J. Black Sea/Mediterranean Environment
Vol. 20, No. 1: 1-12 (2014)

RESEARCH ARTICLE

Morphometric analyses of a *Pinctada radiata* (Leach, 1814) (Bivalvia: Pteriidae) population in the Maltese Islands

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Abstract

Five biometric parameters (shell height, shell length, nacreous height, nacreous width and hinge length) were measured for two populations of *Pinctada radiata* (Leach, 1814) within shallow coastal waters of the Maltese Islands, in the central Mediterranean Sea, as part of a demographic study of the species. In terms of shell height, both populations consisted mainly of small to moderate individuals. Regression analyses between these parameters were carried out, resulting in moderate to high correlations between all parameters except for hinge length. The study represents the first attempt at morphometric characterization of populations of a non-indigenous bivalve in Maltese coastal waters.

Keywords: Central Mediterranean, *Pinctada radiata*, non-indigenous bivalve, biometric

Introduction

Globally, the family Pteriidae (Bivalvia: Pterioida), which includes the group of species known as 'pearl oysters', comprises three genera *Pteria* Scopoli, 1777, *Pinctada* Röding, 1798 and *Electroma* Stoliczka, 1871, distributed predominantly in shallow waters of the tropical and subtropical continental shelf regions and particularly abundant in the Indo-Pacific (Wada and Tëmkin 2008). The family is represented in the Mediterranean Sea by one native, *Pteria hirundo* (Linné, 1758), and three alien species, namely *Pinctada radiata* (Leach, 1814), *Pinctada margaritifera* (Linné, 1758) and *Electroma vexillum* (Reeve, 1857) (Zenetos *et al*. 2010). The small pearly oyster, *P. radiata,* initially described in the genus *Avicula* Bruguière, 1792 was the first lessepsian bivalve, and species, to be reported in the Mediterranean Sea, being described and recorded from Egypt in 1884 by Monterosato (1878) under the junior synonym *Meleagrina savignyi* (Monterosato, 1878).

P. radiata belongs to a complex of three closely related species [*Pinctada fucata* (Gould, 1850), *Pinctada imbricata* Röding, 1798 and *Pinctada radiata* (Leach, 1814)] for which the oldest applicable name is *P. imbricata*. Hence, the systematic status of the taxon depends on authors' criteria for delimiting species. For instance, Tëmkin's mitochondrial and nuclear DNA analysis of Pterioidea (Tëmkin 2010), using 18S, 28S, 16S and H3 markers, is the basis for a conclusion that the three taxa are indeed evolutionarily significant units (ESUs); despite this, "from the taxonomic standpoint it is advocated to [...] recognize them at a subspecies level under the senior synonym, *P. imbricata*" (Tëmkin 2010). Cunha *et al.* (2011), using 18S and CO1 markers, regard *P. imbricata* and *P. radiata* as two specific units that are monophyletic and therefore more closely related together than any of them is to *P. fucata*, a view reiterated in the molecular tree presented in the same paper. The authors of the present paper use *P. radiata* in accordance with the latter view, since this research is of primarily ecological, rather than taxonomic, interest.

Since the Monterosato record, the species has successfully spread throughout the Mediterranean Sea, colonizing new habitats in the eastern basin, becoming very abundant in the Levantine basin (Barash and Danin 1992; Galil and Zenetos 2002; Gofas and Zenetos 2003). It was reported from Cyprus and Israel (Monterosato 1899), Greece (Serbetis 1963), Libya (Barash and Danin 1973), and Southern Turkey and Syria (Kinzelbach 1985). The species has also been imported for aquaculture purposes in some parts of the Mediterranean Sea, mainly in the 1960s and 1970s, and this has contributed towards the establishment of the allochthonous species in the wild, for example in the Saronikos Gulf in Greece (Serbetis 1963; Zenetos *et al.* 2004). More recently invaded Hellenic sites are the Kyklades Islands and Crete (Zenetos *et al*. 2008).

In the central Mediterranean, the bivalve has been recorded since the end of the 19th century in the Gulf of Gabes, Tunisia (Bouchon-Brandely and Berthoule 1891; Vassel 1899), where it is currently represented by very dense populations, becoming established along almost the entire Tunisian coastline from the Libyan border to Bizerta Lagoon (Tlig-Zouari and Zouali 1994, 1998; Tlig-Zouari *et al*. 2009; Zakhama-Sraieb *et al*. 2009). Subsequently, *P. radiata* was recorded from Malta (Pallary 1912), Lampedusa (Bombace 1967) and Pantelleria (Sabelli 1969).

Despite sporadic records from the western Mediterranean, *P. radiata* has spread as far as the Tyrrhenian, the Ionian and the Adriatic. Indeed, it has been recorded in Toulon, France, where it was scraped off a French ship hull (Zibrowius 1979), off Sicily (Di Natale 1982; Ricordi 1993), in Siracusa, on the south-eastern coast of Sicily (Gaglini 1994), in Trieste Bay (Vio and De Min 1996) as live individuals attached to an oil platform originating in the Sicily Channel, in Corsica (Boudouresque 1999) and off Pula, Croatia (Doğan and Nerlović 2008). Most recently, in 2011, *P. radiata* was recorded from Linosa, a small volcanic island in the Sicily Channel (Lodola *et al.* 2013).

Although many studies have been conducted out on *P. radiata* in its native areas, such as the Red Sea, the Persian Gulf and the Gulf of Oman (literature reviewed in Lodola *et al.* 2013), studies on this invasive species in the coastal habitats of the Mediterranean Sea are few. Detailed studies on the Mediterranean populations of *P. radiata* were performed only in Tunisia (Tlig-Zouari and Zouali 1994, 1995, 1998; Derbali *et al*. 2009; Tlig-Zouari *et al.* 2009, 2010, 2011; Derbali *et al*. 2011; Bellaaj-Zouari *et al*. 2012), Egypt (Yassien *et al*. 2000) and Turkey (Goksu *et al*. 2005). Many of these studies have focused on biometric, reproductive and demographic features of this bivalve species. The only previous genetic study on the species was conducted for five different *P. radiata* populations sampled in Greek, Syrian and Tunisian waters (Zenetos 2004).

This study presents an attempt at characterising the biometric characteristics of two *P. radiata* populations sampled in Maltese waters, in the central Mediterranean, and at running complete regression analyses between different bivalve shell attributes, pursuant to identifying the best biometric parameter to be adopted for monitoring the bivalves directly *in situ*.

Materials and Methods

A total of 84 *Pinctada radiata* individuals were either sampled during spring 2012 from a shallow (2-3m) rocky sublittoral area along the eastern coastline of the island of Malta, known as Baħar iċ-Ċagħaq, or were collected from the shore as beached individuals. Five live individuals of the same species were collected from the adjacent locality of Għadira s-Safra, which presented a similar benthic bioceonosis (Figure 1). Individuals were directly detached manually from the substratum and preserved in 96% ethanol. The species is known to occur in numerous shallow, rocky sublittoral localities along the eastern coastline of Malta and as a fouling organism on nets at aquaculture sites. However, the Baħar iċ-Ċagħaq population was the only one with a large enough abundance of individuals to permit a comprehensive biometric analysis, and the Għadira s-Safra *P. radiata* sample was too small to ensure a degree of representation of the source population. This sample was used solely for comparative purposes.

Morphometric parameters of the left valve were taken using a dial caliper with a resolution of 0.1mm, and comprised shell height (SH), shell length (SL), hinge length (HL), height and width of the nacreous part (NPH and NPW) and shell width (SW). This followed the protocol established in Lodola *et al.* (2013). The soft tissue of the sample individuals was retained for subsequent genetic analyses (Barbieri *et al.,* in press). The specimens of *P. radiata* were grouped into 5-mm size classes by SH and the size class distribution of the sampled individuals was plotted (this was possible only for the Baħar iċ-Ċagħaq population, because at Għadira s-Safra too few individuals were collected). Linear regression analyses were also made, for the Baħar iċ-Ċagħaq population only, in order to find the best fit between pairs of biometric parameters.

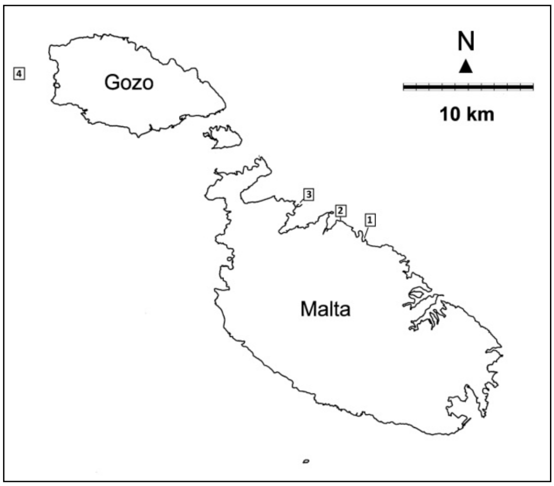

Figure 1. Sampling locations for *Pinctada radiata* individuals within the Maltese Islands. '1' Baħar iċ-Ċagħaq; '2' Għadira s-Safra; '3' tuna pen cages; '4' Dwejra offshore buoy.

Results

Similarly to the *P. radiata* specimens recorded in Linosa (Lodola *et al.* 2013), the individuals of this species collected from Malta showed features consistent with those reported by Wada and Tëmkin (2008). The *P. radiata* population at location 1 occurred with a large population of *Arca noae* (Linné, 1758). The benthic typology of the two Maltese samples sites – open (non-sheltered), shallow sublittoral areas subject to vigorous hydrodynamic activity - is consistent with that reported by other authors (e.g. Tlig-Zouari *et al.* 2009; Derbali *et al.* 2011) as being the preferred habitat for the species and other pteriids.

SH values for the *P. radiata* individuals sampled at Baħar iċ-Ċagħaq ranged between 27.0mm and 60.8mm, with an average SH value of 39.6mm (standard deviation ±6.2mm). Most individuals exhibited a small to moderate SH value, with only 11 out of the 84 sampled individuals having an SH value exceeding 45.0mm (Figure 2). The Għadira s-Safra individuals exhibited SH values ranging between 34.5mm and 48.0mm, with an average SH value of 39.7mm (±5.7mm).

The mean values (±standard deviation) for the other biometric parameters recorded for the *P. radiata* populations at locations 1 and 2 are given in Table 1.

Table 1. Mean values (±standard deviation, in mm) for biometric parameters for the *P. radiata* populations sampled at locations 1 and 2.

Biometric parameter	Location 1	Location 2
Shell length (SL)	42.2 (±7.4)	43.9 (±7.4)
Height of nacreous part (NPH)	33.6 (±5.6)	36.3 (±4.1)
Width of nacreous part (NPW)	33.5 (±5.8)	37.1 (±5.4)
Hinge Length (HL)	34.8 (±5.4)	35.0 (±4.3)
Shell Width (SW)	14.7 (±2.7)	13.3 (±2.4)

The values for the correlation factor R^2 for the pairwise correlations performed between five biometric parameters characterizing the *P. radiata* population at Baħar iċ-Ċagħaq are shown in Table 2. The R^2 value for most (10 out of 15) pairwise correlations exceeded 0.65, with the pairwise correlations involving HL consistently scoring R^2 values below 0.65. The pair of biometric parameters which scored the highest R^2 value consisted of SH and NPH. Figure 3 shows the results of the regression analyses performed sequentially between SH and the other four measured biometric parameters. SH values were well correlated with values for the other biometric parameters, with the exception of HL.

The results of the size class (SH) distribution indicated that the individuals within the Baħar iċ-Ċagħaq population belong to three main size classes, with 27.4% of individuals belonging to size classes smaller than 35mm, 47.7% of individuals having SH values ranging between 35mm and 45mm and 13.1% of individuals belonging to size classes larger than 45mm.

Table 2. Correlation factor (R^2) values for pairwise correlations between different *P. radiata* biometric parameters.

	SH	**SL**	**NPH**	**NPW**	**HL**	**SW**
SH		0.7288	0.8217	0.6889	0.5975	0.7094
SL			0.7490	0.7851	0.6167	0.7448
NPH				0.8334	0.5705	0.7391
NPW					0.5660	0.6645
HL						0.5640

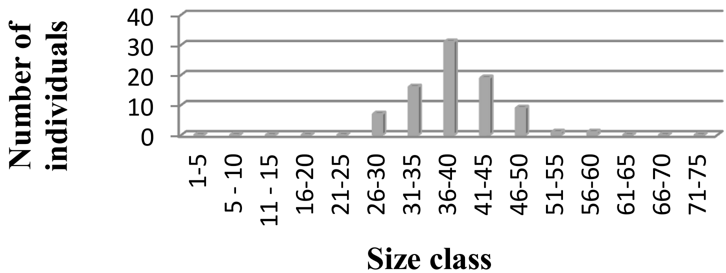

Figure 2. Size class (mm) distribution of *Pinctada radiata* specimens collected at Baħar iċ-Ċagħaq (north-east of Malta Island).

Discussion

The two sampled *P. radiata* populations exhibited large SH ranges, featuring both small (with a minimum SH value of 27.0mm at Baħar iċ-Ċagħaq) and large (with a maximum SH value of 60.8mm at Baħar iċ-Ċagħaq). The similarity in mean SH values for the two sampled sites (39.6mm and 39.7mm) can be explained in terms of the geographical proximity of the two populations, which lie just a few kilometres apart (Figure 1).

The co-occurrence of juvenile and adult stages of this species suggests reproductively-viable populations in both sampled sites, although the maximum SH value attained by *P. radiata* individuals at Għadira s-Safra is only 48.0mm. Such a maximum value is markedly different from that reported from other central Mediterranean localities, including Linosa (78.7mm – Lodola *et al.* 2013), El Bibane Lagoon in Tunisia (85.0mm – Seurat 1929), Bizerte Lagoon in Tunisia (100.5mm – Tlig-Zouari *et al.* 2009, 2010), Hammamet in Tunisia (104.3mm – Bellaaj-Zouari *et al.* 2012) and the Gulf of Gabes in Tunisia (96.0mm – Derbali *et al.* 2011). A marked depression in the maximum SH value recorded in the current study was also registered when making comparisons with values reported from the Red Sea (93.2mm – Yassien 1998). The only comparable maximum SH value with that reported in the present study is the one reported in the Eastern Mediterranean, within Egyptian coastal waters (64.0mm – Yassien *et al.* 2000). Two of the three sampled *P. radiata* populations on the island of Linosa show a modal size distribution class for SH which s higher than that of the Baħar iċ-Ċagħaq population sampled in the current study (Lodola *et al.* 2013). One may speculate that the relatively small adult valves reported for *P. radiata* individuals surveyed at the two sampling sites might be attributed either to the oligotrophic nature of Maltese coastal waters (Azzopardi *et al.* 2013), which might restrict the growth of this bivalve (this hypothesis is supported by the fact that similar maximum SH values were reported in the Eastern Mediterranean, a notoriously oligotrophic region), or to the highly exposed nature of the two sampled Maltese sites, with large *P. radiata* shells being more prone to wave-mediated detachment. The second hypothesis is supported by the regular beaching of live *P. radiata* and *A. noae* specimens along the coastline contiguous to the two samples sites.

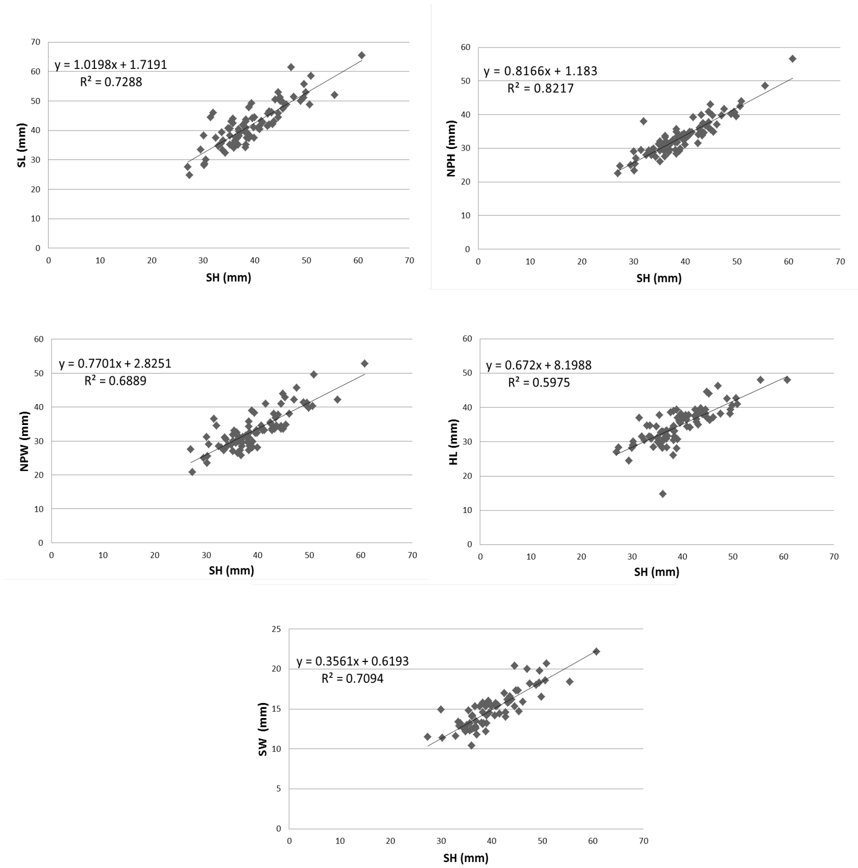

Figure 3. Regression analyses between SH and other measured biometric parameters for *P. radiata* individuals.

An investigative, broad-brush survey of Maltese coastal waters did not record such a high abundance of the species in additional sites within the same waters, with one exception. Several *P. radiata* individuals were observed as part of the fouling community on cages deployed by the local aquaculture industry for the rearing and fattening of bluefin tuna and located a few kilometres to the north-west of the two sites sampled in the current study, as well as on an buoy deployed at Dwejra for wave monitoring purposes off the island of Gozo (Figure 1). The occurrence of *P. radiata* individuals on artificial substrates (such as aquaculture cages and offshore buoys) is consistent with its occurring on artificial substrates (such as buoys and fish nets) in Tunisian waters (Tlig-Zouari *et al.* 2009). Individual specimens have otherwise been recorded from Buġibba (2006), Paradise Bay (2007), Spinola Bay (2010), Balluta Bay (2010) and Qajjenza (2010) by one of the present authors (Cilia, D. P., unpublished data).

Despite its first record from Maltese waters dating back over 100 years (Pallary 1912), the current distribution of extensive *P. radiata* populations in the same waters is restricted to the eastern coastline of Malta (Figure 1). This might be attributed to bathymetric reasons (extensive shallow-water areas are exclusively found on this side of the island) or to hydrodynamic reasons, with the prevailing sea surface currents on this side of the island having a north-west origin. No *P. radiata* individuals were observed attached to seagrass shoots or to some macroalgae, as reported in the Red Sea by Yassien *et al.* (2009). Similar to the *P. radiata* individuals from Linosa (Lodola *et al.* 2013), the bivalve specimens recorded at the two Maltese sites showed homogeneity in colouration, although it is known to vary depending on the species' adaptation to the local environmental conditions (Bellaaj-Zouari *et al.* 2012).

Since SH values were well correlated with values for the other investigated biometric parameters (with the exception of HL values), the in situ measurement (via calipers) of SH values for *P. radiata* individuals, without resorting to destructive sampling, can prove useful in monitoring population dynamics of the species in invaded marine ecosystems.

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Received: 11.12.2013
Accepted: 02.01.2014