Latin American Journal of Aquatic Research, 52(5): 741-751, 2024
DOI: 10.3856/vol52-issue5-fulltext-3171

Research Article

Infestation levels of *Nodipecten subnodosus* (Bivalvia: Pectinidae) by the borer *Polydora* sp. (Polychaeta: Spionidae) in Ojo de Liebre Lagoon, Mexican Pacific

Laura González-Ortiz[1], Pablo Hernández-Alcantara[2]
Verónica Rodríguez-Villanueva[3] & Ilie S. Racotta[3]
[1]Centro de Investigaciones Biológicas del Noroeste, La Paz, B.C.S., México
[2]Unidad de Ecología y Biodiversidad Acuática, Instituto de Ciencias del Mar y Limnología
Universidad Nacional Autónoma de México, Ciudad de México, México
[3]Marine Biology Laboratory, Public Utilities Department City of San Diego
Ocean Monitoring Program, San Diego, CA, USA
Corresponding author: Laura González-Ortiz (lauragortiz90@gmail.com)

ABSTRACT. The infestation of boring polychaetes can represent a serious problem for mollusks in natural populations and aquaculture. In the Mexican Pacific, their effects have been scarcely studied. So, this research aimed to analyze the infestation levels of *Polydora* sp. on *Nodipecten subnodosus* in the Ojo de Liebre Lagoon. Between May 2014 and October 2015, 639 specimens from four banks were collected to examine the spatial and temporal variations of the number of blisters by valve and their relationships with the scallop size. Around the lagoon mouth, the smaller scallops (<51 cm^2) dominated, having the higher infestation percentages: Chocolatero: 88 ind (61%), Zacatoso: 86 ind (51%). In contrast, the larger scallops (51-89 cm^2) were found in the inner lagoon, with smaller percentages of infestation: La Concha: 35 ind (21%) and El Datil: 29 ind (19%). The right valves, in closer contact with the bottom, were more infested than the left; those from Chocolatero and Zacatoso had more blisters (right 51-61%, left 14-15%), whereas in La Concha and El Datil both valves had fewer blisters (right 19-21%, left 6-8%). Larger scallops (51-89 cm^2) from La Concha had low (5 ind) and medium (4 ind) infestation levels, and those smaller from Chocolatero (13-51 cm^2) had high levels (34 ind). However, the relationship size scallop-infestation level needed to be clarified since larger scallops of El Datil also had high infestation levels (6 ind), and smaller specimens of Zacatoso showed lower (25 ind) and medium (27 ind) levels.

Keywords: *Nodipecten subnodosus*; Polychaeta; polydorid borers; infestation scallops; lion's paw scallop

INTRODUCTION

Pectinids are a very important fishing resource, both in temperate as in warm marine regions (Morales-Hernández & Cáceres-Martínez 1996), due to their appreciative taste and high nutrient content on its abductor muscle (González-Anativia 2002). In particular, the infestation of shells by polychaetes belonging to family Spionidae Grube, 1850, especially those from genus *Polydora* Bosc, 1802 and *Boccardia* Carazzi, 1893, also named "blister worms", represents a serious problem to mollusks of commercial importance, both in natural populations as in aquaculture (Sato-Okoshi & Abe 2012, Sato-Okoshi et al. 2015, Martinelli et al. 2020, Waser et al. 2021). The high infestation levels cause serious shell damage, reduce their growth rates (Silina 2006, Diez et al. 2011), and even increase mollusks' mortality (Bergman et al. 1982). The shell infestation by these boring worms starts in their juvenile stages, initially building mud tubes on the valves to later make burrows (Sato-Okoshi 2000, Simon & Sato-Okoshi 2015). Sites with higher infestation levels are associated with environments rich in phytoplankton and organic matter, providing the

Associate Editor: Paulo Paiva

food required to settle and develop the boring organisms (Martin & Britayev 1998).

The shell perforation by polychaetes from the genus *Polydora* can be carried out by two main mechanisms: chemical, secreting acid phosphatases and dioxide of carbon, which dissolve or weaken the calcium matrix of valves; and mechanical, since these polychaetes can use their specialized chaetae from the fifth chaetiger to corrode the shell. The action of both mechanisms allows the build of internal galleries, which can be in a "U", "pear", or "Y" shape or have multiple branches. Consequently, the polychaetes gradually accumulate mud until reaching the mantle cavity (Simon et al. 2006, Diez et al. 2011). So, as a mechanism to keep the mud isolated from the mantle cavity, the mollusk induces the formation of mud blisters, secreting a greater amount of conchiolin and successive calcite layers. These mud blisters give the shell a bad appearance but also a disagreeable odor due to the secretion of anaerobic metabolites contenting hydrogen sulfate, decreasing its commercial value (Lauckner 1983, Handley & Bergquist 1997, Martin & Britayev 1998, Glasby et al. 2000). It is difficult to estimate the energy consumption associated with these protective secretions (Almeida et al. 1996). Still, they reduce the capacity of the bivalve to accumulate nutritive reserves (Wargo & Ford 1993).

In the Mexican Pacific, more than 30 species of scallops have been recorded (Keen 1971). Still, only three have commercial importance: the Catarina scallop *Argopecten ventricosus* (G.B. Sowerby II, 1842), the flying scallop *Euvola vogdesi* (Arnold, 1906) and the lion's paw scallop *Nodipecten subnodosus* (G.B. Sowerby I, 1835) (Roldán-Carrillo et al. 2007). This last scallop is widely distributed in the Eastern Tropical Pacific, from Laguna Manuela, Baja California, Mexico, to Paita, Peru (Rombouts 1991). It is established in lagoons, bays, and deep channels with strong currents (González-Estrada 2003). Populations of *N. subnodosus* in Ojo de Liebre Lagoon, Mexican Pacific, have been heavily harvested, and those wild populations are drastically affected, so since 2012, a permanent ban on its fishing activities was established (González-Ortiz et al. 2017). Along with overharvesting, other factors can also affect the populations of *N. subnodosus*, such as the changes in pH, decay of oxygen levels, and increase in temperature, for example, or diseases caused by boring organisms (Carver et al. 2010, Duckworth & Peterson 2013).

However, the infestation caused by the boring organisms, particularly those belonging to the genus *Polydora* on the lion's paw scallops, and their potential effects have been scarcely examined in the Mexican Pacific (González-Ortiz et al. 2017). Thus, the present study aimed to evaluate the infestation levels of the polychaetes *Polydora* sp. on natural populations of *N. subnodosus* from the Ojo de Liebre Lagoon, Mexican Pacific, estimating the spatial (four banks) and temporal (seven months) variations of the scallop size and the number of blisters built by the boring worm inside each valve.

MATERIALS AND METHODS

Study area

The Ojo de Liebre Lagoon is part of the longer protected area from Mexico, located on the occidental coast of the Baja California Peninsula, Mexican Pacific (27°55'-27°35'N; 114°20'-113°50'W). It is shallow (5 to 12 m depth), around 48 km long and 9 km wide, and together with the Manuela and Guerrero Negro lagoons, make up the aquatic complex Ojo de Liebre, inside of the Sebastian Vizcaino Bay (Fig. 1). It has an area of 366 km^2, characterized by a complex system of channels with depths higher than 3 m (Sánchez 1991). These channels are separated by large, sloped areas with abundant seagrasses (Reinecke-Reyes 1996). The sediments are mainly fine and very fine, with medium sand in channels, while the silts and clays are common in the central lagoon (Phleger & Ewing 1962).

The climate is desertic, dry, and arid, with very low precipitation (180 mm annual rainfall) caused mainly by tropical storms that occur mainly during summer and fall. Annual evaporation is 215 mm per year, exceeding annual precipitation (Obeso-Nieblas & Jiménez-Illescas 1989).

Coastal dunes surround the lagoon, 12 to 15 m high, which harbor unstable vegetation and sandy beaches. Temperature varies between 16 and 24°C. There are no river discharges into the lagoon, and a remarkable hypersaline gradient of up to 47 psu was observed (Contreras 1985). The dominant currents do not exceed the 4 km h^{-1} but can be turbulent; the tidal amplitude is between 1.2 and 2.7 m. On the eastern margin of the lagoon was built an evaporation pond for salt collection, with barriers and channels to enclose shallow pools of brine.

Sampling methods and data analyses

The samplings were carried out in four natural banks from Ojo de Liebre Lagoon, Mexican Pacific, during May and August 2014 and March-May, July, and October 2015. The banks Chocolatero and Zacatoso are

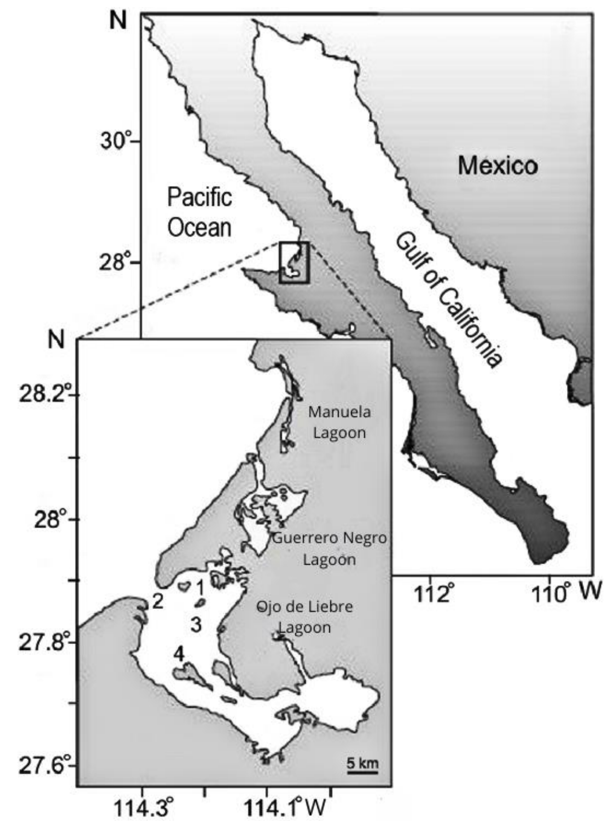

Figure 1. Study area showing the examined scallop banks. 1: Zacatoso, 2: Chocolatero, 3: El Dátil, 4: La Concha.

located around the mouth of the lagoon, having an estimated size of 0.72 and 14.24 ha, respectively. In comparison, El Datil (1.64 ha) and La Concha (2.22 ha) are found in the inner lagoon (Fig. 1). A total of 639 scallops were randomly collected: 147 ind in Chocolatero, 169 ind in Zacatoso, 16 ind in El Datil and 155 ind in La Concha. Only adult specimens were examined, selected because of their larger size and because the left valve exhibited well-grown radial ribs and nodules. The lion's paw scallop juveniles in this lagoon can reach 76 mm in height (Villalejo-Fuerte et al. 2004). Still, in the present study, adult specimens with 4.5 cm height were also collected, whose stage was posteriorly confirmed in the laboratory by the presence of brown or red gonads. The collected specimens were carefully placed in plastic bags with seawater, adding a relaxing magnesium sulfate solution. Later, each scallop was washed with freshwater in the laboratory to count each valve's blisters and remove the intrusive worms. The polychaetes were fixed in formaldehyde at 4%, buffered with borax, and preserved in ethanol 70%. The SEANOE repository collected the data supporting the analysis conducted in this study and is available online through the link https://doi.org/10.17882/97014 (Hernández-Alcántara & González-Ortiz 2023).

The spatial and temporal variations of the scallop size (estimated as the valve area) were examined by sorting their dimensions into five classes, which were determined using the Sturges rule: $K = 1 + 3.322 \log N$ (where K: number of classes; N: total number of scallops), and the width intervals with $C = (V_{max} - V_{min}) / K$ (where V are the maximum and minimum values of the scallop area) (Sturges 1926): class I: 13 to 51 cm^2; class II: 51 to 89 cm^2; class III: 89 to 127 cm^2; class IV: 127 to 165 cm^2; class V: >165 cm^2. To examine the differences among the number of scallops belonging to each class size (five classes) and their variations through the sampling periods (seven months) by bank (four banks), an analysis of similarity (ANOSIM) was made using the Bray-Curtis similarity index. ANOSIM is a non-parametric technique based on ranks, testing the null hypothesis that there are no differences among the abundance by size classes at each month or bank; the separation of those groups was evaluated in a range of R = 0 (groups indistinguishable from one another) to R = 1 (no similarity between groups), with a significance level <1% (Clarke 1993, Clarke & Gorley 2015). The ANOSIM test was also used to estimate the differences between the number of mud blisters inside the right or left scallop valves and among the abundance of blisters at each examined bank.

The *N. subnodosus* scallops have symmetrical valves, and though they are not sessile and can swim propelling themselves through the water using their adductor muscles to open and close their valves, they usually rest on the marine bottom on their left valve. Therefore, to examine the preference of the boring polychaeta by some valve, we also counted the blisters associated with the left valve, which is usually in contact with substrate, and those found in the right valve, in superior position when the scallop is in rest (Osuna-García 2006), which is regularly colonized by boring organisms as sponges or polychaetes (González-Ortiz & Hernández-Alcántara 2021).

So, the collected scallops at each bank were examined to estimate the prevalence, calculated as the percentage of valves infested. The spatial and temporal variations of the prevalence were analyzed by bank and by sampling month calculating the percentage of infected scallops per bank (n ~360 ind $bank^{-1}$) and the percentage of infested scallops at each month by bank (n ~30 ind $month\text{-}bank^{-1}$).

The number of blisters on the right or left valves was quantified under a stereo microscope, expressed as the number of blisters per scallop/valve at each bank and sampling moth. Simultaneously, photographs were taken of each valve; the total surface area of the valve and the area occupied by each blister were measured using a 10-megapixel digital camera at a distance of 15 cm. The Photoshop software was used to demarcate the perimeters of the valve and blisters. Once the area outline was traced, the images were exported to the program Imagen Pro-Plus, and with the subroutine Create Polygon feature, the respective areas were calculated.

The intensity of infestation of *Polydora* sp. was measured at the right and left valves of each scallop, and using the scale suggested by Ciocco (1990), we classified the blisters according to the covered area (cm^2) by each mud bubble inside the scallop: 1 = 0.06 cm^2; 2 = >0.06 and ≤0.3; 3 = >0.3 and ≤1; 5 = >1 and ≤3; 8 = >3. A value representing the intensity of the infestation was assigned to weigh the simultaneous presence of more than one blister by valve, which was obtained by adding the codes previously assigned according to the covered area by the blisters at each valve (Ciocco 1990). Thus, according to its attack index, an infestation level was assigned to each scallop: 0 = 0 (Ab: absent); 1 to 3 = 1 (Lo: low); 4 to 7 = 2 (Me: medium); ≥8 = 3 (Hi: high) (Ciocco 1990).

RESULTS

Six hundred thirty-nine scallops were collected during seven monthly samplings at four natural banks within Ojo de Liebre Lagoon between May 2014 and October 2015. The scallops presented 0 to 8 blisters per valve constructed by the spionid *Polydora* sp.; 2,170 blisters were found.

The abundance of scallops by size class and sampling month at each bank

The number of scallops at each class size was significantly different among them (R_{ANOSIM} = 0.42, P = 0.001), mainly due to higher number of scallops with less than 89 cm^2 (classes I and II) (Fig. 2). Although the number of scallops belonging to these both classes were not distinct between them (R_{ANOSIM} = 0.5, P = 0.057), they recorded significant differences in the number of scallops belonging to higher size classes. The total number of scallops from class I (301 ind) and class II (211 ind) were distinct from those belonging to classes III (65 ind), IV (42 ind), and V (20 ind) (R_{ANOSIM} > 0.56, P = 0.029). The number of scallops among the classes III, IV, and V were not different (R_{ANOSIM} < 0.49, P > 0.17).

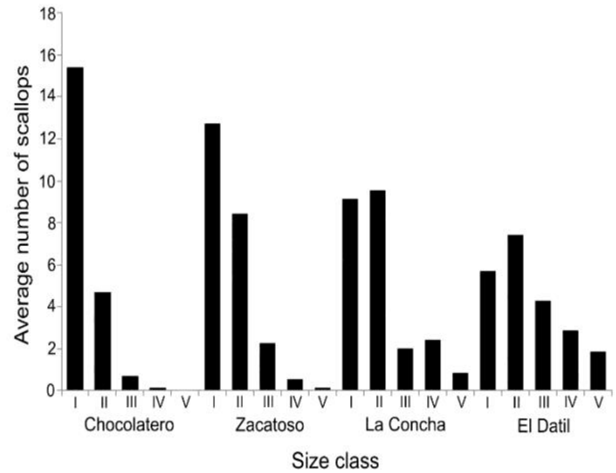

Figure 2. Number of scallops by size class (scallop area) and bank. Class I: 13 to 51 cm^2; class II: 51 to 89 cm^2; class III: 89 to 127 cm^2; class IV: 127 to 165 cm^2; class V: >165 cm^2.

The scallops smaller than 89 cm^2 were the most abundant in the study (mean by month class I: 10.75 ± 8.44 ind; class II: 7.54 ± 6.83 ind), while the larger scallops were less represented (mean = class III: 2.32 ± 2.83 ind; class IV: 1.50 ± 3.2 ind; class V: 0.71 ± 1.7 ind). Nevertheless, the variations in the number of scallops among the banks showed different patterns (Fig. 2). In Chocolatero and Zacatoso, the scallops smaller than 51 cm^2 (class I: 15.43 ± 6.85; 12.71 ± 6.85 ind $month^{-1}$, respectively) were the most abundant, while the larger scallops (>127 cm^2) were poorly represented: class IV = 0.14 ± 0.38; 0.57 ± 1.51 ind $month^{-1}$; class V = 0; 0.14 ± 0.38 ind $month^{-1}$. In contrast, in La Concha and El Datil, on the average, the class II (51 to 89 cm^2) was more abundant (9.57 ± 8.72; 7.43 ± 7.91 ind $month^{-1}$, respectively), but also the scallops larger than 89 cm^2 (classes III, IV and V) increased their presence, mainly in El Datil: class III = 4.29 ± 3.59 ind $month^{-1}$; class IV = 2.86 ± 3.8 ind $month^{-1}$; class V = 1.86 ± 2.97 ind $month^{-1}$; since in La Concha their values were fewer, class III = 2 ± 2 ind $month^{-1}$; class IV = 2.43 ± 4.79 ind $month^{-1}$; class V = 0.86 ± 1.21 ind $month^{-1}$ (Fig. 2).

The scallops exhibited very wide size variations through the sampling months and, in general, no significant trends were observed (R_{ANOSIM} = 0.05, P = 0.8) (Fig. 3). Nevertheless, in Chocolatero and Zacatoso, the smaller scallops (class I: <51 cm^2) were more abundant, increasing their number gradually from May-2014 until April-2015, where reaching their maximum value (23-27 ind $bank^{-1}$); later, the number of scallops decreased progressively (Fig. 3). On the other hand, the scallops from class II decreased in

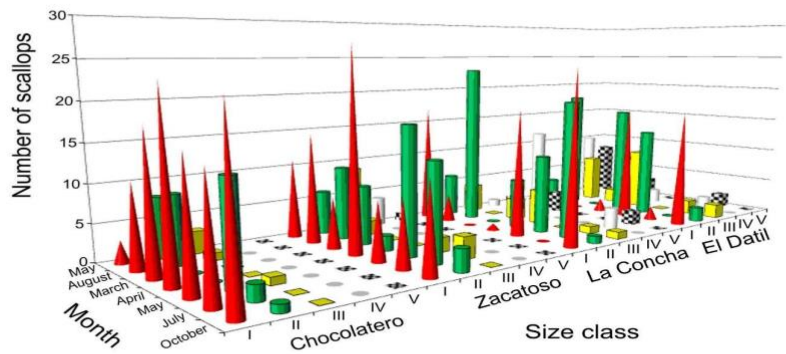

Figure 3. Number of collected scallops per bank and sampling month. Red: class I: 13 to 51 cm^2, green: class II: 51 to 89 cm^2, yellow: class III: 89 to 127 cm^2, gray: class IV: 127 to 165 cm^2, squared black/white: class V: >165 cm^2.

March-2015 and April-2015, but increased their abundance in May-2015. The presence of scallops with the largest size (>89 cm^2: classes III, IV, and V) was constrained to May-2014 since in the other months, these sizes were practically absent (Fig. 3). Thus, May-2014 recorded the smaller scallops, in Chocolatero, the higher differences were precisely found between this month and March-2015 (R_{ANOSIM} = 0.27, P = 0.09), and between May-2014 and April-2015 (R_{ANOSIM} = 0.29, P = 0.09), while in Zacatoso, important differences were only observed between May-2014 and April-2015 (R_{ANOSIM} = 0.29, P = 0.05).

In La Concha and El Datil, the scallops belonging to classes I (<51 cm^2) and II (51-89 cm^2) were also the most abundant but with fewer individuals than in the other banks. In May 2015 and October 2015, class I increased their presence in these banks, while those from class II were more abundant in August 2014 and May 2015 (Fig. 3). In La Concha, the larger scallops (classes III, IV, and V) increased their number in March-2015, while in El Datil they were abundant in May-2014. Thus, due to these wide monthly variations, in La Concha, only significant differences between May 2014 and May 2015 were found (R_{ANOSIM} = 0.27, P = 0.04). In El Datil, May 2014 (R_{ANOSIM} = 0.28, P = 0.02) and May 2015 (R_{ANOSIM} = 0.2, P = 0.08) also recorded important differences, but only with July 2015, since in this month the fewer number of scallops was collected (Fig. 3).

Prevalence of blisters inside scallops

The number of mud blisters, built as a result of the presence of specimens of *Polydora* sp. inside the scallop valves, was very different between valves. Their occurrence was higher in the right valves (238 valves) than in the left (67 valves) (R_{ANOSIM} = 0.008, P = 0.001): right: 0-8 blisters valve^{-1} (mean = 0.77 1.37 blister valve^{-1}; left: 0-4 blisters by valve (mean = 0.15 ± 0.5 blister valve^{-1}). The number of blisters also differed among banks (R_{ANOSIM} = 0.106, P = 0.001). Though in Chocolatero (88 ind) and Zacatoso (86 ind), the blisters were present in more scallops than in La Concha (35 ind) and El Datil (29 ind) (Fig. 4), the number of individuals infested was significantly different among each bank (R_{ANOSIM} = 0.039 to 0.276, P = 0.001).

Chocolatero recorded the higher percentages of infestation; 61.2% of the right valves had blisters (mean = 1.49 ± 1.86 blister valve^{-1}), while only 15% of the left valves were present (mean = 0.18 ± 0.48 blister valve^{-1}). Although the number of infected scallops slightly decreased in Zacatoso: 50.9% in right valves (mean = 1.11 ± 1.53 blister valve^{-1}) and 13.6% in left valves (mean = 0.23 ± 0.7 blister valve^{-1}), its differences with Chocolatero were significant (R_{ANOSIM} = 0.054, P = 0.001) (Fig. 4). In contrast, for La Concha and El Datil the number of blisters was lower than in the other banks, being also more abundant on the right valves, but displaying a distinct trend between them (R_{ANOSIM} = 0.039, P = 0.001). In La Concha, only 20.8% of right valves (mean = 0.26 ± 0.55 blister valve^{-1}) and 6% of the left valves (mean = 0.07 ± 0.3 blister valve^{-1}) had blisters, whereas in El Datil 18.7% of right valves (mean = 0.27 ± 0.67 blister valve^{-1}) and 7.7% of the left valves (mean = 0.11 ± 0.4 blister valve^{-1}) were infested (Fig. 4).

Although in Chocolatero (62.1%) and Zacatoso (50.5%) the percentage of infected scallops was higher than in La Concha (22%) and El Datil (6%), their changes along the sampling months did not show clear trends (Fig. 5). The infestation in Chocolatero ranged between 46.7 and 76.2% of scallops (mean = 62.1 ± 9%), with its lower percentage in spring-summer (46.7-

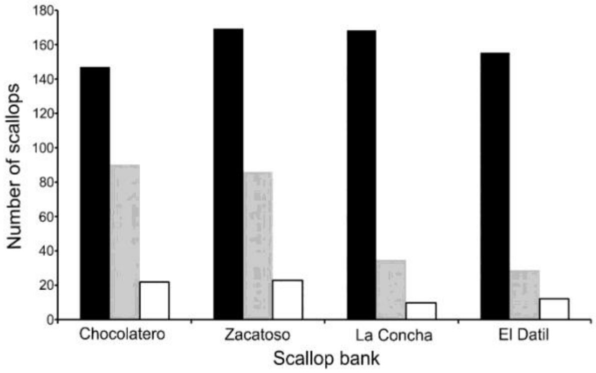

Figure 4. Number of scallops with blisters at each examined bank. Black: total number of scallops; gray: number of right valves with blisters; white: number of left valves with blisters.

58.8%). On the contrary, Zacatoso showed a higher variability (mean = 50.6 ± 22.7%) with 26.7 to 80.6% of infected scallops, and with its maximum values in May 2014 and March 2015, where more than 80% of scallops had blisters.

During the sampling months, the percentage of infested scallops drastically decreased in La Concha (6.9-36.8%) and mainly in El Datil (3.6-12.8%) (Fig. 5). In La Concha (mean = 22 ± 10.4%), the infestation diminished in May-2014 (10.4%) and May-2015 (6.9%), while in March-2015 the higher percentage was found (36.8%). El Datil, where larger scallops were collected, recorded the lower percentage of infestation, and fewer changes along the months were observed (mean = 6 ± 3.7%). Blisters only affected between 3.6 and 12.8% of scallops.

Infestation level by scallop size class and examined bank

The infestation levels caused by *Polydora* sp., according to the area covered by blisters and the number of blisters at each valve, were noticeably higher in the right valve than in the left (R_{ANOSIM} = 0.053, P = 0.001). In Chocolatero and Zacatoso, from the 147 and 169 scallops examined, only 23 (mean = 0.24 ± 0.63 blister valve^{-1}) and 22 (mean = 0.23 ± 0.68 blister valve^{-1}), respectively, presented blisters in their left valves, which nearly half recorded the lowest infestation levels (Lo = 10 and 15, respectively) (Table 1). On the other hand, in La Concha and El Datil, the number of infested left valves was even smaller, with only 10 (mean = 0.11 ± 0.46 blister valve^{-1}) and 12 (mean = 0.17 ± 0.62 blister valve^{-1}) left valves bearing blisters. Still, the infestation levels of these banks were similar in the Lo, Me, and Hi categories (Table 1).

In Chocolatero and Zacatoso, located in the vicinity of the mouth of the lagoon, the number of right-infested valves, 88 (mean = 1.22 ± 1.2 blister valve^{-1}), and 86 (mean = 1 ± 1.14 blister valve^{-1}), respectively, did not present significant differences between them (R_{ANOSIM} = 0.008, P = 0.085), and recorded similar infestation levels (Table 1). Despite that, some small discrepancies were observed since, in Chocolatero, most right valves recorded high infestation levels (Hi = 33 valves). In comparison, in Zacatoso, the right valves with medium infestation were more abundant (Me = 31 valves) (Table 1). The number of right-infested valves and their infestation levels recorded in Chocolatero and Zacatoso were distinct from those found in La Concha and El Datil (R_{ANOSIM} = 0.07-1.55, P = 0.001). Still, these last banks did not show differences (R_{ANOSIM} = 0.003, P = 0.94). That is, in banks of the inner lagoon, the number of infected right valves decreased: 35 valves (mean = 0.35 ± 0.77 blister valve^{-1}) in La Concha and 29 valves (mean = 0.31 ± 0.51 blister valve^{-1}) in El Datil, but also their infestation levels were lower, being more abundant the scallops with low (Lo = 17-14 valves) and medium (Me = 12-11 valves) levels of infestation.

In general, the infestation levels concerning scallop size showed that, in all banks, the smaller scallops (class I = 13-51 cm^2) were more affected by blisters (111 scallops; mean = 0.75 ± 1.08 scallops) followed by individuals from class II (51-89 cm^2) (72 scallops; mean = 0.75 ± 1.08 scallops) (Table 2). On the contrary, the specimens higher than 89 cm^2 showed few infestation levels: class III, 28 scallops (mean = 1.02 ± 1.26 scallop); class IV, 16 scallops (mean = 1.02 ± 1.33 scallop); and class V, 10 scallops (mean = 1.4 ± 1.31 scallop) (Table 2).

Among banks, the infestation levels by size class showed two distinct trends, Chocolatero and Zacatoso recorded the higher infestation levels, whose values were similar between them (R_{ANOSIM} = 0.002, P = 0.12) but significantly different from those lower values found in La Concha and El Datil (R_{ANOSIM} = 0.014-032, P = 0.001). At the same time, the infestation levels between La Concha and El Datil were similar (R_{ANOSIM} = 0.002, P = 0.65). The higher number of infested scallops found in Chocolatero (87 ind) and Zacatoso (86 ind) was mainly linked to smaller individuals (classes I-II) (Table 2). In Chocolatero, 22 scallops of class I had low infestation levels, 18 medium levels, and 21 high levels. In contrast, in scallops of class II, these values decreased; 6 individuals had low infestation levels, eight medium levels, and seven recorded high levels. In this bank, only 5 scallops larger than 89 cm^2 (classes III-IV) were found, with high

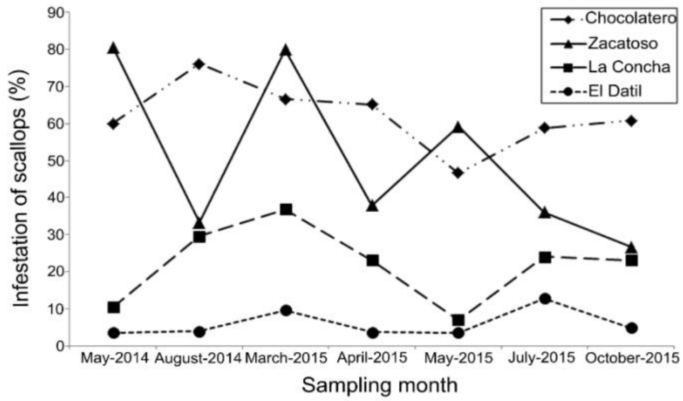

Figure 5. Percentage of infestation in scallops per sampling month and bank.

Table 1. Infestation level at each scallop valve by the examined bank. Ab: absent, Lo: low, Me: medium, Hi: high.

	Chocolatero				Zacatoso				La Concha				El Datil			
Valve / Infestation level	Ab	Lo	Me	Hi	Ab	Lo	Me	Hi	Ab	Lo	Me	Hi	Ab	Lo	Me	Hi
Right	59	28	27	33	83	29	31	26	133	17	12	6	126	14	11	4
Left	124	15	4	4	147	10	6	6	158	4	4	2	143	3	4	5

Table 2. Infestation level of scallops by size class and examined bank. Ab: absent, Lo: low, Me: medium, Hi: high.

	Chocolatero				Zacatoso				La Concha				El Datil			
Class / Infestation level	Ab (0)	Lo (1)	Me (2)	Hi (3)	Ab (0)	Lo (1)	Me (2)	Hi (3)	Ab (0)	Lo (1)	Me (2)	Hi (3)	Ab (0)	Lo (1)	Me (2)	Hi (3)
I	47	22	18	21	53	15	14	7	58	4	1	1	32	5	3	0
II	12	6	8	7	26	12	13	8	53	8	4	2	48	1	3	0
III	1	0	0	4	3	2	4	7	9	4	1	0	24	5	1	0
IV	0	0	0	1	1	0	0	3	11	1	3	2	14	1	3	2
V	0	0	0	0	0	0	0	1	2	0	3	1	8	2	1	2

infestation levels; no scallops of class V were collected. In Zacatoso, the infested scallops belonging to classes I and II showed few differences in their infestation level: 15 and 12 scallops, respectively, presented low level, 14 and 13 medium level, and 7 and 8 ind had high level. The larger scallops from class IV (3 ind) and V (1 ind) recorded a high infestation level (Table 2).

On the contrary, the infested scallops had fewer infestation levels in La Concha (35 ind) and El Datil (29 ind). However, the larger scallops of classes III, IV, and V were more abundant and showed lower infestation levels (Table 2). In La Concha, the scallops from class I and II mainly showed low infestation levels (4 and 8 ind, respectively), and 1 and 4 scallops had medium levels; in class I, II, IV, and V, only 1 or 2 scallops each, presented high infestation level. In El Datil, most scallops of all size classes presented low (14 ind) or medium (11 ind) infestation levels; the scallops with low levels were mainly linked to classes I and III (5 ind each), while those with medium infestation levels were associate with classes I, II and IV (3 ind each); the high levels only were found in larger scallops from classes IV and V (2 ind each) (Table 2).

DISCUSSION

This study represents one of the first efforts to evaluate infestation levels of *Polydora* sp. in wild populations of giant scallop *N. subnodosus* from the Ojo de Liebre Lagoon, an important source of income for the community.

In recent years, the natural populations of this scallop have been drastically depleted on the western coasts of Mexico. However, the results of the present study showed that the infestation of *Polydora* sp. could have a limited effect on decreasing the scallop populations. Although in the study area, there is no information on the polychaete infestation in scallops, the observed results showed that the presence of *Polydora* sp. inside the scallops was relatively low compared to other populations of scallops from other world regions, as New Zealand (Handley & Bergquist 1997) or Argentina (Díaz-Díaz & Liñero-Arana 2009, Diez et al. 2011), among others.

The damages produced by *Polydora* sp. on valves of bivalves can be associated with three main causes: epibiosis, galleries, or mud blisters (Blake & Evans 1973). The first case implies penetration in the calcareous substrate, with worms building tubes on the valve surface, submerged in a slight cape of mud secreted by themselves; in the second case, the polydorid larvae are settled on the external surface of valve, boring galleries in "U", "pear" or "Y" shape, which are filled with mud; finally, the mud blisters are the more common type but also the most harmful (Ciocco 1990), which was precisely the central issue of the present study. Particularly, the damage produced by the formation of mud blisters is due to the accumulation of anaerobic metabolites like hydrogen sulfide, which also produce a bad odor, affecting the mollusk's commercialization (Diez et al. 2013). The damage occurs when the borer polychaete penetrates the surface of the shell and, upon contact with the mollusk, stimulates the secretion of conchiolin to keep it isolated, creating a mud blister. Likewise, it is believed that energy expenditure during conchiolin secretion slows growth, increasing mortality (Almeida et al. 1996), and reduces the ability to accumulate nutritional reserves, debilitating the physiological condition of the bivalve, making it more vulnerable to diseases (Wargo & Ford 1993).

Boring polychaetes can severely affect scallop populations, and worldwide studies on these worms and the damage they cause to bivalves have increased. Still, in the Mexican seas, these studies are scarce (González-Ortiz et al. 2017), and even the taxonomic identity of the boring species distributed in the Mexican Pacific is unclear. The *Polydora* sp. reported in the present study could be an undescribed species whose detailed taxonomic examination is being processed by the authors.

In general, the banks Chocolatero and Zacatoso harbored the smaller scallops, which also had higher infestation levels, while La Concha and El Datil recorded larger scallops with lesser infestation levels. However, a clear relationship was not found between the size of the scallops and their infestation levels since some larger scallops of El Datil also exhibited higher infestation levels, and smaller specimens of Zacatoso showed lower and medium levels. The location of Chocolatero and Zacatoso near the mouth of the lagoon and La Concha and El Datil inside the lagoon, under different environmental conditions such as tidal level, water flow, temperature, and salinity, among others, could influence the recruitment, establishment, and development of scallops, but also influence the dispersion and settling larval stages of the polychaetes, which could increase the probability of infestation. Nevertheless, it is necessary to carry out detailed studies to determine the environmental conditions of the lagoon and their spatial and temporal variations.

The presence of a higher prevalence of infestation of polychaetes in shells of smaller size of other bivalves has also been observed in specimens of *Chlamys tehuelcha* colonized by *Polydora websteri* in Argentina (Ciocco 1990), which could provoke loss of its nutritional condition reducing its capacity to accumulate nourishments and possibly increased mortality rate (Wargo & Ford 1993). Although in *N. subnodosus*, there is no information about the possible physiological alterations caused by *Polydora* sp., the effect of polydorids on mollusks depends on the infestation intensity and the shell damage. Still, in general, a bored polychaete reduces the development of body growth and the size of the gonads (Handley & Bergquist 1997, Simon et al. 2006). Although the "lion's paw" scallop is not sessile pectinid and may do quick and brief swimming movements to escape predators or other disturbances, it habitually rests on the marine bottom on its left valve. So, the right valve is regularly subjected to advection by near-bottom water flows, being more exposed to planktonic larval phases of the polydorids and increasing its likelihood of infestation. The observed results in the present study showed that the right valve (upper valve) was more infected than the left valve (lower valve), as in the number of valves affected by their infestation levels. These same effects were also observed in specimens of *Crassostrea rhizhophorae* infested by the polychaete *P. websteri* (Díaz-Díaz & Liñero-Arana 2009) or in *Aequipecten tehuelchus* where the left shells (upward-oriented) were significantly more affected by the *P. rickettsi* than right shells, which are in closer contact with the bottom (Diez et al. 2013). On the other hand, Ciocco (1990), who studied five natural banks in Argentina, observed that *P. websteri* indistinctly affected both valves of the scallop *C. tehuelcha*.

In the northern Mexican Pacific, the presence of individuals of *N. subnodosus* colonized by polychaetes has been previously reported (Cáceres-Martínez 2003). Still, there is no data on the number or levels of infested scallops or the relationships between these invertebrates.

Despite this, the higher percentage of infected shells observed in the banks Chocolatero and Zacatoso was similar to that reported to other mollusk species: 64.6% of *C. rizhophorae* shells colonized by *P. websteri* in La Restinga Lagoon, Venezuela (Díaz-Díaz & Liñero-Arana 2009). Diez et al. (2011), studying the bivalve species *Aequipecten tehuelchus*, *Mytilus* sp., *Aulacomya atra*, *Ostrea puelchana*, *Prothothaca antigua* and *Pododesmus rudis*, in Argentina, found that around of 54% of their shells were infested by *Polydora rickettsi*; and Gallo-García et al. (2007) in Barra de Navidad, Mexican Pacific, recorded that 60% of *Crassostrea gigas* shells were colonized by *P. websteri*.

The high prevalence of infestation levels is related to the poor condition of the bivalves (Silina & Zhukova 2009), increasing the damage to the shell, reducing the growth rate (Silina 2006), and increasing the mortality (Bergman et al. 1982). The temporal changes in the infestation percentages in the seven sampling months showed no clear trend. Evaluating infestation patterns according to season or host age requires a long time series, but generally, the infestation levels gradually decrease throughout the sampling months. Although the sexual maturity of the lion's paw scallop occurs in August (Arellano-Martínez 2005), the observed temporal variations in the infestation levels were not associated with its reproduction periods. In general, there was a decrease in the infestation levels in May, while in March and August, they slightly increased, without relation to the scallop development. That could be linked to the infection process, which could be before the settlement of juvenile polydorids on small-size scallops, so the infestation would be completed when the polychaetes reach the mantle cavity, stimulating the scallop reaction to build blisters.

Despite the wide spatial and temporal variability observed, the percentage of scallops with blisters was lower, and therefore their infestation intensity was also lower. That is, in the Ojo de Liebre Lagoon, the observed infection levels are unlikely to be a determining factor to explain the population changes, highlighting that future studies should analyze the effect of the environmental changes in the development of the scallops, the dispersion of the polychaete larvae and their infestation levels. The increase in the infestation levels of polydorids in scallops has frequently been associated with a decrease in the bivalve condition. Though in the bank Chocolatero, the valves of some smaller specimens were visibly deformed (González-Ortiz et al. 2017), we cannot establish a clear relationship between the poor scallop condition and their infestation levels.

Credit author contribution

L. González-Ortiz: conceptualization, methodology, sampling, taxonomic revision, validation, writing, review and editing, funding acquisition; P. Hernández-Alcántara: conceptualization, design, data curation, formal analyses, writing, review and editing; V. Rodríguez-Villanueva: methodology, taxonomic revision, validation, writing, review and editing; I.S. Racotta: conceptualization, writing, review, and editing. All authors have read and accepted the published version of the manuscript.

Conflict of interest

The authors declare that they have no potential conflict of interest in this manuscript.

ACKNOWLEDGMENTS

We wish to express our appreciation to CIBNOR (Unidad Guerrero Negro) for predisposing laboratory facilities. We are grateful to the Exportadora de Sal for the facilities provided in the sampling carried out for this research, especially the Department of Environmental Conservation. We also wish to thank Ricardo Martinez Lara for his valuable comments.

REFERENCES

Almeida, M.J., Moura, G., Machado, J., Coimbra, J., Vilarinho, L., Ribeiro, C., et al. 1996. Aminoacid and metal content of *Crassostrea gigas* shell infested by *Polydora* sp. in the prismatic layer insoluble matrix and blister membrane. Aquatic Living Resources, 9: 179-186. doi: 10.1051/alr:1996021

Arellano-Martínez, M. 2005. Características ecofisiológicas de la reproducción de *Nodipecten subnodosus* (Sowerby, 1835) (Pectinidae) en la Laguna Ojo de Liebre, B.C.S. Ph.D. Thesis, Instituto Politécnico Nacional, La Paz.

Bergman, K.M., Elner, R.W. & Risk, M.J. 1982. The influence of *Polydora websteri* borings on the strength of the shell of the sea scallop, *Placopecten magellanicus*. Canadian Journal of Zoology, 60: 2251-2256. doi: 10.1139/z82-327

Blake, J.A. & Evans, J.W. 1973. *Polydora* and related genera Spionidae as borers in mollusk shells and other calcareous substrates. Veliger, 15: 235-249.

Cáceres-Martínez, J. 2003. Gusanos perforadores de los géneros *Polydora* y *Boccardia* y su impacto en el cultivo de moluscos. Boletín del Programa Nacional de Sanidad Acuícola y la Red de Diagnóstico, 4: 24.

Carver, C.E., Thériault, I. & Mallet, A.L. 2010. Infection of cultured eastern oysters *Crassostrea virginica* by the boring sponge *Cliona celata,* with emphasis on sponge life history and mitigation strategies. Journal of Shellfish Research, 29: 905-915. doi: 10.2983/035.029.0423

Ciocco, N.F. 1990. Infestación de la vieyra tehuelche (*Chlamys tehuelcha* (d'Orbigny)) por *Polydora websteri* Hartman (Polychaeta: Spionidae) en el Golfo San José (Chubut, Argentina): un enfoque cuantitativo. Biología Pesquera, 19: 9-18. doi: 10.21703/0067-8767.1990.19.2539

Clarke, K.R. 1993. Non-parametric multivariate analyses of changes in community structure. Australian Journal of Ecology, 18: 117-143.

Clarke, K.R. & Gorley, N.R. 2015. PRIMER v6: user manual/tutorial (Plymouth Routines in Multivariate Ecological Research). PRIMER-E, Plymouth.

Contreras, F. 1985. Las lagunas costeras mexicanas. Centro de Ecodesarrollo, Secretaría de Pesca, Ciudad de México.

Díaz-Díaz, O. & Liñero-Arana, I. 2009. Percentage of infestation level of *Polydora* cf. *websteri* Hartman, 1943 (Polychaeta: Spionidae) by size class of *Crassostrea rhizophorae* (Guilding, 1828) on La Restinga Lagoon (Margarita Island, Venezuela). Revista Científica de la Facultad de Ciencias Veterinarias de la Universidad del Zulia, 19: 113-118.

Diez, M.E., Orensanz, J.M., Marquez, F. & Cremonte, F. 2013. Shell damage in the Tehuelche scallop *Aequipecten tehuelchus* caused by *Polydora rickettsi* (Polychaeta: Spionidae) infestation. Journal of Invertebrate Pathology, 114: 107-113. doi: 10.1016/j.jip.2013.07.001

Diez, M.E., Radashevsky, V.I., Orensanz, J.M. & Cremonte, F. 2011. Spionid polychaetes (Annelida: Spionidae) boring into shells of mollusks of commercial interest in northern Patagonia, Argentina. Italian Journal of Zoology, 78: 497-505. doi: 10.1080/11250003.2011.572565

Duckworth, A.R. & Peterson, B.J. 2013. Effects of seawater temperature and pH on the boring rates of the sponge *Cliona celata* in scallop shells. Marine Biology, 160: 27-35. doi: 10.1007/s00227-012-2053-z

Gallo-García, M.C., García-Ulloa, M., Rejón-Aviña, A., Godínez-Sordia, A. & Díaz, D.E. 2007. Infestación de espiónidos perforadores en el ostión *Crassostrea gigas* cultivado en la Laguna de Barra de Navidad, Jalisco, México. Avances en Investigación Agropecuaria, 11: 63-73.

Glasby, C.J., Hutchings, P.A., Fauchald, K., Paxton, H., Rouse, G.W., Russell, C.W., et al. 2000. Class Polychaeta. In: Beesley, P.L., Ross, G.J.B. & Glasby, C.J. (Eds.). Fauna of Australia. Vol. 4A. Polychaetes and allies. CSIRO Publishers, Melbourne.

González-Anativia, C.R. 2002. Mercados y comercialización de pectínidos. In: Maeda-Martínez, A.N. (Ed.). Los moluscos pectínidos de Iberoamerica. Ciencia y Acuicultura. Limusa, Ciudad de México, pp. 451-468.

González-Estrada, F. 2003. Temperaturas letales y temperatura óptima para crecimiento de una población de almeja mano de león *Nodipecten subnodosus* (Sowerby, 1835). Tesis de Maestría, Centro de Investigaciones Biológicas del Noroeste S.C., La Paz.

González-Ortiz, L. & Hernández-Alcántara, P. 2021. Infestación de *Nodipecten subnodosus* (Mollusca: Bivalvia) por la esponja perforadora *Cliona californiana* en la laguna Ojo de Liebre, noroeste de México. Revista Mexicana de Biodiversidad, 92: e923460. doi: 10.22201/ib.20078706e.2021.92.3460

González-Ortiz, L., Hernández-Alcántara, P., Vázquez-Juárez, R., Quiroz-Guzmán, E., García-Garza, M.E. & de León-González, J.A. 2017. Variación espacio temporal de la Infestación producida por *Polydora* sp. (Spionidae: Polychaeta) sobre la Almeja Mano de León (*Nodipecten subnodosus*) en la Laguna Ojo de Liebre, Baja California Sur. Revista Mexicana de Biodiversidad, 88: 845-852. doi: 10.1016/j.rmb.2017.10.017

Handley, S.J. & Bergquist, P.R. 1997. Spionid polychaete infestations of intertidal Pacific oysters *Crassostrea gigas* (Thunberg), Mahurangi Harbour, northern New Zealand. Aquaculture, 153: 191-205. doi: 10.1016/S0044-8486(97)00032-X

Hernández-Alcántara, P. & González-Ortiz, L. 2023. Dataset of *Polydora* sp. infesting natural banks of *Nodipecten subnodosus* from Ojo de Liebre Lagoon, Mexican Pacific. SEANOE. doi: 10.17882/97014

Keen, A.M. 1971. Seashells of tropical west America. Marine mollusks from Baja California to Perú. Stanford University Press, California.

Lauckner, G. 1983. Diseases of Mollusca: Bivalvia. In: Kine, O. (Ed.). Diseases of marine animals. Volume II: Introduction, Bivalvia to Scaphopoda. Biologische Anstalt Helgoland, Hamburg, pp. 805-817.

Martin, D. & Britayev, T.A. 1998. Symbiotic polychaetes: review of known species. In: Ansell, A.D., Gibson, R.N. & Barnes, M. (Eds.). Oceanography and marine biology annual review. Routledge, London, pp. 217-340.

Martinelli, J.C., Casendino, H.R., Spencer, L.H., Alma, L., King, T.L., Padilla-Gamiño, J.L., et al. 2020. Evaluating treatments for shell-boring polychaete (Annelida: Spionidae) infestations of Pacific oysters

(*Crassostrea gigas*) in the US Pacific Northwest. Aquaculture, 561: 738639. doi: 10.1016/j.aquaculture.2022.738639

Morales-Hernández, R. & Cáceres-Martínez, C. 1996. Pesquería de la almeja mano de león *Lyropecten subnodosus*. In: Casas-Valdés, M. & Ponce-Díaz, G. (Eds.). Secretaría de Recursos Naturales y Pesca, Baja California Sur, pp. 87-100.

Obeso-Nieblas, M. & Jiménez-Illescas, A.R. 1989. Propagación de la constituyente M2 de la marea en La Bahía de La Paz, Baja California Sur, México, mediante un modelo bidimensional hidrodinámico numérico. Master's Thesis, Instituto Politécnico Nacional, La Paz.

Osuna-García, M. 2006. Efecto de la densidad en el cultivo de la almeja mano de león *Nodipecten subnodosus* (Sowerby, 1835), en la Península de Baja California, México. Master's Thesis, Instituto Politécnico Nacional, La Paz.

Phleger, F.B. & Ewing, G.C. 1962. Sedimentology and oceanography of coastal lagoons in Baja California, Mexico. Geology Society American Bulletin, 73: 145-182. doi: 10.1130/0016-7606(1962)73[145:SAOOCL]2.0.CO;2

Reinecke-Reyes, M.A. 1996. Madurez y desove de la almeja mano de león *Lyropecten subnodosus* Sowerby, 1835 (Bivalvia: Pectinidae) en laguna Ojo de Liebre, Baja California Sur, México. Boletín Pesquero - Centro Regional de Investigación Pesquera, 3: 17-20.

Roldán-Carrillo, L.M., Maeda-Martínez, A.N., Massó-Rojas, A. & Sicard-González, M.T. 2007. Salinity tolerance and resistance of the Pacific lion's paw scallop *Nodipecten subnodosus* and the relationships with species distribution and density in a coastal lagoon. Journal of Shellfish Research, 24: 353-36. doi: 10.2983/0730-8000(2005)24(353:ATAROT)2.0.CO;2

Rombouts, A. 1991. Guide to pecten shells. Recent Pectinidae and Propeamussidae of the world. Universal Book Services/Dr. W. Backuys, Oegstgeest.

Sánchez, P.J. 1991. Distribución espacio-temporal de la ballena gris (*Eschrictius robustus*) en la Laguna Ojo de Liebre, Baja California Sur, México. Bachelor Thesis, Universidad Autónoma de Baja California Sur, Baja California Sur.

Sato-Okoshi, W. 2000. Polydorid species (Polychaeta: Spionidae) in Japan, with descriptions of morphology, ecology and burrow structure. 2. Non-boring species. Journal of Marine Biology Association of the United Kingdom, 80: 443-456. doi: 10.1016/j.aquaculture.2012.04.013

Received: November 15, 2023; Accepted: July 30, 2024

Sato-Okoshi, W. & Abe, H. 2012. Morphological and molecular sequence analysis of the harmful shell boring species of *Polydora* (Polychaeta: Spionidae) from Japan and Australia. Aquaculture, 369: 40-47. doi: 10.1016/j.aquaculture.2012.08.046

Sato-Okoshi, W., Abe, H., Okoshi, K., Teramoto, W., Shaw, J., Koh, B.S., et al. 2015. Harmful shell borers, *Polydora* species (Polychaeta: Spionidae), from commercially important mollusc shells in east Asia and Australia. In: Ceccaldi, H.J. (Eds.). Marine productivity: perturbations and resilience of socio-ecosystems. Springer International Publishing, Berlin, pp. 31-42.

Silina, A.V. 2006. Tumor-like formations on the shells of Japanese scallops *Patinopecten yessoensis* (Jay). Marine Biology, 148: 833-840. doi: 10.1007/s00227-005-0120-4

Silina, A.V. & Zhukova, N.V. 2009. Topical and trophic relationships in a boring polychaete-scallop association: fatty acid biomarker approach. Marine Ecology Progress Series, 394: 125-136. doi: 10.3354/meps08189

Simon, C.A. & Sato-Okoshi, W. 2015. Polydorid polychaetes on farmed molluscs: distribution, spread, and factors contributed to their success. Aquaculture Environment Interactions, 7: 147-166. doi: 10.3354/aei00138

Simon, C.A., Ludford, A. & Wynne, S. 2006. Spionid polychaetes infesting cultured abalone *Haliotis midae* in South Africa. African Journal of Marine Science, 28: 167-171. doi: 10.2989/18142320 609504141

Sturges, H. 1926. The choice of a class interval. Journal of the American Statistical Association, 21: 65-66. doi: 10.1080/01621459.1926.10502161

Villalejo-Fuerte, M., Arellano-Martínez, M., Robles-Mungaray, M. & Ceballos-Vázquez, B.P. 2004. Notes on the growth, survival, and reproduction of the lion's paw scallop *Nodipecten subnodosus* maintained in a suspended culture. Hidrobiologica, 14: 161-165.

Wargo, R.N. & Ford, S.E. 1993. The effect of shell infestation by *Polydora* sp. and infection by *Haplosporidium nelsoni* (MSX) on the tissue condition of oysters, *Crassostrea virginica*. Estuaries, 16: 229-234. doi: 10.2307/1352494

Waser, A.M., Knol, J., Dekker, R. & Thieltges, D.W. 2021. Invasive oysters as new hosts for native shell-boring polychaetes: Using historical shell collections and recent field data to investigate parasite spillback in native mussels in the Dutch Wadden Sea. Journal of Sea Research, 175: 102086. doi: 10.1016/j.seares.2021.102086