). This recruitment takes place as the second and may be final renetting of *M. galloprovincialis* as this process allows a stable settlement area for spat *P. nobilis*. The fact that there is a large community of bivalve aquaculture in this area may limit the ability of the fan shell to attach to the long line, and once attached, they may be outcompeted for the limited space on the lines themselves. This interesting outcome does give a glimpse into the prospect of aquaculture of this species, presently under investigation worldwide (Beer & Southgate 2006, Leal-Soto et al. 2011, Mendo et al. 2011), in the future with existing aquaculture facilities and equipment such as on trays/cages (Acarli et al. 2011b, Kozul et al. 2013).

Bivalve shellfish farm installations attract wild organisms (Adams et al. 2011, Fitridge et al. 2012, Sievers et al. 2014) that in most cases are treated as biofoulants. Despite being an endangered species, *Pinna nobilis* are handled like the rest of

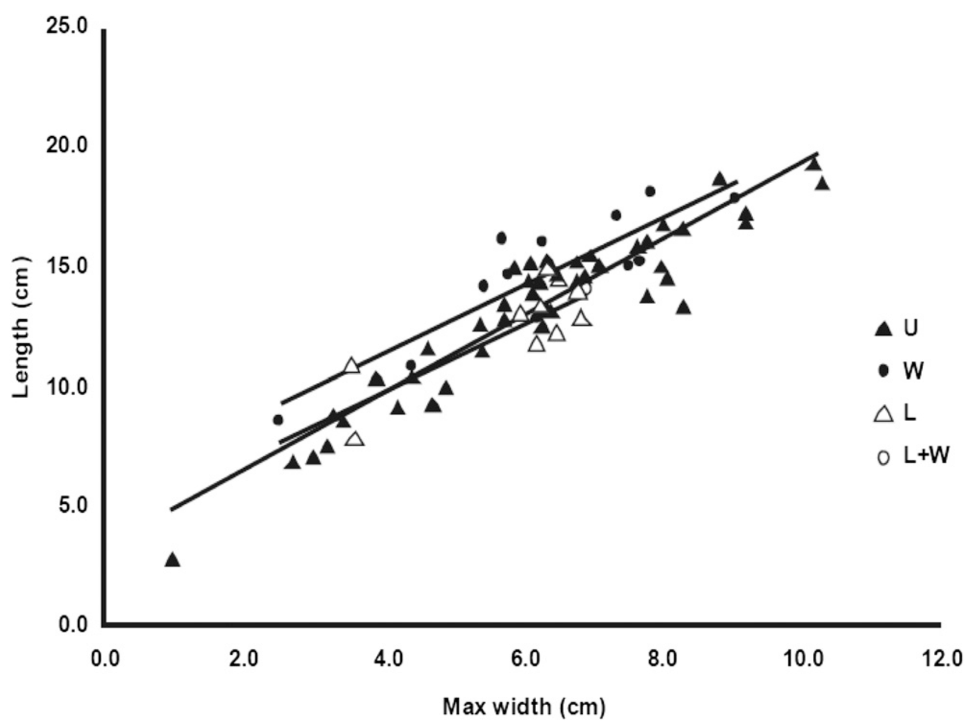

Figure 3. Size of animals found with groups and regression lines. U, unbroken; L, broken length wise; W, broken width wise.

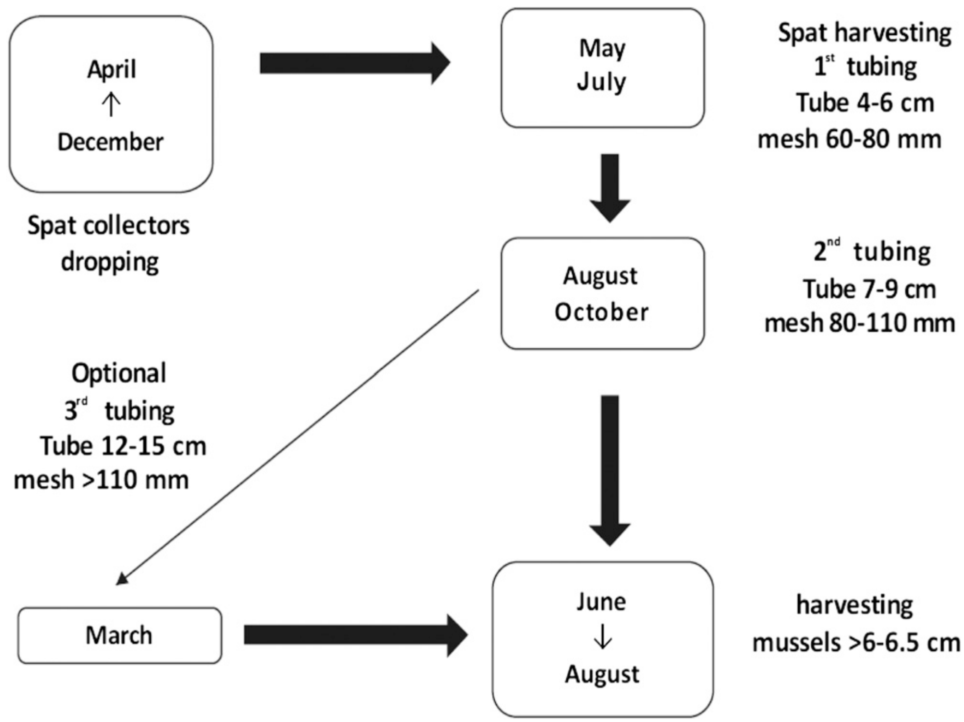

Figure 4. A generalized production model of the Mediterranean mussel farming in Greece (from Theodorou et al. 2011).

the animal by-products of mussel production. Producers usually treat these animals as a biofouling organism without paying attention to the species. As there is not yet any legislation or directives to provide practical guidelines, questions such as who owns the recruited organisms or what must a responsible mussel farmer do, have to be answered. Indeed, guidelines for good environmental practice based on the biology of the species should be available and communicated to shellfish farmers. In addition, more knowledge about the "recreational aquaculture" of the endangered species is needed. The promotion of mussel farmers to the public as "environmental recreation angels" may inspire the farmers to act as "godfathers" of the endangered species, providing, parallel to their own production process, the *P. nobilis* protection and enhancement by providing animals to restock the wild population. An alternative opportunity, coculture, which may add another product and provide supplementary income to the farmers, needs to be investigated in conjunction with the restocking. This practice has been promoted in Europe for another capture-based farmed endangered species, the European eel *Anguilla anguilla* (Linnaeus, 1758), where the harvesters/producers use part of their animal stock for natural restocking purposes (Jacoby & Gollock 2014). Similar effort but in a total different case recently demonstrated by Navedo et al. (2014) where the shrimp farm installations in Mexico, under an appropriate management support the conservation efforts of nearctic shorebirds by providing short term but absolute necessary complementary foraging areas. The combination of aquaculture with conservation of wildlife may be is a current research trend in the industry that could be expressed in various forms and species depending on the local ecosystems specifications and requirements. The social acceptance of these practices also could mitigate the negative pressures for environmental impacts of the activity by the rest of the stakeholders.

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