

## CORRECTED PROOF

## Rapid Communication

**New occurrence of *Pinctada imbricata radiata* (Leach, 1814) in the Balearic Archipelago (NW Mediterranean Sea)**Lydia Png-Gonzalez<sup>1,\*</sup>, Joseba Aguilo-Arce<sup>2</sup>, Maite Vázquez-Luis<sup>1</sup> and Aina Carbonell<sup>1</sup><sup>1</sup>Centro Oceanográfico de Baleares (IEO, CSIC), Muelle de Poniente s/n, 07015 Palma de Mallorca, Spain<sup>2</sup>Universitat de les Illes Balears, Carretera de Valldemossa km 7.5, 07122 Palma de Mallorca, SpainAuthor e-mails: [lydiapng@gmail.com](mailto:lydiapng@gmail.com) (LPG), [josebajusep97@gmail.com](mailto:josebajusep97@gmail.com) (JAA), [maite.vazquez@ieo.es](mailto:maite.vazquez@ieo.es) (MVL), [ana.carbonell@ieo.es](mailto:ana.carbonell@ieo.es) (AC)

\*Corresponding author

**Citation:** Png-Gonzalez L, Aguilo-Arce J, Vázquez-Luis M, Carbonell A (2021) New occurrence of *Pinctada imbricata radiata* (Leach, 1814) in the Balearic Archipelago (NW Mediterranean Sea). *BioInvasions Records* 10 (in press)

**Received:** 2 April 2021**Accepted:** 18 June 2021**Published:** 20 September 2021**Handling editor:** Agnese Marchini**Thematic editor:** April Blakeslee**Copyright:** © Png-Gonzalez et al.This is an open access article distributed under terms of the Creative Commons Attribution License ([Attribution 4.0 International - CC BY 4.0](https://creativecommons.org/licenses/by/4.0/)).

## OPEN ACCESS

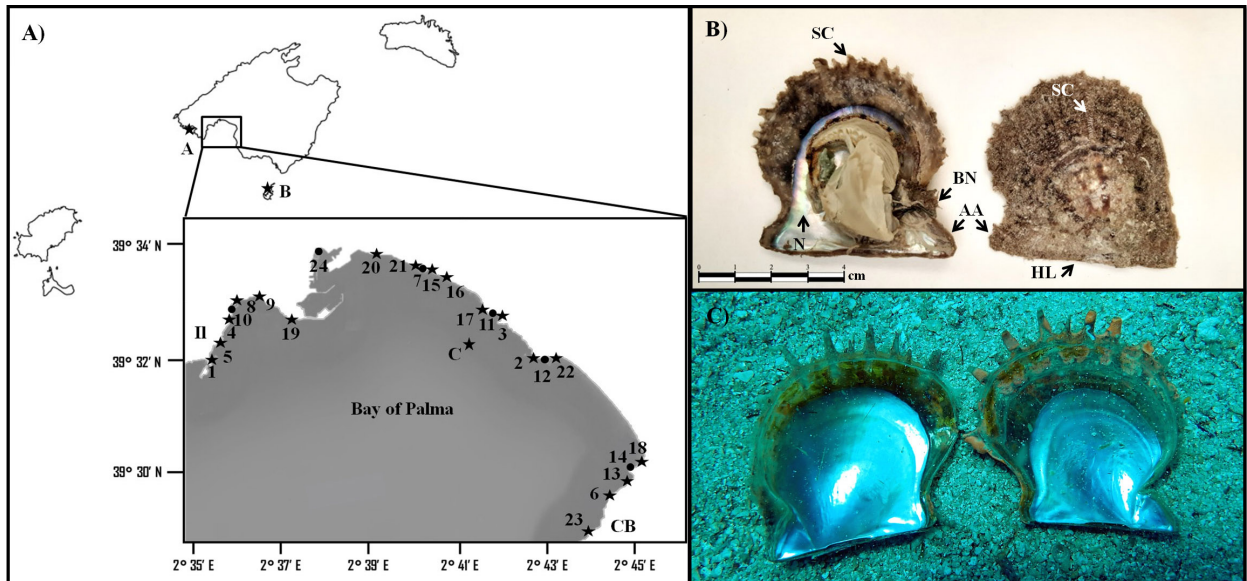
**Abstract**

The presence of *Pinctada imbricata radiata* (rayed pearl oyster) was explored in the Bay of Palma (Balearic Archipelago, NW Mediterranean Sea) by means of Rapid Assessment Surveys (RAS). Forty-three specimens were found in rocky substrates from recreational marinas and neighbouring natural habitats, including Cabrera National Park. Average hinge length was  $26.8 \pm 13.3$  mm and average shell height was  $28.6 \pm 16.2$  mm; a maximum size of  $55.6 \times 55.9$  mm was measured. The main occurrence of the exotic oyster in marinas, and also far away in Cabrera, points to maritime transport as the primary introduction vector; whereas records in the adjacent natural habitats suggest secondary spread by natural dispersal has occurred. Considering the populations of *P. imbricata radiata* documented in the Balearic Archipelago, the bivalve seems to be well established in the area. The study explores the potential of RAS as early detection tools for invasive species along the coastline, and recommends further assessment on the ecological impact of *P. imbricata radiata* in marine protected areas.

**Key words:** rayed pearl oyster, non-indigenous species (NIS), marine invasive species, rapid assessment survey, maritime transport, natural dispersal

**Introduction**

The rayed pearl oyster *Pinctada imbricata radiata* (Leach, 1814), originally from the Indo-Pacific, was among the first invasive Lessepsian migrants that arrived to the Mediterranean Sea in 1874 (Monterosato 1878), where it is considered one of the worst invasive species (Streftaris and Zenetos 2006). This bivalve has successfully spread throughout the Mediterranean, colonising new habitats and establishing populations in the eastern (Barbieri et al. 2016; Theodorou et al. 2019; Moutopoulos et al. 2021) and central basins (Deidun et al. 2014; Gavrilović et al. 2017; Scuderi et al. 2019); nonetheless, records in the north-western area are still scarce. The first citation in the Balearic Archipelago dates from 1999, from a single specimen collected among fishing scraps in Majorca (Pons-Moyà and Pons 2001), and a recent study confirms its presence in the neighbouring island of Minorca (Ballesteros et al. 2020).



**Figure 1.** A) Stations for RAS along the Bay of Palma. Rocky substrates are represented by circles for marinas, and stars for natural habitats (for details see Supplementary material Table S1). B) Morphological features on the internal (left) and external side (right) of the shell: AA, anterior auricle; BN, byssal notch; HL, hinge line; N, nacre; SC, scales. C) Specimen of *P. imbricata radiata* spotted in Cabrera National Park. Photo credit: JAA (B), MVL (C).

Rapid Assessment Surveys (RAS) have been tested in many coastal areas and proven to be suitable tools for the monitoring of benthic non-indigenous species (NIS) (Bishop et al. 2015; Collin et al. 2015). For our study, RAS were adapted with the aim to explore their potential as early detection tools and to determine the presence of invasive NIS in different marine environments, namely recreational marinas and neighbouring natural habitats. Here, the presence and distribution of *P. imbricata radiata* is documented for the Bay of Palma and Cabrera National Park, from the Balearic Archipelago, Spain.

### Materials and methods

The presence and distribution of invasive species was explored by RAS along the Bay of Palma (Balearic Archipelago, Spain), between Illetes (Il: 39.53296°; 2.58958°) and Cala Blava (CB: 39.48016°; 2.72844°) (Figure 1A). Rocky substrates were sampled in recreational marinas (6) and adjacent natural habitats (18), between 0–2 m depth. Optimal strategies were adapted for the different marine environments: (1) in the marinas, pontoon sides were sampled using a handmade scraper with a collecting basket, and submerged substrates were examined (e.g., buoys, mooring ropes); whereas (2) in natural habitats, visual transects were performed by means of snorkelling, and samples were collected with the aid of a trowel (Aguilo-Arce 2020). Specimens of *P. imbricata radiata* were analysed by means of DNA barcoding as part of a complementary study in order to correctly identify the species from other congeners (Aguilo-Arce 2020). Confirmed individuals were measured with a vernier calliper (0.1 mm accuracy) for the hinge length (HL) and the shell height (SH) and were stored at the Universitat de les Illes Balears (UIB, Palma).

## Results

*Pinctada imbricata radiata* was found in 7 out of the 23 surveyed locations. An overall of 43 specimens was collected mainly from the marinas (St. 7, 10, 11, 12, 14), except for two natural habitats (St. 8, 18) (Supplementary material Table S1, Figure 1A). Average HL was  $26.8 \pm 13.3$  mm, while average SH was  $28.6 \pm 16.2$  mm (mean  $\pm$  SD). Playa S'Arenal (St. 18) represented the locality with a higher number of rayed pearl oysters and larger size, including a maximum size of  $55.6 \times 55.9$  mm (Table S1, Figure 1B). In addition to the sampled sites, other individuals were found in natural habitats (Table S1: St. A, B, C), where different scenarios occurred (described below).

Caló des Monjo (St. A) is a sheltered cove with rocky bottoms where a live individual of *P. imbricata radiata* was collected from a mooring rope, between 3–4 m depth. In Cabrera National Park (St. B), during a survey of *Pinna nobilis*, an empty shell of *P. imbricata radiata* was spotted along with *Haliotis tuberculata* shells in the proximity of an octopus shelter at 8 m depth. The condition of the oyster shell suggested that the mollusc was captured recently, since the internal sides were lacking epiphytes (Figure 1C). Finally, those individuals recorded in Cala Gamba (St. C) were found associated with an abandoned fish trap at 2 m depth, along with other marine invasive species such as *Halimeda incrassata*.

## Discussion

The presence of *P. imbricata radiata* was primarily found in artificial substrates of the sampled recreational marinas, compared to natural habitats. This finding suggests that maritime transport is the likely primary introduction vector of the rayed pearl oyster in Majorca. Furthermore, some of the natural habitats where the Indo-Pacific bivalve was recorded are closely related to recreational boating, which is not surprising considering that the Balearics are a natural attraction for this leisure activity. The finding of *P. imbricata radiata* in surrounding areas of the marinas suggests secondary introductions by natural spread.

The existence of *P. imbricata radiata* in the Mediterranean Sea has been documented since the 19<sup>th</sup> century, especially in the eastern part of the basin (Barbieri et al. 2016). The species was intentionally introduced for mariculture purposes with mixed success, leading to naturalised populations that expanded their distribution (Gofas and Zenetos 2003; Lodola et al. 2013). Secondary spread may include marine litter (Ivkić et al. 2019), maritime transport (Tlig-Zouari et al. 2009; Crocetta 2011; Theodorou et al. 2019) and natural dispersal (Oliverio et al. 1992).

Sporadic records have been reported in the north-western Mediterranean (Altimira 1977; Pons-Moyà and Pons 2001; Stasolla et al. 2014), until the first known population was described by López Soriano and Quiñonero-

Salgado (2019) for the Iberian Peninsula. Specimens of *P. imbricata radiata* were collected as part of the fouling attached to mussel ropes in the Ebro Delta, suggesting established populations in the area. Recently, Ballesteros et al. (2020) confirmed established populations on the neighbouring island of Minorca, all of them restricted to harbour areas and originally associated to shellfish farming, pointing to a recent introduction of the species around 2016. Authors also reported sporadic observations of the oyster in Majorca since 2010.

The rayed pearl oyster shows a high capacity for dispersal at different stages of its life cycle. The larval phase of *Pinctada* spp. ranges from 16–30 days, depending on species, temperature, nutrition and the availability of settlement substrates (Gervis and Sims 1992). Similarly, the efficiency of spat recruitment may be influenced by hydrodynamics, depth, biotic and abiotic changes in water parameters, as well as the collector material types (Yiğitkurt et al. 2017). After settlement, some motility is retained, and adults of *P. imbricata radiata* can actively move by the byssal threads (Giraldes et al. 2019), which implies advanced displacement mechanisms for this benthic species under unfavourable conditions.

The shell measurements of the oysters recorded in Majorca contrast with the data reported by Ballesteros et al. (2020), where average HL was  $56.7 \pm 8.9$  mm and average SH was  $59.6 \pm 12.1$  mm. The dimensions described by the authors correspond with the maximum sizes obtained in our study, which implies that the individuals we collected are younger. Studies on *Pinctada radiata* reproduction have proven that sexual maturity is reached between 15–20 mm (Tlig-Zouari et al. 2009), so it can be assumed that most of the specimens examined were adults and therefore spawners. Moreover, the smaller size of the individuals associated with an abandoned fish trap denotes that it functioned as a collector for spats and spawners in the vicinity, at least in terms of oceanographic distance.

Considering the documented populations in Minorca, the previous observations in Majorca and the results of the current study, *P. imbricata radiata* seems to be well established in the Balearic Archipelago. The pathway of introduction by maritime transport is considered the likely primary vector for the species, either via biofouling or ballast water. Also, secondary spread by natural dispersal seems significant due to the great dispersion capacity of this bivalve.

An increase of *P. imbricata radiata* can be expected in the coming years, thus RAS are encouraged for early detection of the species in sensitive areas nearby hotspots (e.g., commercial ports, recreational marinas), since it has been demonstrated to be a useful tool to determine the presence and distribution of invasive species along the coastline. Further monitoring surveys on NIS are recommended in order to provide quantitative data and to assess the ecological impact of *P. imbricata radiata* in marine protected areas.

## Acknowledgements

We would like to thank the reviewers and editors for valuable comments and suggestions. The authors are grateful to the general managers of the 6 marinas visited along the Bay of Palma for permission to sample. We also thank M. Capa for providing the handmade scraper and storing the samples at the Universitat de les Illes Balears.

## Funding declaration

This study was supported by the LIFE-IP INTEMARES project (LIFE15 IPE/ES/000012), financed by the European Commission and coordinated by Fundación Biodiversidad, as part of the Ministry for the Ecological Transition and Demographic Challenge. MVL was supported by a postdoctoral contract Juan de la Cierva-Incorporación (IJCI-2016-29329) of the Ministry of Science, Innovation and Universities. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

## Authors' contribution

LPG and AC conceived the research, the sample design and methodology. LPG, JAA and MVL performed the data collection, data analysis and interpretation. LPG wrote the manuscript. All authors reviewed and approved the final manuscript.

## References

- Aguilo-Arce J (2020) Caracterización de especies invasoras en la Bahía de Palma por métodos de muestreo rápidos y taxonomía integrativa. MSc Thesis, Universitat de les Illes Balears, Palma de Mallorca, Spain, 53 pp
- Altimira C (1977) Fauna malacològica marina de Sant Pol de Mar (Litoral N de la provincia de Barcelona). Primera parte. *Miscellània Zoològica* 4(1): 23–32
- Ballesteros E, Marsinyach E, Bagur M, Sales M, Movilla J, Bolado I, Cefali ME (2020) The pearl oyster *Pinctada imbricata radiata* (Leach, 1814) (Bivalvia: Pteriidae) reaches Minorca, Balearic Islands. *Bolletí de la Societat d'Història Natural de les Balears* 63: 97–108
- Barbieri M, Deidun A, Maltagliati F, Castelli A (2016) A contribution to the phylogeography of *Pinctada imbricata radiata* (Leach, 1814) (Bivalvia: Pteriidae) from the Eastern Mediterranean Sea by means of the mitochondrial COI marker. *Italian Journal of Zoology* 83: 113–120, <https://doi.org/10.1080/11250003.2015.1106012>
- Bishop JDD, Wood CA, Lévêque L, Yunnice ALE, Viard F (2015) Repeated rapid assessment surveys reveal contrasting trends in occupancy of marinas by non-indigenous species on opposite sides of the western English Channel. *Marine Pollution Bulletin* 95: 699–706, <https://doi.org/10.1016/j.marpolbul.2014.11.043>
- Collin SB, Tweddle JF, Shucksmith RJ (2015) Rapid Assessment of marine non-native species in the Shetland Islands, Scotland. *BioInvasions Records* 4: 147–155, <https://doi.org/10.3391/bir.2015.4.3.01>
- Crocetta F (2011) Marine alien Mollusca in the Gulf of Trieste and neighbouring areas: a critical review and state of knowledge (updated in 2011). *Acta Adriatica* 52(2): 247–260
- Deidun A, Gianni F, Cilia DP, Lodola A, Savino D (2014) Morphometric analyses of a *Pinctada radiata* (Leach, 1814) (Bivalvia: Pteriidae) population in the Maltese Islands. *Journal of Black Sea/Mediterranean Environment* 20(1): 1–12
- Gavrilović A, Piria M, Guo XZ, Jug-Dujaković J, Ljubučić A, Krkić A, Ivešai N, Marshallj BA, Gardner JPA (2017) First evidence of establishment of the rayed pearl oyster, *Pinctada imbricata radiata* (Leach, 1814), in the eastern Adriatic Sea. *Marine Pollution Bulletin* 125: 556–560, <https://doi.org/10.1016/j.marpolbul.2017.10.045>
- Gervis MH, Sims NA (1992) The biology and culture of pearl oysters (Bivalvia: Pteriidae). ICLARM Studies and Reviews 21, 49 pp
- Giraldes BW, Leitão A, Smyth D (2019) The benthic sea-silk-thread displacement of a sessile bivalve, *Pinctada imbricata radiata* (Leach, 1819) in the Arabian-Persian Gulf. *PLoS ONE* 14: e0215865, <https://doi.org/10.1371/journal.pone.0215865>
- Gofas S, Zenetos A (2003) Exotic mollusks in the Mediterranean basin, current status and perspectives. *Oceanography and Marine Biology* 41: 237–277
- Ivkic A, Steger J, Galil BS, Albano PG (2019) The potential of large rafting objects to spread Lessepsian invaders: the case of a detached buoy. *Biological Invasions* 21: 1887–1893, <https://doi.org/10.1007/s10530-019-01972-4>
- Lodola A, Nicolini L, Savini D, Deidun A, Occhipinti-Ambrogi A (2013) Range expansion and biometric features of *Pinctada imbricata radiata* (Bivalvia: Pteriidae) around Linosa Island, Central Mediterranean Sea (Italy). *Italian Journal of Zoology* 80: 303–312, <https://doi.org/10.1080/11250003.2013.775363>

- López Soriano J, Quiñonero-Salgado S (2019) Primera cita de *Pinctada radiata* (Leach, 1814) (Bivalvia: Pteriidae) para la Península Ibérica. *Elona* 1: 52–56
- Monterosato TA (1878) Enumerazione e sinonimia delle conchiglie Mediterranee. *Giornale di scienze naturali ed economiche di Palermo* 13: 61–113
- Moutopoulos DK, Ramfos A, Theodorou JA, Katselis G (2021) Biological aspects, population and fishery dynamics of the non-indigenous pearl oyster *Pinctada imbricata radiata* (Leach, 1814) in the Eastern Mediterranean. *Regional Studies in Marine Science* 45: 101821, <https://doi.org/10.1016/j.rsma.2021.101821>
- Oliverio M, Gerosa G, Cocco M (1992) First record of *Pinctada radiata* (Bivalvia, Pteriidae) epibiont on the loggerhead sea turtle *Caretta caretta* (Chelonia, Cheloniidae). *Bollettino Malacologico* 28: 149–152
- Pons-Moyà J, Pons GX (2001) Primera cita de *Pinctada radiata* (Leach, 1814) (Mollusca: Bivalvia: Pteriidae) a les Illes Balears. In: Pons GX (ed) (2001) III Jornades del Medi Ambient de les Illes Balears. Can Tàpera, 14-16 Novembre, 2001. Societat d'Història Natural de les Balears, Palma, pp 129–130
- Scuderi D, Balistreri P, Germanà A (2019) Are *Pinctada radiata* (Leach, 1814) and *Pinctada fucata* (Gould, 1850) (Bivalvia Pteriidae) only synonyms or really different species? The case of some Mediterranean populations. *Biodiversity Journal* 10: 415–526, <https://doi.org/10.31396/Biodiv.Jour.2019.10.4.415.426>
- Stasolla G, Riolo F, Macali A, Pierri C, Crocetta F (2014) Further spreading in the Italian seas of already established non-indigenous mollusc species. *Marine Biodiversity Records* 7: e120, <https://doi.org/10.1017/S1755267214001079>
- Streftaris N, Zenetos A (2006) Alien Marine Species in the Mediterranean - the 100 'Worst Invasives' and their Impact. *Mediterranean Marine Science* 7: 87–118, <https://doi.org/10.12681/mms.180>
- Theodorou JA, Perdikaris C, Spinos E (2019) On the occurrence of rayed pearl oyster *Pinctada imbricata radiata* (Leach, 1814) in Western Greece (Ionian Sea) and its biofouling potential. *Biharean Biologist* 13(1): 4–7
- Tlig-Zouari S, Rabaoui L, Irathni I, Fguiri H, Ben Hassine OK (2009) Distribution, habitat and populations' densities of the exotic species *Pinctada radiata* (Mollusca, Bivalvia) along the north and east of Tunisian coast. *Cahiers de Biologie Marine* 50: 131–142
- Yığıtkurt S, Lök A, Kırtık A, Küçükdermenci A, Kutay E (2017) Preliminary results of spat collection of Rayed pearl oyster (*Pinctada radiata*) in Turkey. *Ege Journal of Fisheries and Aquatic Sciences* 34: 211–218, <https://doi.org/10.12714/egejfas.2017.34.2.13>

### Supplementary material

The following supplementary material is available for this article:

**Table S1.** Surveyed locations where *P. imbricata radiata* was found.