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Comparative distribution of the fan mussel *Atrina fragilis* (Bivalvia, Pinnidae) in protected and trawled areas of the north Aegean Sea (Thermaikos Gulf)

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Abstract

The distribution of the fan mussel *Atrina fragilis* was studied at two contrasting areas of the north Aegean Sea (Thermaikos Gulf): one routinely trawled and one closed to trawlers for over 25 years. Significant differences were detected between the two areas with decreased values in density and size of *A. fragilis* individuals at the trawled area. As habitat differences, i.e. sediment composition and bathymetry, had a non-significant effect, extensive trawling activities probably explain the observed results.

Keywords: population structure, trawling impacts, bivalves, Aegean Sea.

Introduction

Fan mussels or pen shells are generally large bivalves, triangular in shape, belonging to the Pinnidae family. They comprise the genus *Pinna* and *Atrina*; their species exist as metapopulations, composed of small patches of individuals, with a worldwide distribution (Leal-Soto *et al.*, 2011). Fan shells are found in mud, sand, gravel and meadow habitats (Poutiers, 1987). Being considered a delicacy they are exploited for human consumption (An *et al.*, 2011); moreover, their shells are collected for decoration. In addition, their populations are indirectly threatened through habitat degradation (Solandt, 2003).

The fan mussel *Atrina fragilis* (Pennant, 1777) is one of the largest Pinnidae bivalves. It is considered rare, although *Atrina fragilis* is widely distributed in the Atlantic and the Mediterranean. Concerning the latter area, the species has been reported from the Alboran Sea (Hiscock & Jones, 2004), the Balearic (Pubill *et al.*, 2011), the Ligurian (Alliani & Meloni, 1999), the Tyrrhenian (Alliani & Meloni, 1999), the Adriatic (Hall-Spencer *et al.*, 1999; Pranovi *et al.*, 2001; Simunovic *et al.*, 2001; Casellato & Stefanon, 2008), and the Aegean Sea (Zenetos, 1997; Demir, 2003). *A. fragilis* lives on sandy bottoms consisting of a mixture of with and terrigenous ooze sediments (Gamulin-Brida, 1967; Simunovic *et al.*, 2001); it is a characteristic species of detritic bottom communities (Gamulin-Brida, 1974). The species occurs from surface waters down to 600 m in depth (Poutiers, 1987); dense populations are usually found at a depth of 25 to 50 m (Simunovic *et al.*, 2001). In contrast to other Mediterranean Pinnidae species, such as the noble fan shell *Pinna nobilis* which has been traditionally exploited (Chintiroglou *et al.*, 2005) and is currently under strict protection (Katsanevakis, 2006; Katsanevakis *et al.*, 2008), *A. fragilis* is only occasionally harvested (Poutiers, 1987), although often reported from fisheries discards (Batista *et al.*, 2009; Voultsiadou *et al.*, 2011). Local populations of the species are considered endangered (Act. No. 1990-54) mainly due to habitat degradation and intensive bottom trawling. Recently, *A. fragilis* has been assigned priority species status for conservation in the UK (Solandt, 2003; Hiscock & Jones, 2004); although protective measures as regards the distribution of the species, *i.e.* at European level, have not been taken so far.

Data on the biology of *A. fragilis* are extremely scarce; available information is limited to species distribution and dynamics in the Adriatic (Simunovic *et al.*, 2001) and the UK and Glask (Woodward, 1985; Turk & Seaward, 1997; Solandt, 2003), whereas relevant data, although preliminary, have been collected recently from the Aegean Sea (Papoutsi & Galinou-Mitsoudi, 2010).

This study aims at a preliminary assessment of the current distribution of *A. fragilis* populations in protected and trawled areas of the north Aegean Sea (Thermaikos Gulf), by providing information on density and size structure. These data will serve as a basis for estimating trawl impact, and will highlight the needs and priorities for species preservation.

Materials and Methods

The study was conducted in the Thermaikos Gulf, which is the biggest gulf of the Aegean Sea and one of the most productive eastern Mediterranean areas, as it receives water and fertile materials from large rivers (Sakellariou & Alexandri, 2007). According to the Hellenic Statistical Authority trawl fishery provides 27% of the annual catch of the Hellenic fisheries, whereas 12% of the above percentage derives from Thermaikos Gulf; these figures are indicative of the intensive fishing activity taking place within the Gulf. However, in the inner part of the Gulf, namely Thessaloniki Bay, trawling was prohibited in 1978 (according to Presidential Decree 189/1978).

Sampling was conducted using commercial otter trawls at the end of the annual fishing period, in May (2006); trawl fishing is prohibited in Greece from June to September. In total, fifteen hauls (20 mm mesh size, vessel speed during haul at 3.2 knots) were completed: five hauls were taken from the restricted area of Thessaloniki Bay, and ten from the adjacent, heavily trawled outer Thermaikos Gulf (details on samplings are presented in Figure 1 and Table 1). The shrimps *Melicertus kerathurus* and *Parapenaeus longicornis* constituted target species in all sampling efforts, whereas constant catchability is assumed. Sediment samples were also collected and clustered to classify soft substrata in main sediment types of the Thermaikos Gulf: i) sediment composed of over 50% sand, ii) composed of 20-30% sand and 60-80% clay, iii) composed of over 90% silt/clay (Voultsiadou *et al.*, 2011).

All living and dead individuals of *Atrina fragilis* were sorted out from total catch; undamaged specimens were measured on board to the nearest mm to estimate shell length (L), *i.e.* maximum distance along the anterior-posterior axis, and width (W), *i.e.* distance measured at the point of maximum dorso-ventral length of the shell (Garcia-March *et al.*, 2006), using a tapeline. The age of undamaged specimens was also estimated by counting the number of posterior adductor muscle scars at the inner part of the shell (Richardson *et al.*, 1999). Population density was estimated as the number of individuals caught per one kilometre distance (ind.km^{-1}). Analysis of variance (three-way unbalanced ANOVA) was used to test the effect of depth (three-level random factor), sediment typology (three-level random factor) and trawling effort (two-level fixed factor) on the abundance and the estimated biometric variables (*i.e.* L, W), through a general linear model (Underwood, 1997). The Bonferroni method was used for post hoc comparisons. ANOVAs were performed using the SPSS software package (IBM SPSS statistics version 19). Size-frequency distribution analysis was calculated per 1 cm size classes; data were pooled over trawled and protected areas.

Results

Atrina fragilis was recorded over the entire sampled area, *i.e.* for all fifteen hauls conducted, with a density ranging from 0.03 to 6.27 ind.km^{-1}. ANOVA results showed that trawling had a significant effect in the abundance of *A. fragilis* ($F = 91.88$ $p<0.001$), in contrast with depth ($F = 0.03$ $p = 0.97$) and sediment type ($F = 0.15$ $p = 0.86$); population density was much higher in the protected area compared with the trawled one (Fig. 2).

Overall, 93 live individuals of *A. fragilis* were collected and measured. Their size ranged from 14.17 to

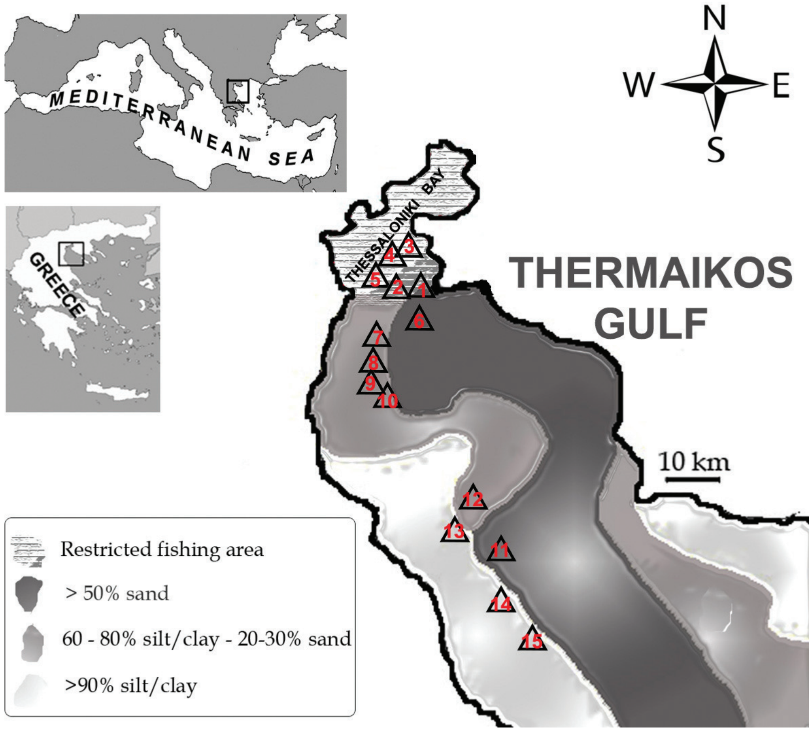

Fig. 1: Map of the Thermaikos Gulf indicating sampling stations and sediment composition (modified from Voultsiadou *et al.*, 2011).

Table 1. Sampling protocol and density of the studied Atrina fragilis population in protected (P) and trawled (T) areas of Thermaikos Gulf: details on completed hauls (H), main sediment characteristics (Sa = >50% sand, SiSa = 60-80% silt clay 20-30% sand, Si = >90% silt clay) and number of individuals collected.

Hauls (H)	Area	Duration (min)	Depth	Sediment type	N	Density ($N \cdot km^{-1}$)
H1	P	25	30 m	Sa	13	5.43
H2	P	25	30 m	SiSa	12	5.02
H3	P	25	30 m	Si	15	6.27
H4	P	25	30 m	Si	11	4.60
H5	P	25	30 m	Si	14	5.85
H6	T	270	50 m	Sa	1	0.04
H7	T	270	50 m	SiSa	4	0.15
H8	T	270	50 m	SiSa	3	0.11
H9	T	300	50 m	SiSa	1	0.03
H10	T	270	50 m	SiSa	2	0.07
H11	T	270	70 m	Sa	2	0.07
H12	T	270	70 m	SiSa	6	0.22
H13	T	270	70 m	Si	4	0.15
H14	T	300	70 m	Si	4	0.15
H15	T	300	70 m	Si	1	0.03

46.53 cm in length and from 8.52 to 28.7 cm in width, with a mean of 34.89 ± 9.19 cm and 20.29 ± 4.66 cm, respectively. Significant differences in the biometric characters of the species were recorded with respect to trawling effort (ANOVA results: $F = 11.34$ $p<0.001$ for length; $F = 8.15$ $p<0.001$ for width) as decreased values were observed for the population within the routinely trawled area (Fig. 2). Sediment type ($F = 0.77$ $p = 0.48$ for length; $F = 0.41$ $p = 0.67$ for width) and depth ($F = 1.60$ $p = 0.21$ for length; $F = 2.08$ $p = 0.13$ for width) did not have a significant effect on the estimated biometric variables of the species. Length- and width-frequency histograms constructed for the protected and the trawled area of Thermaikos, separately, revealed a similar pattern; both variables had right-skewed distributions at the protected site (Fig. 3). The age of *A. fragilis* ranged from 7 to 16 years corresponding to an annual growth rate of 2.6 $cm.y^{-1}$. In addition, 14 dead shells were recorded: 5 from the protected area and 9 from the trawled one; their mean dimensions were 23.21 and 30.77 cm for shell length and 13.39 and 21.53 cm for shell width, respectively.

Discussion

A clear difference in the population density of *A. fragilis* was detected. A locally dense population was found in the area where bottom trawling has been prohibited for over 25 years – a time period which probably allows population recovery - in contrast to the sparse population of the species over the heavily trawled area of the Thermaikos Gulf. Density values were higher than those previously reported from Thermaikos (Papoutsi & Galinou-Mitsoudi, 2010), but lower than the ones reported from the north Adriatic Sea (Hall-Spencer *et al.*, Pranovi *et al.*, 2001; 1999; Simunovic *et al.*, 2001). Historic records are only available from UK waters referring to gregarious populations up to the middle of the 19th century (Jeffreys, 1863 from Solandt, 2003), while contemporary records reported scarce populations or individuals (Solandt, 2003). However, as no strategic survey dedicated to *A. fragilis* populations has been conducted over its distributional range, the current estimation of natural stocks remains inaccurate.

Sandy bottoms from 30 to 50 m in depth, containing large amounts of clay and terrigenous mud, seem to be the preferred habitat for *A. fragilis*, as dense populations have been maintained in such cases (Gamulin-Brida, 1967; Simunovic *et al.*, 2001). The depth of the study area is within the species' range and close to its favoured depth zone (*i.e.* 25-50 m depth), whereas the sea bottom of the Thermaikos Gulf consists of soft sediments composed of silt, clay and sand (Karageorgis & Anagnostou, 2001); fine materials predominate sediment composition in the protected area, whereas the presence of sand is slightly increased south-eastward (see Fig. 1). Although environmental characteristics fulfil the ecological demands of *A. fragilis* throughout the entire Gulf, its population thrives only in the area where trawling is restricted. Accordingly, intensive trawling became the more relevant explanation of the observed results, taking also into account that differences in sediment composition and bathymetry did not have a significant effect in the species' density. It is well documented that sediment composition affects trawling catchability and this, indirectly, may cause a bias when estimating density. In this study, constant catchability is assumed, as clearly stated in the methodology. Although the effect of this factor cannot be entirely excluded, shrimp trawl catchability is considered high in the Thermaikos Gulf (Voultsiadou *et al.*, 2011), and thus, the relevant pos-

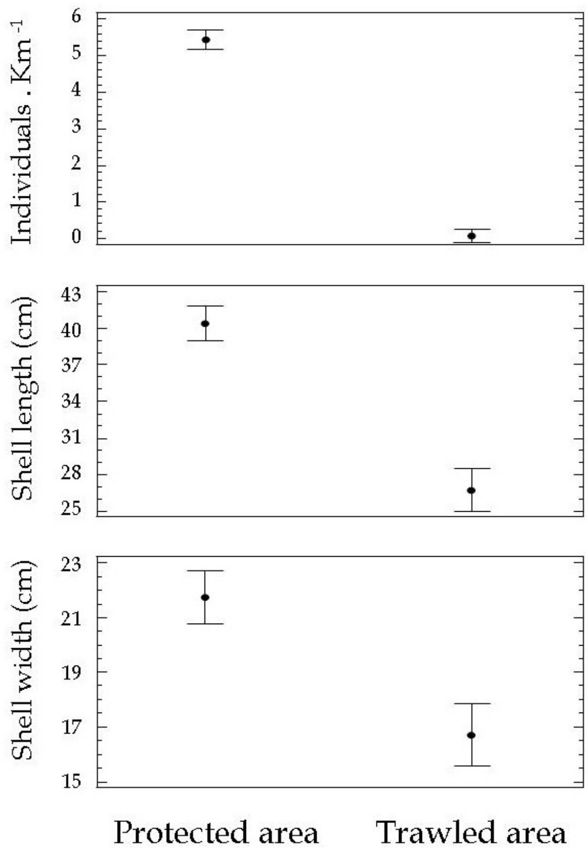

Fig. 2: Variability in population density (ind.km^{-1}) and estimated biometric variables, i.e. L, W (cm) (mean ± 95% Bonferroni intervals) of the studied *A. fragilis* population in the protected and trawled areas of the Thermaikos Gulf.

sible bias in the estimated *A. fragilis* abundance can be deemed of minor importance. Bottom trawling has long ago been documented as a major disturbance for a variety of benthic organisms, including *A. fragilis* (Hall-Spencer *et al.*, 1999; Pranovi *et al.*, 2001; Simunovic *et al.*, 2001; Solandt, 2003). *A. fragilis* is ranked as a highly susceptible species to physical disturbance and bottom trawling due to its fragile shell, longevity, size, and inability of re-burrow into sediment after a disturbance event (Hall-Spencer *et al.*, 1999; Pranovi *et al.*, 2001; Solandt, 2003; Hiscock & Jones, 2004). As demonstrated comprehensively by Hall-Spencer *et al.* (1999) trawling has caused over 70% reduction in the *A. fragilis* population of the Adriatic (Gulf of Venice), whereas 90% of the specimens caught by trawlers were lethally damaged. Accordingly, the populations of *Atrina fragilis* seem to suffer from severe reductions due to trawling, as the results of this study also suggest.

Apart from living *A. fragilis* individuals, empty shells measuring from 15 to 35 cm were also collected, mostly from the trawled area, in conformity with previous data from the same area (Papoutsi & Galinou-Mitsoudi, 2010). Apart from natural mortality, this observation can be indicative of severe trawling effect. A common practice of trawlers is discarding non-target species during hauling or when approaching fishing ports, and this provides an explanation of the presence of dead shells in the area restricted to trawling. Unfortunately, no comprehensive study has been conducted on the fate of discarded Pinnids, but, as stated above, it is widely accepted that the species suffer from lethal damage due to trawling (Hall-Spencer *et al.*, 1999; Pranovi *et al.*, 2001). It is also worth mentioning the large number of damaged dead *A. fragilis* shells collected, implying that the devastating effect of trawling is much more severe.

Significant differences in the biometry of the studied *A. fragilis* population were detected between the trawled and the protected area, whereas neither sediment typology nor bathymetry had a significant effect. The population consisted mainly of a few sparse, medium-sized individuals (about 26 cm for shell length) in the former area, in contrast with the protected one, where the bulk of the population had large dimensions (about 41 cm for shell length) producing a right-skewed size frequency distribution. These results suggest enhanced growth rates or longevity. Apart from trawling, the above areas differ with respect to their trophic status: the former has been assigned as mesotrophic and the latter as eutrophic (Gotsis-Skretas & Ignatiades, 2007). Environmental differences may severely affect the growth rate of Pinnids (Shimeta & Jumars, 1991; Richardson *et al.*, 2004) giving an alternative possible explanation of the large-sized specimens derived from the eutrophic Thessaloniki Bay. The complete absence of small, juvenile, specimens, suggests bad recruitment, in conformity with a previous study carried out in the same area (Papoutsi & Galinou-Mitsoudi, 2010). These observations are of special concern, directly threatening the survival of the species in the Thermaikos Gulf.

According to Poutiers (1987) the maximum shell length of the species is 35 cm, while recently much larger specimens measuring 42.9 cm have been reported (Papoutsi & Galinou-Mitsoudi, 2010); by incorporating the results of this work, the maximum shell length of the species increases to 46.53 cm. Although comprehensive studies of the biology of the species have not been, so far, conducted, its growth rate has been estimated at around 3 to 4 cm per year; accordingly, its lifespan extends beyond 12 years (Solandt, 2003). Quite recently, specimens measuring from 29.5 to 37.5 cm in shell length have been aged at 7 to 32 years old, respectively (Papoutsi & Galinou-Mitsoudi, 2010), corresponding to a much reduced growth rate (1.2 cm.y^{-1}). Based on the results of this study, the age of the caught specimens ranged from 7 to 16 years at lengths of 15 to 34 cm, respectively, corresponding to an annual growth rate of 2.6 cm·y^{-1}. These estimations derive from shell growth ring counts, a method recently documented to produce strong biases in assessing the growth of Pinnidae, and thus strongly argued (Garcia-March & Marquez-Aliaga, 2007).

Unfortunately the lack of scientific data on the reproductive biology of the species hinders any possible

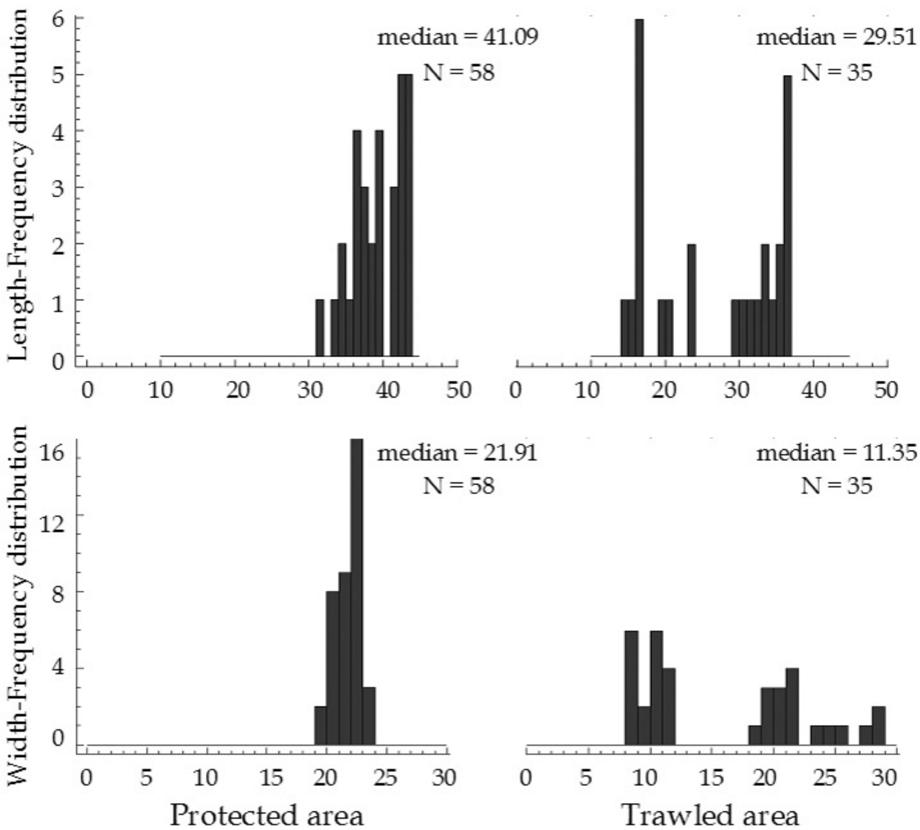

Fig. 3: Size–frequency distribution analysis of the studied *A. fragilis* population in the protected and trawled areas of the Thermaikos Gulf.

prediction of the future state of the *A. fragilis* population. Congeneric species in temperate waters follow an annual cycle highly correlated with water temperature and food supply (Angel-Perez *et al.*, 2007; Freites *et al.*, 2010), while in Mediterranean *Pinna nobilis* populations recruitment, which is considered highly variable inter-annually (Cabanellas-Reboredo *et al.*, 2009), takes place in late summer early autumn (Richardson *et al.*, 1999, 2004). Considering that population density (*i.e.* proximity of individuals) is a determining major for reproductive success, as is the case in all marine broadcast spawners (Solandt, 2003), the reported sparse populations in the European seas are rather discouraging for the species' viability. Therefore, the existence of an aggregated population inside the Thessaloniki Bay seems to be crucial for species sustainability in the Aegean Sea.

Concluding, the results of this study, although preliminary, suggest that bottom trawl fisheries may have severely affected *A. fragilis* populations in the Thermaikos Gulf, as reduced population density and size were recorded in the heavily trawled area; differences in trophic status may have also contributed synergistically. The need to conserve *A. fragilis* over its distributional range and to monitor its populations is evident, especially considering the lack of relevant data and the fact that Pinnids are ecosystem-engineering species supporting increased diversity of macrobenthic species and thus, any disruption of their populations could have cascade effects on the associated benthic community (Cummings *et al.*, 1998; Rabaoui *et al.*, 2009).

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