Research Article

Argopecten purpuratus (Mollusca, Pectinidae) post-El Niño 1997-98 response in La Rinconada Marine Reserve (Antofagasta, Chile)

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ABSTRACT. From 1999-2001, the *Argopecten purpuratus* population at La Rinconada was directly evaluated by monitoring larvae and their subsequent settlement on artificial collectors to determine their density, size structure, and abundance. An increase in specimens, doubling the number observed in 1997, occurred in 1999. However, reductions in the distribution area, specimens, and average size occurred in 2000 and 2001, reflecting anthropogenic impacts. Application of the growth parameters to the annual size structure indicated losses of 5.7 million individuals between 1999 and 2000 and 5 million between 2000 and 2001. The specimens increase over 90 mm, from 130,000 in 1997 to 2.6 million in 2001, explains the high larvae numbers found, with records of 17,667 and 21,756 in 1999; 16,100 in 2000; and 34,175 and 21,700 in 2001. A relationship between larval presence and postlarval settling could not be established; only the relationships between periods of larval abundance and those of maximum fixation could be observed. In conclusion, a viable solution to illegal fishing affecting the reserve with complementary or substitute measures for local fishers is urgently required.

Keywords: El Niño; marine reserve; *Argopecten purpuratus*; larval stages; spat collection; clandestine fishing

INTRODUCTION

The Chilean scallop, *Argopecten purpuratus* (Lamarck, 1819) (Bivalvia: Pectinidae), inhabits the southeastern Pacific along the coasts of Peru and Chile. In Chile, its natural distribution ranges from Arica (18°25'S) to Valparaíso (33°S) (Boré & Martínez 1980) in disjunct populations, and the most important beds are Mejillones del Sur Bay (23°54'S), La Rinconada (23°28'S) and Tongoy (30°14'S).

The banks of Mejillones and La Rinconada in the Antofagasta region have been identified as having the highest densities in the country, contributing 82.3% of the largest landings recorded as a result of the high recruitment associated with El Niño/Southern Oscillation (ENSO) 1982-1983 (Cantillánez 2000, Stotz 2000, Avendaño & Cantillánez 2005). *A. purpuratus* has been suggested as a relict form of a subtropical animal that inhabited Peruvian and Chilean waters in the mid-and late Miocene, preserving its characteristics as a species of warm waters and thus exhibiting spectacular population increases with events such as El Niño (Wolff 1987).

The studies conducted on the populations of this resource in Chile have confirmed that La Rinconada holds one of the most important *A. purpuratus* banks in the country, with the capacity to recover from the deplorable state of the national beds resulting from clandestine extractions (Avendaño et al. 2017). Additionally, this population features high genetic variability and hybrid vigor, necessary for the repopulation of collapsed banks, to benefit the artisanal fishing sector (Avendaño 1993, Avendaño & Cantillánez 1997a). Both attributes have contributed to the fact that in 1997, La Rinconada became the first marine reserve in the country to support a juvenile population of *A. purpuratus*, which was distributed over an area of 162.6 ha and numbered 6,157,930 individuals in May 1997 (Avendaño & Cantillánez 1996, 1997b). An important milestone was marked in 1999, when the State of Chile financed installing a protection system on the site to reduce illegal fishing pressure in the area.

When this reserve was established, studies allowed its characterization as an area of intense reproductive activity for *A. purpuratus,* extending from September

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to April (Cantillánez et al. 2005). Larval retention and constant settlement of postlarvae on artificial collectors were commonly observed. Recruitment on the natural substrate that dominates the bottom, the red alga *Rhodymenia* sp., was affected by the heating caused by El Niño, which generated considerably decreases in its biomass (Cantillánez et al. 2005, Cantillánez-Silva et al. 2007, Avendaño et al. 2006, 2008a,b, 2017, 2019, Avendaño & Cantillánez 2016).

The objective of the present study is to evaluate the effects caused by El Niño 1997-98 on the population of *A. purpuratus* at La Rinconada, Chile, through an analysis of the variations in three indicators adopted for the annual monitoring of the distribution, number, and size structure of the scallops during the three years after this event (1999-2001) coincident with the installation of the protection system in the area of the reserve starting in 1999. Additionally, the study evaluated and analyzed the larval cycle of this species and its postlarval stage on artificial collectors that were quantified to support the design and planning of future massive collection programs.

MATERIALS AND METHODS

Study area

The study area is located in the Antofagasta Bay, in the sector of La Rinconada, located at 23°28'S, 70°30'W, 20 km north of the city of Antofagasta, Chile (Fig. 1). One of the most important *Argopecten purpuratus* banks in the country are distributed in this sector (Avendaño & Cantillánez 1996). Oceanographically, at a microscale, this area is subject to alternating current flows, which result from a predominant current northward, but which meet the barrier imposed by the beach and are reflected cyclically at daily time scales. This process produces an exchange and mixing of water masses and the retention of particulate matter in suspension, including *A. purpuratus* larvae, within an area of 5 km (Cantillánez 2000, Cantillánez-Silva et al. 2007). At the macroscale, it should be noted that the area where this reserve is located corresponds to a subtropical transition environment. Its geographical orientation towards the south and southwest and its latitudinal position expose it to the confluence of various types of water bodies. Among them, Subantarctic Water (SAW) predominates in normal years, dominating the upper 200 m of the northern branch of the cold Humboldt Current. In this area, the SAW is mixed with a lower proportion of Subtropical Water (STW), which has higher salinity and temperature, and periodically with colder waters that originate from greater depths, corresponding to Subsurface Equatorial Water (SSEW), which rises to the coast due to upwelling processes induced by the south and southwest winds (Escribano et al. 1995). These phenomena occurring in the area supported by the presence of SSEW, SAW, or intermixed water during the spring and summer and sometimes in autumn allow the incorporation of sufficient nutrients in the higher levels and the existence of a phytoplanktonic community typical of upwelling areas (Avaria & Muñoz 1982, Rodríguez & Escribano 1996). In this bay, a strong seasonal winter mixture has been observed that is driven by wind, causing the isotherm of 13 or 14°C to rise very close to the surface (Escribano et al. 1995, Rodríguez & Escribano 1996). The average daily water temperature of this bay, in years lacking El Niño or La Niña, oscillates at the bottom level (16 m depth) between 13 and 19°C, with the highest averages recorded during the summer months (Cantillánez et al. 2005).

Studies on the biology of *A. purpuratus* in this reserve have revealed that at the reproductive level, spawning occurs throughout the year due to the absence of interindividual synchronism and prolonged periods of sexual rest, with a period of high reproductive activity between September and April of each year (Avendaño 1993, Avendaño & Le Pennec 1997, Cantillánez 2000, Cantillánez et al. 2005).

Measurement of physicochemical parameters

During this study, measurements of chlorophyll-*a* and phaeopigments were performed monthly at a depth of 16 m in the sampling area (Fig. 1) according to Strickland & Parsons (1972), and measurements of particulate organic matter (POM) were obtained by applying the methodology used by Chauvaud & Thouzeau (1995). The samples were obtained with sampling bottles.

In addition, the temperature was recorded daily in 6 h intervals by a micrologger (8-bit Minilog TR, Vemco) installed at 16 m depth in the sampling area. These measurements were used to obtain a daily average.

Estimation of the abundance of the scallop resource

Annually, throughout March in 1999-2001, the abundance of the resource was estimated through diving, proceeding according to the method described by Avendaño & Cantillánez (2005) to cover the perimeter of the distribution area and delimit it through the installation of indicator buoys, whose geographical positions were referenced with the help of a global positioning system (GPS, Garmin 12XL). The subsequent projection of the points on a planar map of the area allowed us to calculate the surface on which the organisms were distributed through a Zeting KP-27 polar compensation planimeter (Avendaño & Cantillánez 2003, 2005).
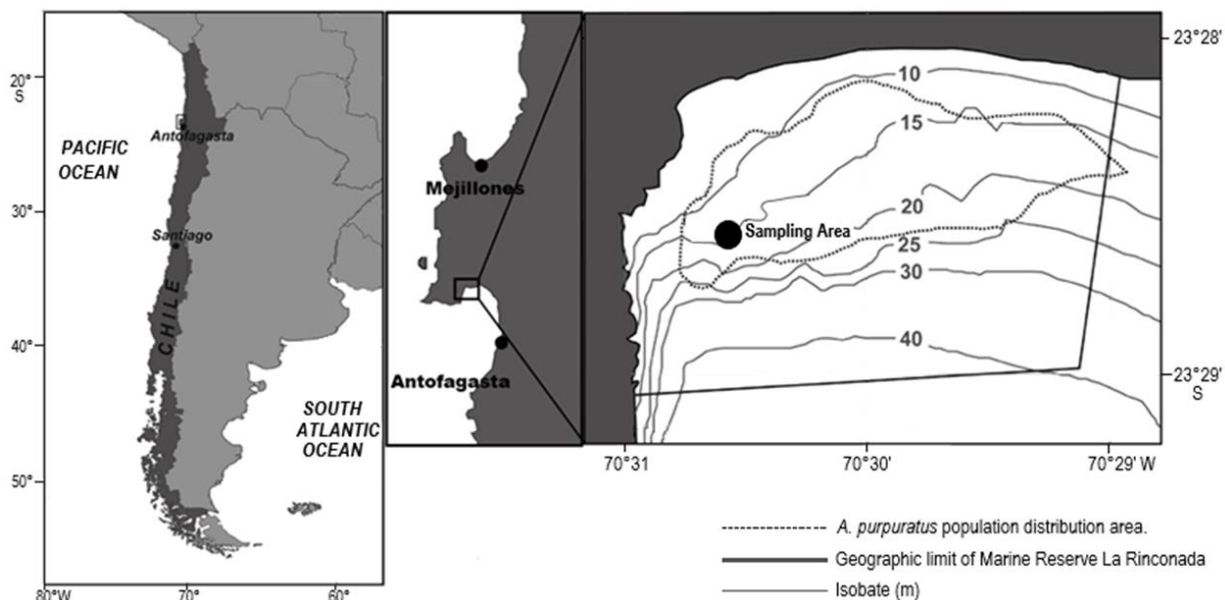
Figure 1. Geographic location of La Rinconada Marine Reserve (23°28'28"S, 70°30'35"W), 20 km north of the city of Antofagasta, Chile. The distribution area of the *Argopecten purpuratus* population is shown, as is the position of the sampling station for monitoring physicochemical parameters, larval stages, and seed collection (sampling area).

Once the distribution area of the organisms was delimited, pilot sampling was carried out to determine the minimum number of sampling units required to estimate the density and total abundance of the *A. purpuratus* population, according to Thompson (1992). The sampling methodology employed is described by Avendaño & Cantillánez (2005) with a predefined symmetric sampling grid. In this manner, sampling stations were established, representing 10% of the total surface occupied by the bank each year.

Because the densities of specimens obtained in the pilot sampling showed variability concerning position within the sampled area, strong stratification of the population could be established, indicating the need for stratified random sampling. The method consisted of establishing a simple random sample in each stratum once its presence was recognized. Once the minimum number of samples to be obtained was defined, based on the results obtained in the pilot sampling, samples were differentially allocated according to the weight of each stratum (surface), randomly sampling 10 quadrats of 1 m², within areas of 70×70 m, according to Avendaño & Cantillánez (2005). The specimens counted were all those visible and loose on the background substrate. Subsequently, in each stratum, the average values of density and abundance were calculated according to Thompson (1992). The estimator of the population variance was obtained by multiplying the variance of the stratified mean by the square of the total surface of the bank expressed in

sample units (Thompson 1992). The abundance analysis in each stratum was performed by combining the data obtained in the final sampling with the pilot sampling data to reduce uncertainty in the true abundance.

Population structure determination

At each station where the density of organisms was obtained, scallops from five quadrats where recovered and the maximum length (antero-posterior) was measured with the aid of 0.1 mm precision Mitutoyo electronic calipers. Data obtained were tabulated to determine the size-frequency, plotted *vs.* length, and how the different size groups were represented within the distribution area.

Estimation of the fraction of the spawning stock

The fraction of the spawning stock of the population during 1999-2001, measured in biomass, was determined following the methodology applied by Avendaño & Cantillánez (2016). It was estimated as the product of total biomass at each size and the proportion of mature specimens at that size, with the latter being determined by the logistic function: $P(R_{50}) = 1 \times (1 + e^{(6.678 - 0.114 \times height)})^{-1}$ which was calculated by a nonlinear adjustment for the population of *A. purpuratus* in this marine reserve (Avendaño & Cantillánez 2016). The potential function $Wt = 0.0001 \times Lt^{3.0416}$ (r = 0.9912) was used to estimate weight for the mean size (Lt) at

each length interval (range of 5 mm), modeled for the same population by Avendaño & Cantillánez (2008).

Larval sampling

Between 1999 and 2001, we performed a quantitative sampling of larvae at periodicities of 15 and 30 days from a station recognized as a natural prerecruitment area (Cantillánez 2000), which coincided with a sector where internal currents turn. Vertical hauls obtained the samples with a 53 µm plankton net along the entire water column (16 m depth). These samples were then deposited and homogenized within a plankton sampler of 10 divisions, and two subsamples were taken to count and measure the larvae of each sample under a stereomicroscope and microscope with a graduated eyepiece. The sizes of the larvae were obtained by measuring their lengths (Salaün 1994). Subsequently, they were separated into two groups, smaller (immature) and greater than 170 µm (mature). This length was used as a criterion for this separation because, at this size, *A. purpuratus* larvae complete the total number of teeth in the hinge, which does not change until metamorphosis (Avendaño 1993). The number of larvae in the column was determined by averaging the values obtained in the two subsamples and considering the volume of water filtered by the network in each sampling through the following formula: $V = \pi \times r^2 \times h$, where V: volume of filtered water in m^3, r: radius of the mouth opening of the net in m, and h: drag distance of the net in m.

Spat collection

From a long-line installed according to Thouzeau (1991a), in the 16-m water column within the area identified as the best area for spat collection (Cantillánez 2000), three Japanese scallop seed collectors, positioned at 1, 2, and 3 m from the bottom, were placed and replaced throughout each year for immersion periods lasting between 21 and 58 days. The collectors were transported to the laboratory, where thorough cleaning was performed to extract all the spat settled. These spats were deposited and homogenized within a plankton sampler of 10 divisions, and two subsamples were taken to count and measure fixation on each collector (Avendaño et al. 2007). A stereomicroscope with a graduated eyepiece was used for these measurements. The number of spat collected was obtained by averaging the quantity found in the three collectors.

RESULTS

Physicochemical parameters

The concentration of chlorophyll-*a* at 16-m depth showed high variability throughout the study, with the highest values recorded in June 1999 (11.9 µg L^{-1}), February 2000 (19.1 µg L^{-1}), and April 2001 (12.5 µg L^{-1}) (Fig. 2a). The concentration of phaeopigments showed variability very similar to that observed for chlorophyll-*a*; however, the increases recorded were displaced concerning the patterns for chlorophyll. These results show that the greatest increases occurred in September 1999 (4.8 µg L^{-1}), September 2000 (2.9 µg L^{-1}), and December 2001 (3.1 µg L^{-1}) (Fig. 2b). The POM concentration varied in 1999 between 1.2 and 4.0 mg L^{-1}, between 1.1 and 7.8 mg L^{-1} in 2000, and between 2.3 and 19.9 mg L^{-1} in 2001, with the highest value recorded in September 2001 (Fig. 2c). The temperature varied considerably, with daily averages ranging between 13 and 15°C, and increases generally occurring in summer months when temperatures exceeded 17°C (Fig. 3).

Scallop population distribution

The *A. purpuratus* populations in 1999, 2000, and 2001 were distributed in areas of 270.9, 259.8, and 254.8 ha, respectively, at depths between 6 and 25 m. Scallops were preferentially concentrated in 44.5, 34.5, and 50.4 ha in these years, respectively, at depths of 7 to 17 m (Fig. 4).

Scallop density and population structure

The area occupied by the scallop population in March 1999 was 270.9 ha, with an estimated abundance of 11,305,813 ± 416,453.72 ind, while a population decline to 8,660,478 ± 411,401.55 ind was identified for 2000. The population abundance in March 2001 was estimated at 10,130,758 ± 367,057.08 ind (Fig. 5). For comparative purposes, this figure also incorporates the number of scallops in 1997 above and below the minimum legal size (MLS), established at 90 mm for the *A. purpuratus* fishery in Chile (Avendaño & Cantillánez 1997b).

In 1999, the highest density recorded in the scallop bed was 4.2 ind m^{-2} (variance = 0.02362), which declined to 3.3 ind m^{-2} (variance = 0.025068) in 2000 and again increased to 4.0 ind m^{-2} (variance = 0.020759) in 2001 (Fig. 6).

High-density areas showed a value of 10.6 ind m^{-2} in 1999, increasing progressively up to 12.1 ind m^{-2} in 2001. Low-density or peripheral areas, on the contrary, decreased from 2.9 ind m^{-2} in 1999 to 2.0 ind m^{-2} in 2001 (Fig. 6).

The average size was 65.5 mm (standard deviation SD = 26.0) in 1999; the maximum size found was 125 mm. In that year, 56.2% of the individuals were larger than 70 mm, and 12% were larger than the MLS (Fig. 7).
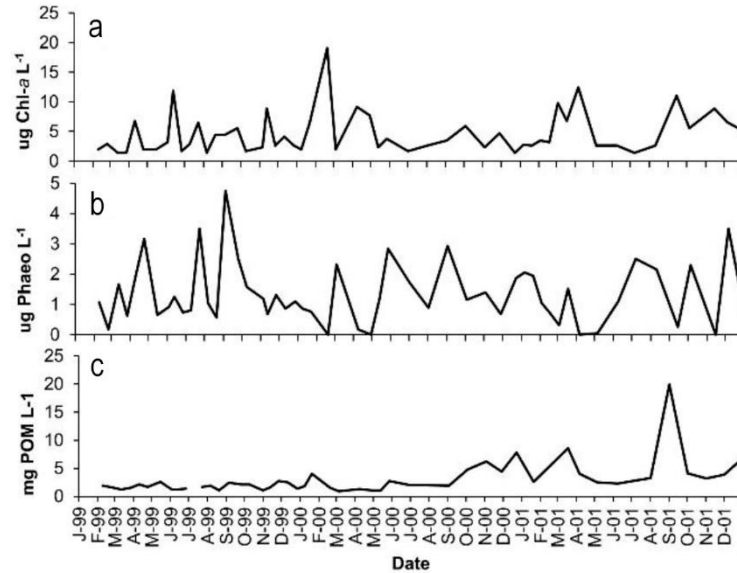
Figure 2. Recorded monthly concentration values of a) chlorophyll-*a* (µg L^{-1}), b) photopigments (µg L^{-1}), and c) particulate organic matter (POM) (mg L^{-1}) in La Rinconada Marine Reserve from 1999 to 2000.

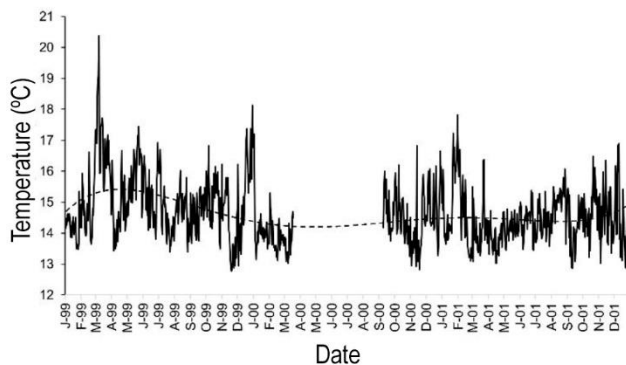**Figure 3.** Recorded daily temperatures (°C) at 16 m deep in La Rinconada Marine Reserve between 1999 and 2001. Dashed line: shows the temperature trend.

In March 2000, scallop size varied between 1.5 and 132.5 mm, averaging 57.8 mm (SD = 37.0). Twenty-seven percent exceeded the MLS, and a remarkable proportion (35% of the population) were pre-recruits of 1.5 to 31.5 mm (Fig. 7). In 2001, height varied between 10.2 and 137.2 mm, with an average of 75.8 mm (SD = 19.8). A total of 25.8% exceeded the MLS, and only 7.5% were smaller than 50.0 mm (Fig. 7).

Spawning stock fraction

In 1999, the spawning fraction of the population was 411.6 t, with the largest contribution to gametes from individuals with a size of 82.5 mm. One year later, the spawning biomass was 410.6 t, increasing by 37% for a record of 563.1 t in 2001. In 2000 and 2001, scallops

with the greatest contributions to gamete production were 92.7 and 92.4 mm, respectively.

The abundance of scallop larvae

A. purpuratus larvae were continuously present during 1999, exceeding 1000 ind m^{-3} in March, July, and September-December. Two peaks of larvae were recorded in November and December, with 17,667 and 21,756 ind m^{-3}, respectively (Fig. 8). Values exceeding 1000 ind m^{-3} were recorded in three periods: between February and August 2000, October 2000 and June 2001, and September 2001. Larval peaks occurred in April and July 2000, with values of 16,100 and 9600 ind m^{-3}, respectively, and in May and December 2001, 34,175 and 21,700 ind m^{-3}, respectively. Competent larvae (>170 µm) were present during all periods of high larval abundance (Fig. 8).

Spat collection

From 1999-2001, the fixation of *A. purpuratus* postlarvae on artificial collectors was a continuous process within the reserve area (Table 1). The maximum averages of spat collection occurred between mid-August and mid-September 1999, with 4180 and 5908 individuals per collector and sizes between 353 and 1760 µm and between 353 and 2120 µm, respectively. During 2000, the maximum spat amounts collected were recorded in November and January-March, with averages of 3622, 6805, 14,153, and 4370, respectively. The sizes varied between 303 and 5100 µm, with the broadest range being 450 and 5100 µm,
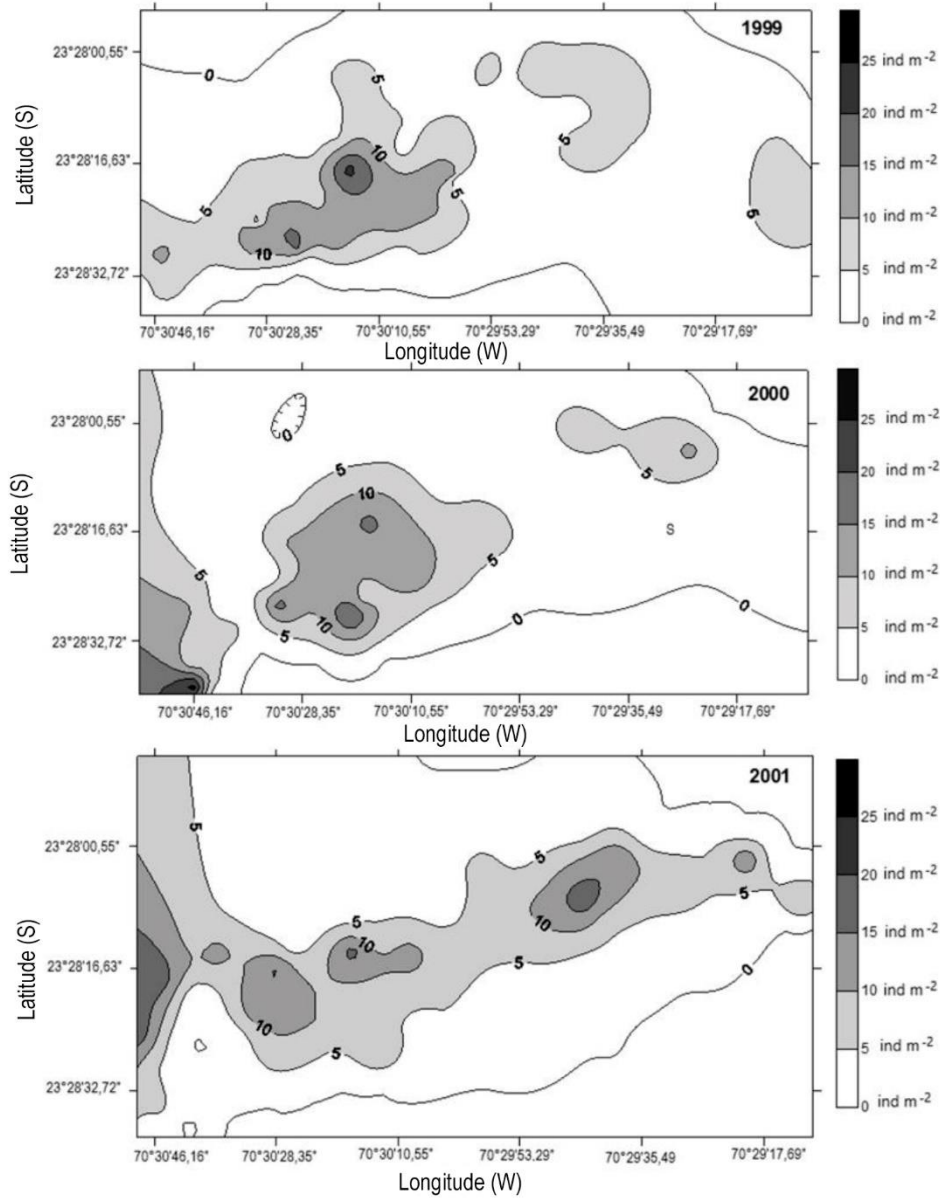
Figure 4. Distribution of *Argopecten purpuratus* individuals in La Rinconada Bay in March 1999, 2000 and 2001. The areas of high and low density are shown.

recorded during the November-January period. During 2001, the highest collection levels were recorded between October and December, with a maximum average of 15,340 spat recorded in November.

DISCUSSION

Monitoring of the *Argopecten purpuratus* bank in the marine reserve revealed the magnitude of the interannual variation in the population's distribution, abundance, and structure after the impacts of El Niño and the establishment of the protective measures in the area. The abundance value of 6.16 million individuals in 1997, reported by Avendaño & Cantillánez (1997b), contrasts significantly with that observed immediately after the end of El Niño 1997-98. Thus, the results reflect an increase in the distribution area and the doubling of the total scallop population of the bank, quantified as 11.31 million individuals in 1999. This finding is explained by applying the growth parameters established by Avendaño & Cantillánez (2005) as a 39.4% increase in the juvenile fraction of the population (up to 89 mm in size) in one year. These patterns of the population increase in the species have
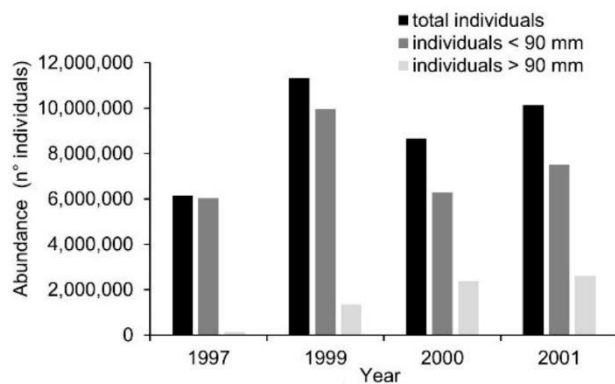
Figure 5. Total abundance of *Argopecten purpuratus* in La Rinconada Bay in March 1999, 2000, and 2001 discriminating individuals above and below the minimum legal size (90 mm). The year 1997 is included for comparison (extracted from Avendaño & Cantillánez 1997).

Figure 6. The density values recorded in March 1999, 2000, and 2001 for *Argopecten purpuratus* bed of La Rinconada Marine Reserve. Estimated density is indicated for the distribution areas of the bank as "high-density area" or "low-density area".

been reported by Mendo & Wolff (2003), indicating that the greatest increases in capture volume of *A. purpuratus* along the Peruvian coasts occur approximately one year after the maximum temperature anomalies caused by El Niño. The patterns of population increase recorded to reflect the expected positive effects of this event leading to significant increases in the natural populations of the species (Wolff 1987), as has been reported for the Mejillones del Sur bank, with 18.24 million individuals observed in its northern area after the occurrence of this same event (Avendaño & Cantillánez 2003). On the other hand, the values that represent the increase that occurred in the first year after the reserve was established are also explained by the immediate cessation of clandestine extraction due to the continuous presence of a surveillance body that began its operations in 1999, effectively safeguarding the natural heritage present there.

However, application of growth parameters established by Avendaño & Cantillánez (2005) to the annual size structure exhibited by this population indicates that the number of recruits of the new annual cohorts that were integrated into the population after March 1999 and 2000 was 35% in 2000 and 35.8% in 2001. Subtracting these individuals from the total number found in each of these years leaves a fraction of scallops older than one year, which corresponds to the number of adults surviving the previous year and allows estimation of the loss between the two years. In this manner, losses of 5.7 million organisms between 1999 and 2000 and 5.0 million between 2000 and 2001 occurred. The systematic disappearance of older and larger organism accounts for the illegal fishing activities that affect this population, as also noted by
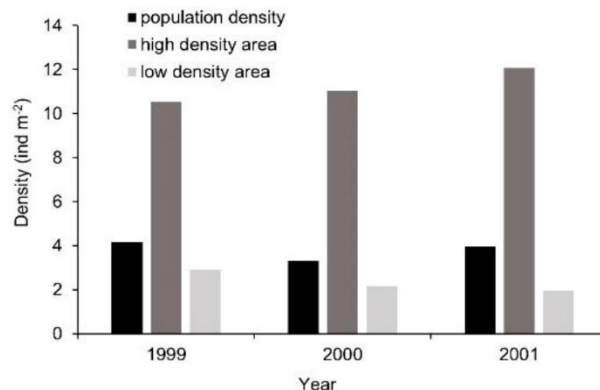
Ortiz et al. (2009, 2010). In the reserve, this anthropic impact on *A. purpuratus* is also manifested in the number and average size of individuals reductions observed within the distribution area in this population during 2000 and 2001 compared to those measures in 1999, which, to this day, has not been halted despite a 24-h surveillance system (Avendaño et al. 2017).

The constant presence of *A. purpuratus* larvae found in the plankton samples obtained in this study confirms the continuous reproductive activity of this species in the reserve (Avendaño & Le Pennec 1997, Cantillánez et al. 2005), while the high number of individuals representing a broad range of sizes confirms the larval retention capacity of this area (Cantillánez-Silva et al. 2007, Avendaño et al. 2008a).

During the period of greatest reproductive activity, which occurs annually between September and April of each year, the larval density is greater than 1000 ind m^{-3}, with shell sizes exceeding 170 µm, a size close to the threshold indicating competence. In November and December 1999, record larvae numbers of 17,667 and 21,756 were registered, respectively, including 16,100 in April 2000, 34,175 in May, and 21,700 in December 2001. Compared to values obtained in previous studies, these increases in the larval density of *A. purpuratus* can be explained by the proportion of adult individuals increment in this bank, which increased from 130,000 individuals in 1997 to 1.4 million in 1999 then to 2.6 million in 2001. A relationship describing the number of oocytes produced by *A. purpuratus* as a function of body size was established by Avendaño et al. (2001), who indicated that scallops of 60 mm height release approximately 6.5 million oocytes, compared to approximately 28 million oocytes released by a 90 mm
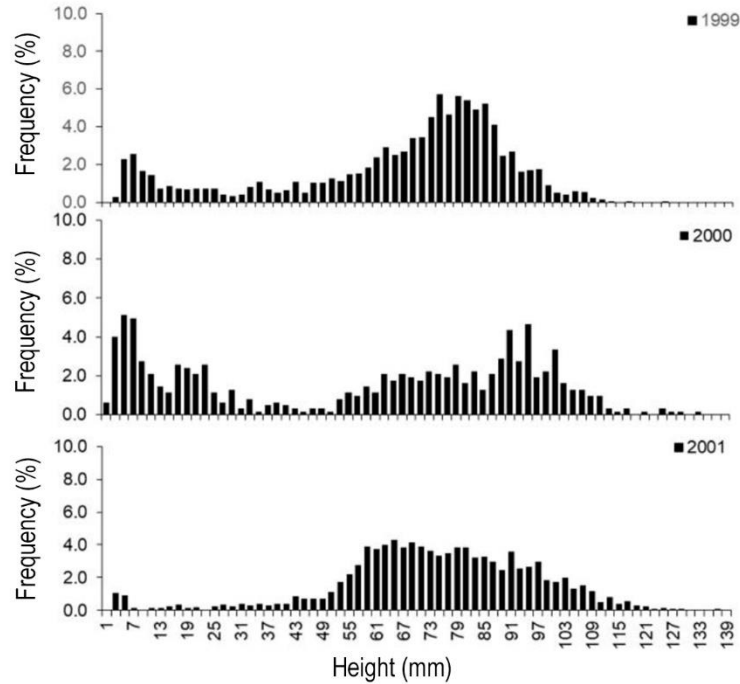
Figure 7. Size structure of the *Argopecten purpuratus* population in La Rinconada Marine Reserve in March 1999, 2000, and 2001.
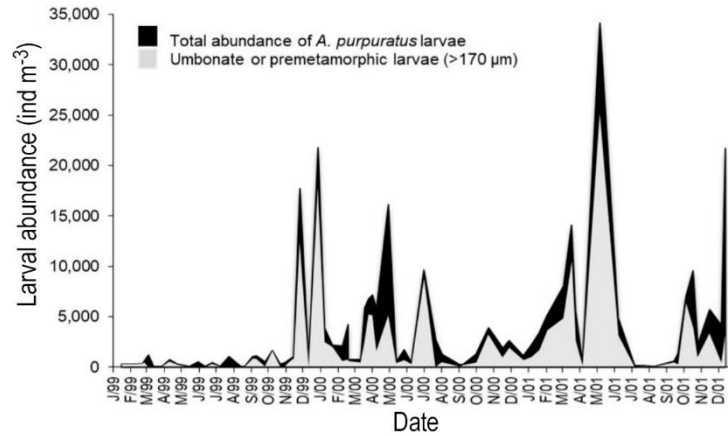

Figure 8. Total abundance of *Argopecten purpuratus* larvae and the fraction corresponding to competent larvae (>170 µm), expressed as larvae m^{-3}, in La Rinconada Marine Reserve during 1999, 2000, and 2001.

individual. This finding confirms the total spawning biomass estimates made for the years 1999, 2000, and 2001, which indicated that the sizes that made the greatest contributions to larval production during those three years were 82.5, 92.7, and 92.4 mm, respectively, with an increase of 37% of the spawning biomass in 2001 over the level in the bank in 1999.

Consequently, a relationship can be postulated between the abundance of spawners and the abundance of larvae in this reserve, as supported by evidence indicating that high larval density is dependent on the number of spawners greater than 90 mm present (Cantillánez-Silva et al. 2007, Avendaño et al. 2008 a,b).

Furthermore, the periods during which the maximum levels of the settlement were recorded in the collectors correspond to the periods of greatest larval abundance, particularly when a large fraction of the larvae exhibited a competent size for settlement (240 µm), an apparent relationship also indicated for *Pecten yessoensis* by Ventilla (1982) which, however, are not consistent when such conditions are absent. Boucher

Table 1. Results of the capture of postlarvae of *Argopecten purpuratus* performed annually in La Rinconada Marine Reserve from 1999 to 2001.

Installation/ removal date in 1999	Average spat settlement n spat/collector	Size range (μm)	Installation/ removal date in 2000	Average spat settlement n spat/collector	Size range (μm)	Installation/ removal date in 2001	Average spat settlement n spat/collector	Size range (μm)
16/01-09/02	1587 ± 479	245-5780	07/01-21/01	218 ± 36	353-858	06/01-03/02	12883 ± 896	303 - 2121
09/02-24/02	1429 ± 785	245-7888	21/01-08/02	550 ± 104	353-1210	03/02-03/03	14153 ± 2725	303 - 1515
24/02- 13/03	987 ± 193	303-4490	08/02-18/02	20 ± 5	353-606	03/03-06/04	4370 ± 466	354 - 2929
13/03-27/03	240 ± 30	303-1910	18/02-11/03	438 ± 71	354-1162	06/04-06/05	1170 ± 197	312 - 3586
27/03-09/04	873 ± 232	275-1010	11/03-25/03	122 ± 3	354-758	06/05-08/06	878 ± 137	353 - 2270
09/04-24/04	852 ± 163	303-1410	25/03-08/04	132 ± 30	354-758	08/06-06/07	1450 ± 473	353 - 1515
24/04-15/05	1888 ± 462	303-1660	08/04-12/05	1985 ± 588	354-2070	06/07-09/08	72 ± 31	303 - 606
15/05-30/05	628 ± 198	303-1210	12/05-08/06	1272 ± 544	354-1111	09/08-14/09	798 ± 101	278 -1061
30/05-25/06	433 ± 131	303-1810	08/06-21/07	143 ± 235	707-2980	14/09-05/10	200 ± 28	505 - 1313
25/06-23/07	2202 ± 1112	353-2320	21/07-25/08	8 ± 0	354-1010	05/10-15/11	15340 ± 2786	404 - 3788
23/07-20/08	65 ± 23	353-1760	25/08-01/10	313 ± 293	555-2220	15/11-08/12	890 ± 71	303 - 1363
20/08-25/09	4180 ± 992	353-1760	01/10-20/10	8 ± 10	707-1919	08/12-08/01	4270 ± 622	278 - 1313
25/09-22/10	5908 ± 1,017	353-2120	20/10-16/11	1472 ± 240	404-1565			
22/10-30/10	132 ± 18	353-6060	16/11-06/01	3422 ± 435	454-5360			
30/10-15/11	687 ± 231	353-1010						
15/11-26/11	3327 ± 804	353-1560						
26/11-10/12	570 ± 129	353-1210						
10/12-23/12	133 ± 45	353-2220						
23/12-07/01	995 ± 276	353-1110						

(1985) described the absence of a relationship between the number of larvae present and the number of settled seeds in *Pecten maximus* likewise, pointing out that the effect on the incidence of the metamorphosis of the fluctuations observed in pre-recruitment is marked due to the lack of a systematic relationship between the abundance of larval cohorts and the performance of seed collection. According to this author, the absence of fixation corresponding to many larval cohorts implies the existence of strong mortality, independent of larval density. However, the availability of larvae as a determinant of population abundance was recognized at the beginning of the last century (Hjort 1914) and reconsidered in later years by many authors in several of the deterministic models used in the theories developed on recruitment regulation (Cushing 1982, Lewin 1986, Rothshild 1986, Roughgarden et al. 1988, Sinclair 1988, Underwood & Fairweather 1989, Doherty & Fowler 1994). Nevertheless, few studies of pectinid larvae in plankton and even fewer for *A. purpuratus* exist. The reason for the low number of available studies has been attributed to the high costs and great effort that this type of research demands and the long-term nature of the benefits (Dames & Moore 1994); regardless, studies carried out on species such as *Pecten magellanicus* and *P. maximus* have permitted the elucidation of aspects of their larval dynamics (Sinclair et al. 1985, Thouzeau et al. 1991b, Salaün 1994).

The effectiveness of the reproductive strategy of this *A. purpuratus* population is reflected in the results obtained in this study, also noted by Cantillánez (2000)

and Cantillánez-Silva et al. (2007). These authors pointed out that after the appearance of competent larvae of this species in plankton, effective pediveliger settlements occur in the natural environment on the fronds of the red alga *Rhodymenia* sp. This alga was seriously affected by the heating caused by El Niño, which caused it to disappear from the bottom and was no longer available as a natural settlement substrate for *A. purpuratus* (Avendaño et al. 2019), forcing the use of collectors as alternative substrates to enhance scallop repopulation (Avendaño & Cantillánez 2008). The absence of a primary settlement substrate, where the scallop is usually settled, has been identified as another factor affecting its recruitment, indicating that subsequent recruitment is seriously affected after substrate removal, limiting population size. Lack of substrate has also been employed to explain the lack of relationship between the availability of larvae and their subsequent settlement on natural substrates (Wolff 1988, Orensanz et al. 1991, Cantillánez-Silva et al. 2007).

On the other hand, the physicochemical parameters recorded concerning temperature confirm the indicated by Escribano et al. (1995): a strong wind-driven winter mixture caused the isotherm of 13 or 14°C to rise close to the surface. This sector's irregular presence of upwelling can often break the seasonal cycle. It would be expected to generate great variability in the temperature conditions, which would explain the high daily variability in temperature observed in the present study (Escribano et al. 1995). The average daily temperature recorded also coincides with that indicated

by Cantillánez et al. (2005) in years with normal conditions and oscillating between 13 and 19°C at the bottom level (16 m depth) highest averages recorded during the summer months.

The periodic upwelling of cold water from greater depth in the reserve area (Escribano et al. 1995) can occur with a frequency of 0.2 to 0.4 cycles per day during its most intense period (Marín et al. 1993). Allows the incorporation of sufficient nutrients at higher levels and a phytoplanktonic community typical of upwelling areas (Avaria & Muñoz 1982, Rodríguez & Escribano 1996) which explains the results obtained for chlorophyll-*a* in the present study. The levels of phytoplankton biomass, recorded as the chlorophyll-*a* concentration, showed intermediate values at the end of summer, increasing in early autumn and decreasing in winter, and then rising again in spring. As expected, since the reserve is a retention zone, the pheopigments were generally high after the occurrence of phyto-plankton blooms. Low concentrations of this indicator would represent the emergence of new phytoplankton populations, favorable physiological conditions, and high rates of cell division, as evidenced by the chlorophyll-*a* values obtained in this study. The highest values of POM were recorded in early autumn during spring and summer when chlorophyll-*a* values were usually low. Lorrain et al. (2000) indicated that the most important environmental factors for the growth of bivalves are temperature, food, and current speed and emphasized food as a limiting factor for *P. maximus* in Brest Bay (France). Food becomes a limiting factor for growth when chlorophyll-*a* concentrations are below 1.0 mg L^{-1} (Thouzeau 1991a,b).

Consequently, the high productivity of this marine reserve, reflected by the values of chlorophyll-*a*, phaeopigments, and POM recorded in this study, indicates that food is not a limiting factor for the growth and survival of *A. purpuratus* in different develop-mental stages in this bank. Therefore, if this aspect of scallop ecology that favors the biological sustainability of this *A. purpuratus* population enables the maintenance of a minimum protected stock of 2.5 million spawners, the implementation and success of massive spat collection programs, i.e. the objective of this reserve, would be assured. The sustained and systematic extraction of larger individuals by illegal fishers in the reserve has prevented the stock of spawners necessary to achieve the proposed objective from being realized (Avendaño & Cantillánez 2016).

Solving this major problem affecting the reserve requires urgently complementary or substitute measures for local fishers. Implementing such measures is essential to allow effective and equitable participation by artisanal fishers regarding the use of this resource.

Considering that this reserve area has been banned for more than 20 years, these regulatory measures imposed by the state have not yielded the expected results.

According to Morales & Gezan (1986), applying bans and prohibitions on fishery resource commercia-lization leads some fishermen to not respect them due to the short-term economic interest imposed by the demand. For these fishermen, short-term economic interest prevails over awareness of rational protection in the longer term, thus violating the current policies regarding artisanal fishing development that propose long-term marine fishing resource conservation (SUBPESCA 1995). Luamba et al. (2016) point out that illegal fishing that affects coastal zones, including marine protected areas, is one of the worst problems in fishing, and its origin is difficult to understand and address; the authors suggest that this problem can occur when fishers do not understand the logic behind fishery regulations, such as conservation and sustainability. In this context, Blount & Pitchon (in Jones 2009) conducted an anthropological analysis reporting that fishers often view equity problems in terms of proposal effects and policies on their way of life rather than only in terms of the distribution of costs and benefits. The situation of illegal fishing in the marine reserve has not changed until now. The last evaluation of the reservation in 2009 revealed a population of only 8,954,969 organisms, which is very similar to that in 2000, although only 149,500 organisms were documented on the MLS (Avendaño et al. 2017).

Consequently, in the current scenario, the popu-lation increases due to the El Niño event, only benefit the illegal fishermen, as recorded for Mejillones in 1999 and 2000 (Avendaño & Cantillánez 2003). Official spaces for discussion regarding the mana-gement of species conservation in the reserve area have operated for many years around the measures of illegal fishing control. However, the participatory perspective of fishermen and other entities representing the community, such as non-governmental organizations interested in reserve conservation and biodiversity, has been a turning point in recognizing the need to rethink the necessary strategies for conserving the natural bank of the Chilean scallop.

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