

Shell Infestation of the Farmed Pacific Oyster *Magallana gigas* by the Endolith Bivalve *Rocellaria dubia*

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Abstract: Oyster shells are substratum for different epibiotic and endobiotic organisms, including pests and parasites. *Rocellaria dubia* is endolithic and facultative tube-dwelling bivalve, boring in different calcareous substrates, including the shells of bivalves. In 2020, *R. dubia* was found as endolithic in the shells of the Pacific oyster *Magallana gigas*, from an oyster farm off the Sacca di Goro lagoon (Emilia-Romagna region, Northern Adriatic Sea, Italy). The purpose of this study was to describe this newly recorded association. Altogether, 136 specimens of *R. dubia* were found in 15 oysters, photographed under a stereoscope, and their length was measured. Heavily infested oysters hosted tens of *R. dubia* borers, which were perforating the whole thickness of the oyster valves. The flesh of these oysters was heavily damaged, suggesting parasitic association. *R. dubia* specimens were categorized into three age classes (0–1, 1–2, and 2–3 years old). *M. gigas*/*R. dubia* might be a widespread association, overlooked due to the very scarce research on macrofauna associated with *M. gigas*. Considering the negative effects of *R. dubia* endobiosis on oyster fitness, and possible impacts on oyster aquaculture, further research should be conducted in order to elucidate the distribution and ecological characteristics of this parasitic association.

Keywords: endobiont; borer; parasite; Mediterranean; Adriatic; flask shells; Gastrochaenidae; *Crassostrea*; aquaculture

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1. Introduction

Rocellaria dubia (Pennant, 1777) is an endolithic and facultative tube-dwelling bivalve from the family Gastrochaenidae. It bores in a wide variety of natural and artificial non-biogenic and biogenic calcareous substrates, from shallow subtidal habitats down to 200 m depth [1–3]. It is an important bioeroder [4,5], and it can also be found as a fossil in deposits of marine origin [6–8]. *R. dubia* is distributed in the Mediterranean Sea, Black Sea, British islands, and various locations in the eastern Atlantic Ocean, including Morocco, Angola, West Africa, the Canaries, Cape Verde Islands, and Island St Helena [2,3,9–13]. The species is very common and widely distributed in the Adriatic Sea, boring in infralittoral rocks of carted limestone, coralligenous biogenic outcrops, and other biogenic structures, as well as artificial concrete blocks [2,14–17]. *R. dubia* perforates skeletons and shells of different dead and live marine organisms, such as stone corals [5,17], coralline algae [5], echinoderms [6], gastropods [18], and bivalves [2]. Some studies suggest a negative impact of this borer on host bivalves [19].

The shells of oysters act as a support for an array of epibiotic and endobiotic organisms [20–24]. Many of them are pests and parasites and damage the oyster aquaculture industry [24–26]. Despite its importance, the knowledge on the fauna associated with natural or farmed oysters in the Adriatic and the Mediterranean Sea is very scarce.

The Pacific oyster *Magallana gigas* (Thunberg, 1793), native to Japan and south-east Asia, was introduced across Europe and the Mediterranean Sea for aquaculture purposes in the second half of the 20th century. It replaced the farming of the European flat oyster *Ostrea edulis* Linnaeus, 1758, whose production decreased due to the high mortalities caused by viral and parasitic diseases [27–29]. *M. gigas* has also been introduced for farming in many other parts of the world in order to support and develop oyster aquaculture. While initially it was limited to farming sites, it soon spread outside farming sites, establishing wild populations. Nowadays, the Pacific oyster is the most commonly farmed oyster with worldwide distribution [30]. Although in Italy, Pacific oyster farming is limited and less important than the aquaculture of other mollusks, such as the Mediterranean mussel (*Mytilus galloprovincialis* Lamarck, 1819) and Manila clam (*Ruditapes philippinarum* (A. Adams and Reeve, 1850)), it is continuously developing [31–33]. In Italy, most of the *M. gigas* farms are in Sicily, Liguria, Apulia, Sardinia, and Emilia-Romagna regions [34], Prioli, *pers. comm.*

In the frame of a project investigating the fauna associated with Pacific oysters *M. gigas* along the Emilia-Romagna coast (Italy, northern Adriatic Sea), *R. dubia* boring in oyster shells were observed in the aquaculture facility off the Sacca di Goro lagoon. Careful analyses of the literature revealed that *R. dubia* was never reported in association with *M. gigas* neither in wild, nor in farmed oysters. Moreover, information on the effects of *R. dubia* infestation on oyster hosts are very limited.

The aims of this research were to report for the first time the association between *M. gigas* and *R. dubia*, and to describe the morphological characteristics of the oyster hosts and the borers.

2. Materials and Methods

Sampling was performed in the frame of the project “Monitoraggio delle specie aliene negli impianti di molluschicoltura dell’Emilia Romagna: impatti e misure di mitigazione”. Pacific oysters (*M. gigas*) were sampled in September 2020 from the oyster farm off the Sacca di Goro lagoon (Northern Adriatic Sea, Italy), managed by Cooperativa Sant’Antonio di Gorino (Figure 1). Oysters are grown in tubular baskets of about 3 to 5 m depth attached on a long line system, which extends along about 3 nautical miles.

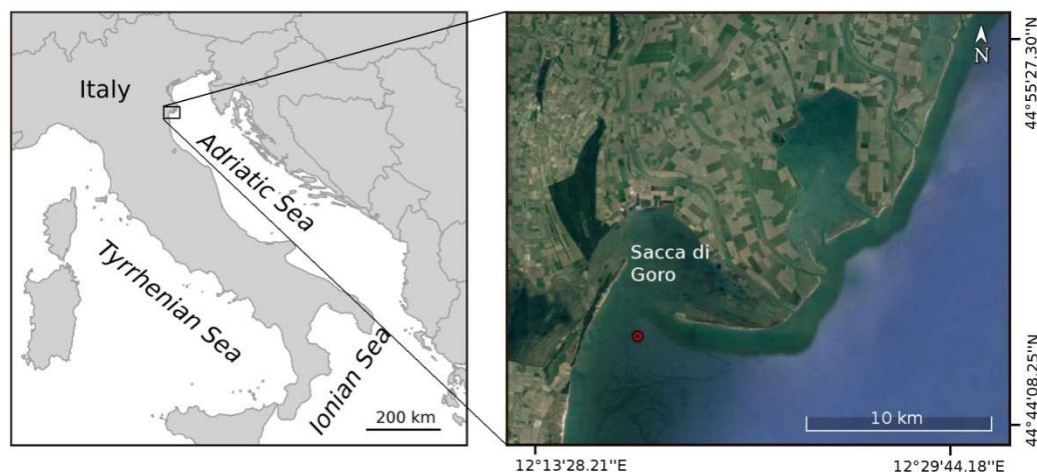


Figure 1. Map of sampling site. Sampling site marked with a red dot.

Three samples, of five oysters each, were collected manually from three random sites along the long line and placed in plastic containers filled with sea water. In the laboratory, oysters were first rinsed with running water on a 0.5 mm mesh size sieve, in order to separate vagile epibiotic organisms for later taxonomic analyses, and then transferred to 90% ethanol. Each oyster was opened, the soft flesh was removed, and the length and width of both the upper and lower valves were measured with a caliper following Harding *et al.* [35]. Shells were then carefully broken with pliers in order to avoid damage to the observed bivalve *R. dubia* and other associated invertebrates. Fragments of shells were analyzed under a stereoscope (Leica Wild M3B), and all specimens were extracted and preserved in 90% ethanol for later taxonomic determination. The abundance of *R. dubia* was determined cumulatively for each sample containing 5 oysters. Photographs of the outer and inner sides of the shell were taken only of the most infested oysters, and specimens of *R. dubia* were counted separately.

Each specimen of *R. dubia* was observed under a stereoscope (Nikon SMZ1500) with mounted DS-5M-U1 Digital Photomicrographic Camera System with 5Mpixels sensor. The shell length (maximum distance along the anterior posterior axis) and width (maximum lateral axis) of each specimen were measured following Ricci *et al.* [4], Schiaparelli *et al.* [36], and Carter *et al.* [37], using the computer program Motic Images Plus 3.0.

3. Results

The smallest oyster had a 71.4 mm long and 50.3 mm wide upper valve and a 60.02 mm long and 37.4 mm wide lower valve (Table S1). The largest oyster had a 204 mm long and 120.6 mm wide upper valve and a 192.0 mm long and 89.8 mm wide lower valve.

On the external sides of some oyster shells, characteristic “8”-shaped siphons of the boring bivalve *R. dubia* were visible (Figures 2a). *R. dubia* siphons were also perforating other epibionts covering the oysters, such as barnacles and serpulid polychaetes (Figure 2a). One oyster from the first sample, with a 79.3 mm long and 48.8 mm wide upper valve and a 67.8 mm long and 42.9 mm wide lower valve (Table S1), was infested by 32 *R. dubia* individuals. In this, and other heavily infested oysters, *R. dubia* was perforating the whole thickness of the valves, and the holes were internally visible. Some of these holes were partly or completely covered by the internal callus produced by the host oyster in order to protect itself (Figure 2b). The flesh inside heavily infested oysters was reduced to approximately one-third of the flesh size found in undamaged oysters of similar size (Figure 3). Moreover, the flesh color was grey, instead of the normal white-grey-yellowish color, and it had a soggy structure. The white-yellow greasy muscular part of the flesh seemed completely absent.

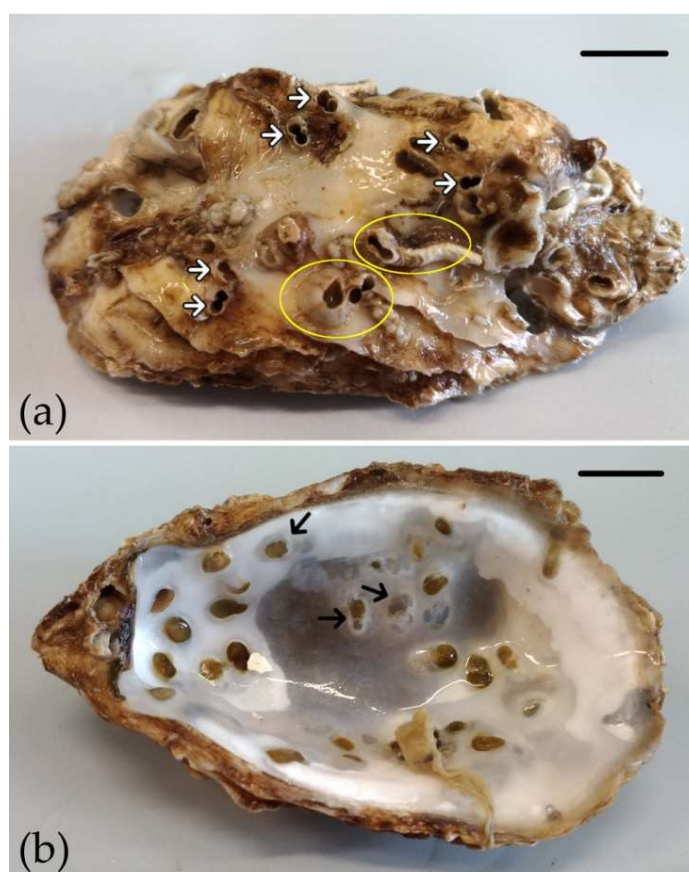


Figure 2. Upper valve of the oyster *Magallana gigas* infested by *Rocellaria dubia* (the most infested oyster from research): (a) external view: white arrows indicate “8”-shaped siphon openings of *Rocellaria dubia*, yellow circles indicate siphons penetrating through barnacle and polychaete tube; (b) internal view: black arrows indicate holes made by *Rocellaria dubia*, covered by the callus produced by the oyster. Scale bars—10 mm.

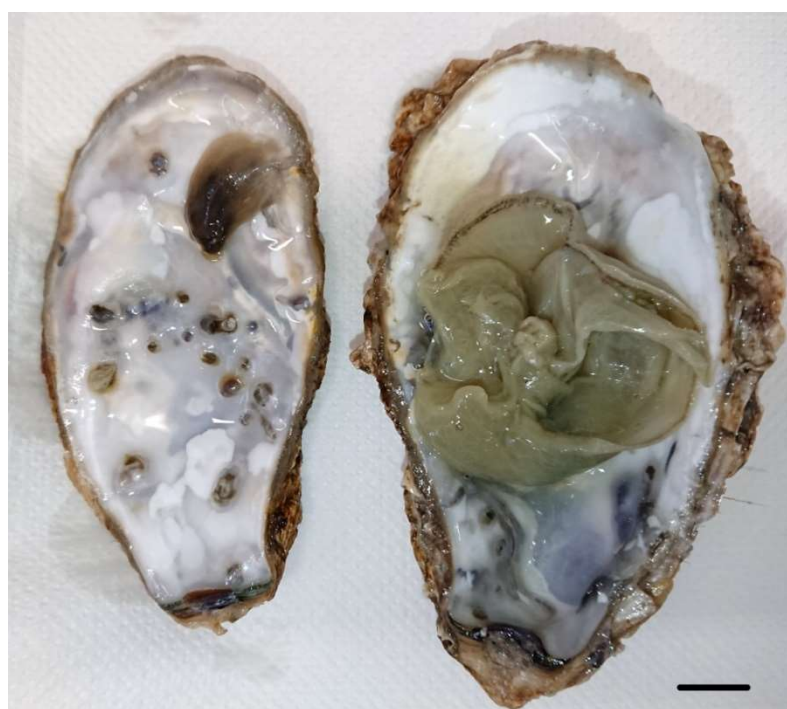


Figure 3. Lower (left) and upper (right) valve of the oyster *Magallana gigas* infested by *Rocellaria dubia*. Scale bar—10 mm.

Altogether, 136 specimens of *R. dubia* were found in 15 oysters: 68 specimens in Sample 1 (including 32 from the most infested oyster), 49 in Sample 2, and 19 in Sample 3 (Figure 4). The shell length and width of 122 specimens were measured, while the shells of the remaining 14 specimens were damaged during extraction (Table S2). The smallest *R. dubia* was 1.58 mm long and 0.83 mm wide, while the largest one was 12.86 mm long and 6.18 mm wide (Table S2). In the most heavily infested oyster, the smallest *R. dubia* was 4.69 mm long and 1.98 mm wide, while the largest one was 9.67 mm long and 4.97 mm wide. Overall, most *R. dubia* were 7–8 mm long (Figure 5a). A similar size distribution of the *R. dubia* specimens is also reported in the most infested oyster (Figure 5b).

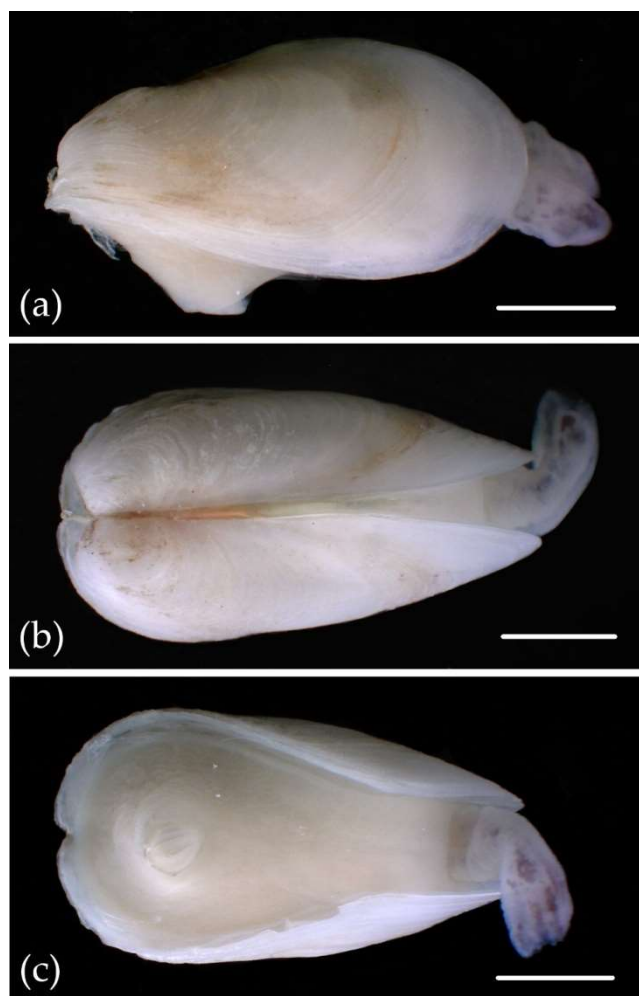


Figure 4. *Rocellaria dubia* extracted from the oyster *Magallana gigas*: (a) lateral view, right valve; (b) dorsal view; (c) ventral view. Scale bars—2 mm.

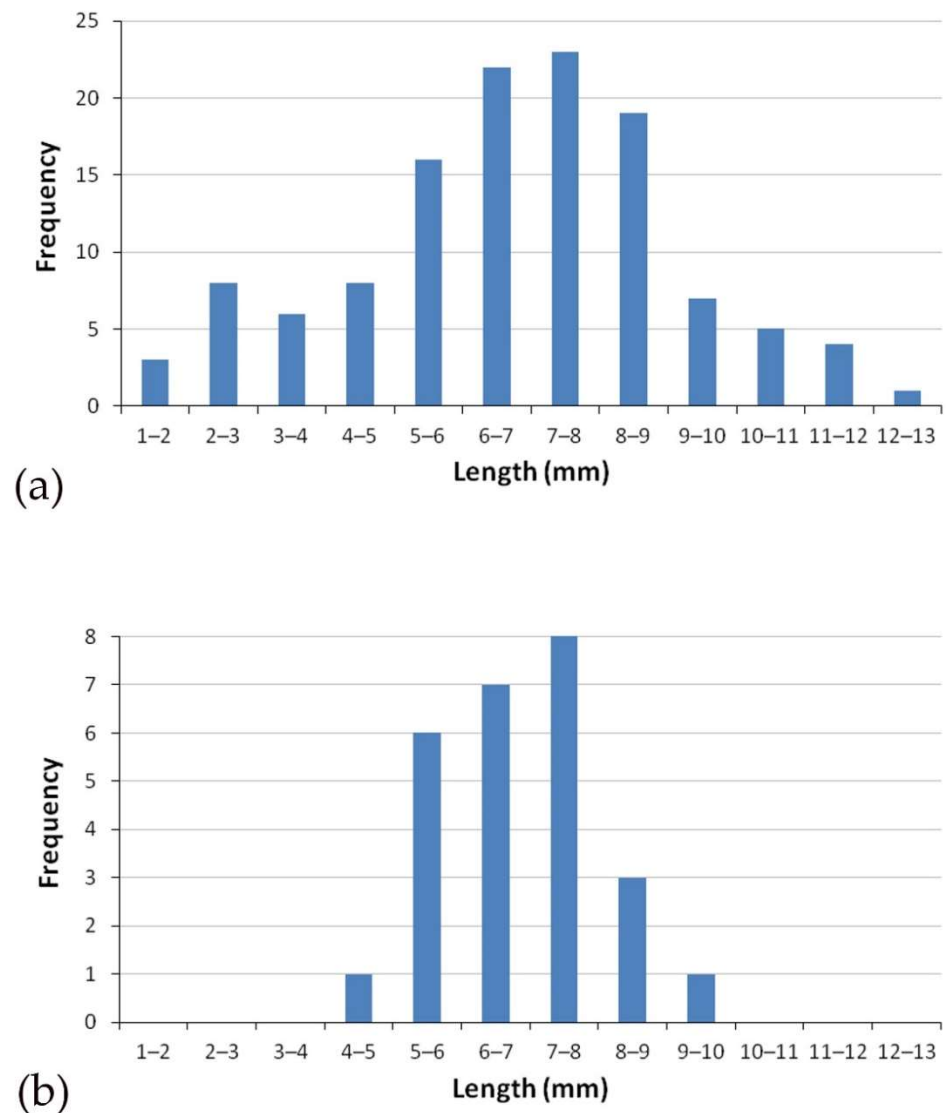


Figure 5. Size distribution of *Rocellaria dubia* shell length: (a) 122 individuals from all samples; (b) 26 individuals from the most infested oyster.

4. Discussion

The endolithic bivalve *R. dubia* was found for the first time boring into the shells of Pacific oyster *M. gigas*. Until now, it has been reported as a borer in the shells of bivalves *O. edulis* [2,3,10,38,39], *Spondylus sp.* [3], *Pinna nobilis* Linnaeus, 1758 [2,3,38], *Venus verrucosa* Linnaeus, 1758 [2,19], *Glycymeris nummaria* (Linnaeus, 1758) [2], *Arca noae* Linnaeus, 1758 [17], *Modiolus barbatus* (Linnaeus, 1758) [14,17], *M. galloprovincialis* Lamarck, 1819 [40,41], *Pseudochama gryphina* (Lamarck, 1819) [17], *Mimachlamys varia* (Linnaeus, 1758) [17], and gastropode *Stramonita haemastoma* (Linnaeus, 1767) [18]. Oysters are well known to host different epibiotic and endobiotic invertebrates [20–26]. They have friable, multilayered shells suitable for colonization by *R. dubia* [2]. Indeed, *R. dubia* was reported in wild and farmed populations of the European flat oyster, *O. edulis*. In 1865, Jeffreys found a cluster of a dozen *R. dubia* in a single oyster shell from Britain [10], while in 1906, Clark recorded *R. dubia* from oysters in England [39]. Rodríguez and Sánchez reported in 1997 *R. dubia* from oysters in the Canaries [3]. In the Mediterranean, in 1961, Parenzan outlined that *R. dubia* often infests larger oysters in Taranto Gulf (Italy) [38],

while in 2011, Morton and co-authors found that almost all *O. edulis* specimens in an oyster farm at Mali Ston Bay (south Adriatic Sea) were infested by this endolith [2].

Considering the ability of *R. dubia* to bore in a variety of non-biogenic and biogenic calcareous substrates, it is surprising that it has never been reported in association with a widely distributed and commercially important species such as *M. gigas*. The absence of *R. dubia* in farmed oysters might be partly due to its ecological requirements, since it is considered to be a species very sensitive to disturbance [42]. Aquaculture facilities are usually located in shallow areas in proximity to the coast, lagoons and estuaries. These habitats show a high variability of environmental parameters, siltation rate, and organic matter load, which might be unfavorable for the development of *R. dubia*. In the frame of our project, aimed at investigating the macrofauna associated with natural and farmed *M. gigas*, oyster samples were collected at four locations in the Northern Adriatic Sea. Farmed oysters were sampled from two aquaculture facilities, one referring to this study, located off the Sacca di Goro lagoon, and one inside the Sacca di Goro lagoon. Wild oysters were sampled inside the Sacca di Goro lagoon and in the river Bevano estuary. However, *R. dubia* was recorded only from the farmed oysters off the Sacca di Goro lagoon. Both Sacca di Goro lagoon and river Bevano estuary are characterized by high concentrations of organic matter, reduced water exchange with the open sea, and high variability of environmental parameters, which might negatively affect the survival of *R. dubia*. The influence of environmental conditions on endolith infestation in farmed mollusks was reported previously [14]. Further research should be performed to understand the relationship among environmental conditions, farming method, and the incidence of *R. dubia* infestation in oysters.

On the other hand, the lack of reports of *R. dubia* on farmed *M. gigas* might also be derived from the lack of research on fauna associated with Pacific oysters, particularly in the Mediterranean Sea. There are only three papers reporting species associated with farmed *M. gigas* in the Mediterranean Sea [43–45], while no papers refer to the fauna associated with natural populations of Pacific oysters (Mikac et al., in prep.). Moreover, comprehensive investigation of the literature dealing with fauna associated with farmed Pacific oysters outside the Mediterranean (Mikac et al., in prep.), suggests that there are no studies covering regions in which *R. dubia* occurs. Considering the high level of infestation of *M. gigas* we found, we suppose that the association between *R. dubia* and *M. gigas* could be a much more widespread phenomenon than currently known, and it could be largely overlooked.

Heavily infested oysters hosted tens of *R. dubia* specimens, some of which were completely penetrating the shell of the host. The holes of *R. dubia* on the inner side of the oyster valves were completely or partially covered by the internal callus, an energetically costly material produced by the oyster in order to prevent complete perforation of the shell. This phenomenon is also well documented in *O. edulis* and other bivalves infested by *R. dubia* [2,19]. Moreover, heavily infested oysters had highly reduced flesh inside. Formerly, Trigui El-Menif and co-authors reported that the occurrence of *R. dubia* had negative effects on shell thickness, dry weight, and flesh biomass of *V. verrucosa*, leading to the death of the occupied host [19]. These authors classified the interaction between the *R. dubia* endobiont and the *V. verrucosa* host depending on the level of infestation. As long as *R. dubia* does not completely perforate the host shell, the association can be regarded as commensalism, while progressive internal perforation of the clam shell can disturb the host, and lead to a parasitic association. The endobiont can weaken the valve structure of the host by multiplying the number of galleries and their size, and can also prevent the host from hermetically closing its valves, making the host more vulnerable to further attacks from pathogenic agents and predators [19]. The magnitude of infestation and the state of infested oysters in our research suggest a parasitic relationship between *R. dubia* and *M. gigas*.

Based on available data on shell length/age correlation in Pacific oysters, the collected specimens range from 1 to 4 years [35,46,47]. However, defining age classes based

on shell length seems to not be very accurate, since the literature data differ for wild and farmed oyster populations [47]. Measurements of *R. dubia* shells showed that analyzed oysters hosted individuals of different sizes, probably having different ages. The growth rate of *R. dubia* was investigated on vertical substrata in the Marine Protected Area (MPA) of Baiae (Tyrrhenian Sea, Naples, Italy) [1]. Based on that study, the following size–age relationship was proposed: 0–5 mm length (age up to one year), 5–9 mm length (age 1–2 years), and 9–13 mm length (age 2–3 years). In another study on horizontal substrata conducted in the same area, a higher growth rate than what was observed on vertical experimental panels for the same age class was found [1,4]. It is well known that *R. dubia* prefers horizontal or slightly inclined substrates [5,48], so horizontal position might positively influence its growth. Unfortunately, there are no other studies on the settlement and growth of *R. dubia*. Based on previous data [1], the size distribution of *R. dubia* shell length in our research shows that specimens might appertain to three age classes, 0–1, 1–2, and 2–3 years. However, the favorable horizontal position of the studied substrate (i.e., *M. gigas* shells positioned more or less horizontally in the aquaculture chests) might have favored a higher growth rate. In general, despite its wide distribution and importance as a borer, the ecology of *R. dubia* is studied very little. More research regarding the growth rate and age of *R. dubia* in relation to environmental conditions (such as substrate type, inclination, morphology of the rocky bottom, and depth) should be performed.

As suggested by our observations, heavy infestation of *R. dubia* has negative impacts on the oyster host and can be considered parasitic. Considering the importance of oyster aquaculture and damages that endolithic organisms could provoke in this industry, efforts should be made to better understand the settlement and growth process of *R. dubia* on *M. gigas*, and the effect of this endobiont on the oyster host should be clarified. Moreover, extensive research should be conducted in order to obtain information on the geographic distribution of this newly reported association, both in the Mediterranean Sea and worldwide.

Supplementary Materials: The following are available online at www.mdpi.com/article/10.3390/d13110526/s1, Table S1: Length and width measures of *Magallana gigas* from each sample. Table S2: Length and width measures of *Roccellaria dubia* found in oysters from each sample.

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Institutional Review Board Statement: Ethical review and approval were waived for this study, since it included animals that are normally harvested for human consumption.

Data Availability Statement: Data supporting reported results are presented in Table S1 of the Supplementary Material.

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References

- Casoli, E.; Ricci, S.; Antonelli, F.; Perasso, C.S.; Belluscio, A.; Ardizzone, G. Impact and colonization dynamics of the bivalve *Rocellaria dubia* on limestone experimental panels in the submerged Roman city of Baiae (Naples, Italy). *Int. Biodeterior. Biodegrad.* **2016**, *108*, 9–15. <https://doi.org/10.1016/j.ibiod.2015.11.026>.
- Morton, B.; Peharda, M.; Petrić, M. Functional morphology of *Rocellaria dubia* (Bivalvia: Gastrochaenidae) with new interpretations of crypt formation and adventitious tube construction, and a discussion of evolution within the family. *Biol. J. Linn. Soc.* **2011**, *104*, 786–804. <https://doi.org/10.1111/j.1095-8312.2011.01763.x>.
- Rodríguez, R.G.; Sánchez, J.M.P. *Moluscos Bivalvos de Canarias*; Ediciones del Cabildo Insular de Gran Canaria: Las Palmas de Gran Canaria, Spain, 1997; 480p.
- Ricci, S.; Sacco, C.P.; Antonelli, F.; Petriaggi, B.D. Marine bivalves colonizing Roman artefacts recovered in the Gulf of Pozzuoli and in the Blue Grotto in Capri (Naples, Italy): Boring and nestling species. *Int. Biodeterior. Biodegrad.* **2015**, *98*, 89–100. <https://doi.org/10.1016/j.ibiod.2014.12.001>.
- Schiaparelli, S.; Franci, G.; Albertelli, G.; Cattaneo-Vietti, R. Autoecologia del bivalve perforatore *Gastrochaena dubia* lungo la falesia del promontorio di Portofino. *Atti Ass. It. Ocean. Limn.* **2003**, *16*, 29–36.
- Belaústegui, Z.; De Gibert, J.M.; Nebelsick, J.H.; Domènech, R.; Martinell, J. Clypeasteroid echinoid tests as a benthic island for gastrochaenid bivalve colonization: Evidence from the middle Miocene of Terragona, North-East Spain. *Palaeontology* **2013**, *56*, 783–796. <https://doi.org/10.1111/pala.12015>.
- Donovan, S.K.; Fearnhead, F.E.; Underwood, C.J. Recent borings in limestone cobbles from Marloes Bay, southwest Wales. *Lethaia* **2007**, *40*, 233–236. <https://doi.org/10.1111/j.1502-3931.2007.00020.x>.
- La Perna, R. Tube-dwelling in *Gastrochaena dubia* (Bivalvia): Ecological requirements, functional morphology and structure of the crypt. *Boll. Soc. Paleontol. It.* **2005**, *44*, 145–154.
- Albano, P.H. Mediterranean Gastrochaenidae (Mollusca: Bivalvia). *Boll. Malacol* **2003**, *38*, 135–138.
- Jeffreys, G.J. *British Conchology, or an Account of the Mollusca which Now Inhabit the British Isles and the Surrounding Seas. Volume 3. Marine Shells, Comprising the Remaining Conchifera, the Solenoconchia, and Gasteropoda as far as Littorina*; John Van Voorst, Pater-noster Row: London, UK, 1865; 420p.
- Pallary, P. Exploration scientifique du Maroc. Malacologie. *Arch. Sci. Du Prot. Français* **1912**, *2*, 1–108.
- Poppe, T.; Goto, Y. *European Seashells Volume II. (Scaphopoda, Bivalvia, Cephalopoda)*; Verlag Christa Hemmen: Wiesbaden, Germany, 1993; 221p.
- Tebble, N. *British Bivalve Seashells*; Natural History Museum Publications: London, UK, 1966; 217 p.
- Ćurin, M.; Peharda, M.; Calcinaï, B.; Golubić, S. Incidence of damaging endolith infestation of the edible mytilid bivalve *Modiolus barbatus*. *Mar. Biol. Res.* **2014**, *10*, 179–189. <https://doi.org/10.1080/17451000.2013.814793>.
- Ponti, M.; Fava, F.; Abbiati, M. Spatial-temporal variability of epibenthic assemblages on subtidal biogenic reefs in the northern Adriatic Sea. *Mar. Biol.* **2011**, *158*, 1447–1459. <https://doi.org/10.1007/s00227-011-1661-3>.
- Spagnolo, A.; Cuicchi, C.; Punzo, E.; Santelli, A.; Scarcella, G.; Fabi, G. Patterns of colonization and succession of benthic assemblages in two artificial substrates. *J. Sea Res.* **2014**, *88*, 78–86. <https://doi.org/10.1016/j.seares.2014.01.007>.
- Šiletić, T. Marine fauna of Mljet national park (Adriatic Sea, Croatia). 5. Mollusca: Bivalvia. *Nat. Croat.* **2006**, *15*, 109–169.
- El Ayari, T.; Lahbib, Y.; Trigui El Menif, N. Associated fauna and effects of epibiotic barnacles on the relative growth and reproductive indices of *Stramonita haemastoma* (Gastropoda: Muricidae). *Sci. Mar.* **2015**, *79*, 223–232. <https://doi.org/10.3989/scimar.04151.18A>.
- Trigui El-Menif, N.; Guezzi, Y.; Le Pennec, M.; Boumaiza, M.; Le Pennec, G. Infestation of the clam *Venus verrucosa* by Sipunculoidea and the lithophagus bivalve, *Gastrochaena dubia*. *Acta Adriat.* **2005**, *46*, 83–90.
- Arakawa, K.Y. Competitors and fouling organisms in the hanging culture of the pacific oyster, *Crassostrea gigas* (Thunberg). *Mar. Behav. Physiol.* **1990**, *17*, 67–94. <https://doi.org/10.1080/10236249009378759>.
- Haupt, T.M.; Griffiths, C.L.; Robinson, T.B. Intra-regional translocations of epifaunal and infaunal species associated with cultured Pacific oysters *Crassostrea gigas*. *Afr. J. Mar. Sci.* **2012**, *34*, 187–194. <https://doi.org/10.2989/1814232X.2012.673293>.
- Igić, Lj. Biotic action in fouling communities on edible shellfish—oysters (*Ostrea edulis* Linnaeus) and mussels (*Mytilus galloprovincialis* Lamarck) in the northern Adriatic. *Acta Adriat.* **1984**, *25*, 11–27.
- Rosell, D.; Uriz, M.J.; Martin, D. Infestation by excavating sponges on the oyster (*Ostrea edulis*) populations of the Blanes littoral zone (north-western Mediterranean Sea). *J. Mar. Biolog. Assoc. UK* **2001**, *79*, 409–413. <https://doi.org/10.1017/S0025315498000526>.

24. Sato-Okoshi, W.; Okoshi, K.; Koh, B.S.; Kim, Y.H.; Hong, J.S. Polydorid species (Polychaeta: Spionidae) associated with commercially important mollusk shells in Korean waters. *Aquaculture* **2012**, *350–353*, 82–90. <https://doi.org/10.1016/j.aquaculture.2012.04.013>.
25. Handley, S.J.; Bergquist, P.R. Spionid polychaete infestations of intertidal Pacific oysters *Crassostrea gigas* (Thunberg), Mahurangi Harbour, northern New Zealand. *Aquaculture* **1997**, *153*, 191–205. [https://doi.org/10.1016/S0044-8486\(97\)00032-X](https://doi.org/10.1016/S0044-8486(97)00032-X).
26. Simon, C.A.; Sato-Okoshi, W. Polydorid polychaetes on farmed molluscs: Distribution, spread and factors contributing to their success. *Aquac. Environ. Interacts.* **2015**, *7*, 147–166. <https://doi.org/10.3354/aei00138>.
27. Ezgeta-Balić, D.; Šegvić-Bubić, T.; Stagličić, N.; Lin, Y.; Bojanić, D.V.; Grubišić, L.; Briski, E. Distribution of non-native Pacific oyster *Magallana gigas* (Thunberg, 1793) along the eastern Adriatic coast. *Acta Adriat.* **2019**, *60*, 137–146. <https://doi.org/10.32582/aa.60.2.3>.
28. Grizel, H.; Héral, M. Introduction into France of the Japanese oyster (*Crassostrea gigas*). *J. Cons. int. Explor. Mer.* **1991**, *47*, 399–403. <https://doi.org/10.1093/icesjms/47.3.399>.
29. Stagličić, N.; Šegvić-Bubić, T.; Ezgeta-Balić, D.; Bojanić, D.V.; Grubišić, L.; Žuvić, L.; Lin, Y.; Briski, E. Distribution patterns of two co-existing oyster species in the northern Adriatic Sea: The native European flat oyster *Ostrea edulis* and the non-native Pacific oyster *Magallana gigas*. *Ecol. Indic.* **2020**, *113*, 106233. <https://doi.org/10.1016/j.ecolind.2020.106233>.
30. Ruesink, J.L.; Lenihan, H.S.; Trimble, A.C.; Heiman, K.W.; Micheli, F.; Byers, J.E.; Kay, M.C. Introduction of non-native oysters: Ecosystem effects and restoration implications. *Annu. Rev. Ecol. Syst.* **2005**, *36*, 643–689. <https://doi.org/10.1146/annurev.ecolsys.36.102003.152638>.
31. Bordignon, F.; Zomeño, C.; Xiccato, G.; Birolo, M.; Pascual, A.; Trocino, A. Effect of emersion time on growth, mortality and quality of Pacific oysters (*Crassostrea gigas*, Thunberg 1793) reared in a suspended system in a lagoon in Northern Italy. *Aquaculture* **2020**, *528*, 735481. <https://doi.org/10.1016/j.aquaculture.2020.735481>.
32. Finotti, F. *Tecniche di Allevamento Innovative e Qualità di Ostriche Concave (Crassostrea gigas) in Sacca degli Scardovari. Tesi di Laurea Magistrale in Biologia Marina*; Università degli Studi di Padova: Padova, Italy, 2017; pp. 1–57.
33. Graham, P.; Brundu, G.; Scolamacchia, M.; Giglioli, A.; Addis, P.; Artioli, Y.; Telfer, T.; Carboni, S. Improving Pacific oyster (*Crassostrea gigas*, Thunberg, 1793) production in Mediterranean coastal lagoons: Validation of the growth model “Shell-SIM” on traditional and novel farming methods. *Aquaculture* **2019**, *516*, 734612. <https://doi.org/10.1016/j.aquaculture.2019.734612>.
34. Bronzi, P.; Rambaldi, E.; Cardillo, A.; Dell’Aquila, M.; Di Dato, P.; Cataudella, S. Aquaculture. The state of Italian Aquaculture. In *The State of Italian Marine Fisheries and Aquaculture*; Cataudella, S., Spagnolo, M., Eds.; Ministry of Agriculture, Food and Forestry Policies: Rome, Italy, 2011; pp. 239–270.
35. Harding, J.M.; Mann, R. Age and Growth of Wild Suminoe (*Crassostrea ariakensis*, Fugita 1913) and Pacific (*C. gigas*, Thunberg 1793) Oysters from Laizhou Bay, China. *J. Shellfish Res.* **2006**, *25*, 73–82. [https://doi.org/10.2983/0730-8000\(2006\)25\[73:AAGOWS\]2.0.CO;2](https://doi.org/10.2983/0730-8000(2006)25[73:AAGOWS]2.0.CO;2).
36. Schiaparelli, S.; Franci, G.; Albertelli, G.; Cattaneo-Vietti, R. A non-destructive method to evaluate population structure and bioerosion activity of the boring bivalve *Gastrochaena dubia*. *J. Coast. Res.* **2005**, *21*, 383–386. <https://doi.org/10.2112/03-0054.1>.
37. Carter, J.G.; McDowell, T.; Namboodiri, N. The Identity of *Gastrochaena cuneiformis* Spengler, 1783, and the Evolution of *Gastrochaena*, *Rocellaria*, and *Lamychaena* (Mollusca, Bivalvia, Gastrochaenoidea). *J. Paleontol.* **2008**, *82*, 102–117. <https://doi.org/10.1666/04-066.1>.
38. Parenzan, P. Malacologia Jonica. Introduzione allo studio dei Molluschi dello Jonio. *Thalassia Jonica* **1961**, *IV*, 1–184.
39. Clark, J. Zoology. Marine. In *The Victoria history of the county of Cornwall*; Page, W., Ed.; James Street Haymarket: London, UK, 1906; Volume 1, pp. 113–159.
40. Cerrano, C.; Pica, D.; Di Camillo, C.; Bastari, A.; Torsani, F. *Caratterizzazione Biocenotica e Restituzione Cartografica per l’Individuazione di Eventuali Habitat e Specie di Interesse Comunitario nelle Aree Prospicienti le Aree Protette delle Marche. Relazione Tecnica*; Università Politecnica delle Marche, Dipartimento Scienze della Vita e dell’Ambiente: Ancona, Italy, 2015; pp. 1–53.
41. Curini Galletti, M.; Galleni, L. Le mitilae del litorale livornese 1—catalogo faunistico. *Atti Soc. Tosc. Sci. Nat. Mem. Serie B* **1981**, *88*, 127–141.
42. Borja, A.; Franco, J.; Pérez, V. A Marine Biotic Index to Establish the Ecological Quality of Soft-Bottom Benthos Within European Estuarine and Coastal Environments. *Mar. Pollut. Bull.* **2000**, *40*, 1100–1114 + updated in <http://ambi.azti.es> (AMBI LIST OF June 2019; accessed on 10 September 2021).
43. Cilenti, L.; Scirocco, T.; Specchiulli, A.; Vitelli, M.L.; Manzo, C.; Fabbrocini, A.; Santucci, A.; Franchi, M.; D’Adamo, R. Quality aspects of *Crassostrea gigas* (Thunberg, 1793) reared in the Varano Lagoon (southern Italy) in relation to marketability. *J. Mar. Biol. Assoc. UK* **2017**, *98*, 71–79. <https://doi.org/10.1017/S0025315417001692>.
44. Feis, M.E.; Goedknegt, M.A.; Arzul, I.; Chenuil, A.; den Boon, O.; Gottschalck, L.; Kondo, Y.; Ohtsuka, S.; Shama, L.N.S.; Thielges, D.W.; et al. Global invasion genetics of two parasitic copepods infecting marine bivalves. *Sci. Rep.* **2019**, *9*, 12730. <https://doi.org/10.1038/s41598-019-48928-1>.
45. Sala, A.; Lucchetti, A. Low-cost tool to reduce biofouling in oyster longline culture. *Aquac. Eng.* **2008**, *39*, 53–58. <https://doi.org/10.1016/j.aquaeng.2008.06.001>.
46. Holm, M.W.; Davids, J.K.; Dolmer, P.; Vismann, B.; Hansen, B.W. Moderate establishment success of Pacific oyster, *Crassostrea gigas*, on a sheltered intertidal mussel bed. *J. Sea Res.* **2015**, *104*, 1–8. <https://doi.org/10.1016/j.seares.2015.07.009>.

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47. Rasmussen, R.S.; Morrissey, M.T.; Cheney, D.A.N. Effect of Age and Tissue Weight on the Cadmium Concentration in Pacific Oysters (*Crassostrea gigas*). *J. Shellfish Res.* **2007**, *26*, 173–179. [https://doi.org/10.2983/0730-8000\(2007\)26\[173:EOAATW\]2.0.CO;2](https://doi.org/10.2983/0730-8000(2007)26[173:EOAATW]2.0.CO;2).
 48. Kleemann, K. Raumkonkurrenz bei Ätzmuscheln. *Mar. Biol.* **1974**, *26*, 361–364. <https://doi.org/10.1007/BF00391519>.