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Research Article

Biophysical performance indicators for secondary resources reveal positive effects at the community level in La Rinconada Marine Reserve (Antofagasta, Chile), SE Pacific Ocean

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ABSTRACT. Direct evaluations of the main resource *Argopecten purpuratus* and its accompanying benthic fauna developed between 1999 and 2013 in La Rinconada Marine Reserve (Antofagasta, northern Chile) confirmed the presence of two subsystems made up of different species that cohabit with the principal resource (designated SS1 and SS2). SS1 has a medium and fine sand substrate with a coverage of over 80% at the center of the red algae *Rhodymenia corallina*. In addition to the primary resource, the scallop *A. purpuratus*, we also found secondary resources such as *Thaisella chocolata*, *Romaleon setosum*, and, under ENSO conditions, *Octopus mimus* recruits. In SS2, which runs parallel to the coastline, coarser substrates are observed, mainly shells and quartzite gravel mixed with fine and medium sand areas occupied by the bivalves *Transennella pannosa* and *Tagelus dombeii*. Our results show that anthropogenic activities have not affected the abundance and size structure of secondary resources in SS1 and density and size structure in SS2, evidencing a permanent pre-recruitment of organisms. The information generated in this study can complement the current criteria applied to assess the performance of this reserve by accounting for the state of the main commercial resource of interest (*A. purpuratus*). We also discuss the benefits of a more integrative methodology that evaluates the benthic community and the ecosystem based on a conservation and management approach. An inventory of the recorded species in the marine reserve is also provided for the first time and may constitute a baseline for future studies.

Keywords: *Argopecten purpuratus*; scallop; benthos; biotic indicators; northern Chile

INTRODUCTION

La Rinconada Marine Reserve, in northern Chile, was established to protect one of the largest natural banks of *Argopecten purpuratus* (Mollusca, Pectinidae) in the country, a species of commercial interest and ecological importance (Ortiz et al. 2010). In the shallow benthic community, the algae *Rhodymenia corallina* (Rhodophyta) dominates (Avendaño & Cantillánez 2022a), with turfs that serve as habitat for scallops and, other marine resources (i.e. mollusks and crustaceans) that, although not the focus of conservation, may be key for the community structure and the functioning of the ecosystem (Cantillánez 2000, Avendaño & Cantillánez 2008).

Previous studies on trophic models in this reserve have confirmed the presence of two subtidal systems comprising different aggregations of commercial and non-commercial organisms (Avendaño & Cantillánez 2008, Ortiz et al. 2009, 2010). The SS1 subsystem, between 8 and 30 m depth, is characterized by the predominance of scallops, as other mollusks like *Thai-*

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sella chocolata (Gastropoda) and *Aulacomya atra* (Bivalvia) and the crustacean *Romaleon setosum* (Decapoda). In SS2, between 4 and 11 m, there is a predominance of species of commercial interest (*A. purpuratus*, *T. chocolata*, *Transennella pannosa*, *Tagelus dombeii* and, sporadically, *Octopus mimus*) (Fig. 1).

In the context of *A. purpuratus* conservation sustainable management, the performance of this marine reserve was previously analyzed by Avendaño & Cantillánez (2016) based on three biotic indicators for the species: abundance, size structure, and recruitment success. In addition, evidence of illegal fishing, which directly impacts this resource's long-term survival, has been addressed, highlighting the limited success of the policies in place (Avendaño et al. 2017). More than 20 years after its creation, no inventories on the biodiversity of La Rinconada Marine Reserve or information about the status of other resources cohabiting with *A. purpuratus* are available.

Biotic indicators, such as those described by Pomeroy et al. (2006), can record changes in the characteristics and properties of Marine Protected Areas (MPAs) over time. These authors define four indicators that characterize the ecological condition of MPAs: habitat distribution and complexity, community composition and structure, recruitment success, and food web integrity.

This work aims to generate preliminary data on the distribution, abundance, and size structure of La Rinconada Marine Reserve secondary resources (*T. chocolata*, *R. setosum*, *T. pannosa*, *T. dombeii,* and *O. mimus*), providing for the first time an inventory of the main species recorded in this reserve. This information is expected to contribute as a baseline for future assessments of this reserve's status.

MATERIALS AND METHODS

Study area

La Rinconada Marine Reserve (Fig. 1) is a MPA that was established in 1997 (Decreto Supremo 522, Chile). The reserve is located in the southeastern Pacific Ocean, about 30 km north of Antofagasta (23°28'28"S, 70°30'35"W), associated with the Humboldt Current System (HCS), one of the most productive ecosystems in the world in terms of the abundance of fisheries resources (Gutiérrez et al. 2016). It covers approximately 300 ha, with depths ranging from 6 to 29 m, on a bottom of fine to medium sand, colonized by the red algae *R. corallina* (Avendaño 1993, Avendaño & Cantillánez 2008). The area's main objectives are to protect the breeding grounds and habitat of the scallop *A. purpuratus* and preserve and recover this important hydrobiological resource (Decreto Supremo 522, Chile).

Physical environment

The influence of permanent winds from the S-SW causes the upwelling of cold, nutrient-rich, subsurface waters on the coastline (Piñones et al. 2007). Even when there is a residual current in the north direction, the local topography generates a gyre of approximately 5 km in diameter to the west of the bay, resulting in the retention of particulate material and larval stages of different species (Avendaño et al. 2004). This zone is located immediately over or near the sites where high densities of scallops have been recorded (Avendaño et al. 2023a). Residence time of water in the bay varies from 4 to 12 days in summer and 2 to 24 days in winter (Avendaño et al. 2004). The influence of ENSO also affects the area, with disturbances that can extend throughout the ecosystem depending on its phase and intensity (Escribano & Hidalgo 2000).

Substrate composition and algal coverage

The substrates and coverage of the red algae *R. coralline* were characterized at each sampling station.

We collected sediments in duplicate with a PVC cylindrical corer (100 cm^3 cross-section). Samples were homogenized into separate trays, with 200 g aliquots stored in labeled plastic bags. We then washed the sediments with tap and distilled water to remove salt and dried them in an oven at 70ºC to constant weight (MEMMERT UTM-500). Dehydrated samples were sieved using Tyler wire meshes with openings of 4, 1, 0.5, 0.25, 0.125, 0.063 and <0.063 mm in diameter mounted on a RoTap JEL shaker (J. Engelsmann AKT-GES). The different sediment fractions were weighed on a precision balance with a readability of 0.01 g (RADWAG WTC 2000). We statistically analyzed particle sizes after converting them from milimeters to phi units ($-\log_2$) (Holme & McIntyre 1974).

These data were used to build a granulometric map of the reserve's substrate. We defined the following sediment types: gravel (G = >50% particles larger than 2 mm), silt (Z = >50% particles smaller than 0.063 mm), sand (S = >80% particles between 0.063 and 2 mm), silty sand (zS = >50% sand and the rest silt) and gravelly sand (gS = >50% sand and the rest gravel).

R. corallina coverage was measured using a 50×50 cm quadrat subdivided into 10×10 cm squares. Finally, the depth and location of the secondary resources found were recorded with an underwater computer (BEUCHAT

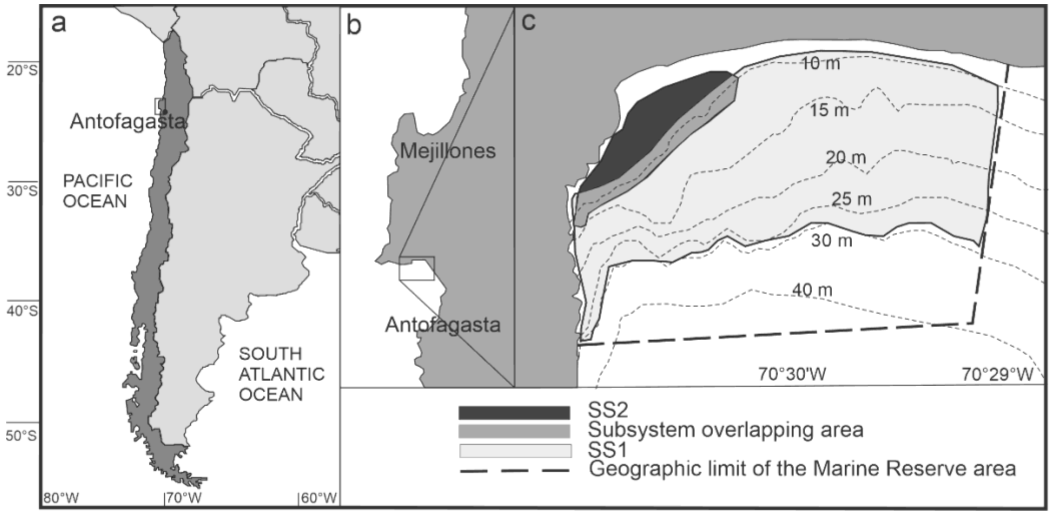

Figure 1. The geographic location of a) the study area and b) the area where the La Rinconada Marine Reserve is located is in the Antofagasta region. c) The spatial distribution of subsystems 1 and 2 (SS1 and SS2) and the overlapping area were used as a reference for monitoring species distribution in the area.

CX 2000 comex) and a GPS receiver (GARMIN GPSmap 76CSx).

Species inventory

The reserve's species inventory was recorded simultaneously with the primary resource assessment via hookah diving (Avendaño & Cantillánez 2005, 2016, 2022b, Avendaño et al. 2017, 2023a). Biota was collected from quadrats at each sampling station and later identified in the laboratory using a reference bibliography (Marincovich 1973, Boré & Martínez 1980, Guzmán et al. 1998).

Divers recorded *in situ* the frequency of organisms' occurrence. The species categorized as frequent correspond to those found over the years of monitoring, while the occasional ones were observed only in some monitoring years, and rare species were observed only once.

Resource abundance and size structure in SS1

Sampling was conducted following the methodology described by Avendaño & Cantillánez (2003, 2005).

In 1999, we visited 104 stations (6-29 m depth), covering an area of 271 ha. In 2000, 64 stations (6-25 m), covering 260 ha. In 2009, 137 stations (5-24 m) and 278 ha. For 2013, *T. chocolata* was sampled at 117 stations in 206 ha. Figure 2 shows the sampled stations for the 4 years.

The sampling area was established based on the perimeter that delimited the distribution of the primary resource (*A. purpuratus*), as this is the most abundant and has the greatest coverage within the reserve. For this purpose, we used demarcation buoys and a compensated polar planimeter ZETING KP-27 (Avendaño & Cantillánez 2003, 2005).

Following a pilot study, the number of stations to be sampled within the distribution area of *A. purpuratus* was defined, establishing the minimum number of sampling units required to estimate its density and total abundance, according to Thompson (1992). The asymmetric grid was predefined, with 70×70 m stations covering 10% of the total distribution area. Ten 1 m^2 quadrats were randomly sampled at each station, counting all the organisms visible on the substrate. The average density and abundance were calculated using the surface occupied by each species. All organisms were collected in five of the ten 1 m^2 quadrats. Back on the boat, the maximum length of each specimen was measured using a digital caliper (± 0.1 mm). The animals were then returned to the water. Size frequency histograms were plotted with these data (3 mm intervals). Size distributions were entered into the MIX 3.1.a software (MacDonald & Pitcher 1979) to identify the number of cohorts' mean sizes. Histograms were decomposed according to a normal distribution (α = 0.05).

Estimates of the distribution, abundance, and size structure of *T. chocolata*, *R. setosum*, and *O. mimus* were obtained in 1999, 2000, and 2009. In 2013, only *T. chocolata* was assessed. Ten specimens of *O. mimus*

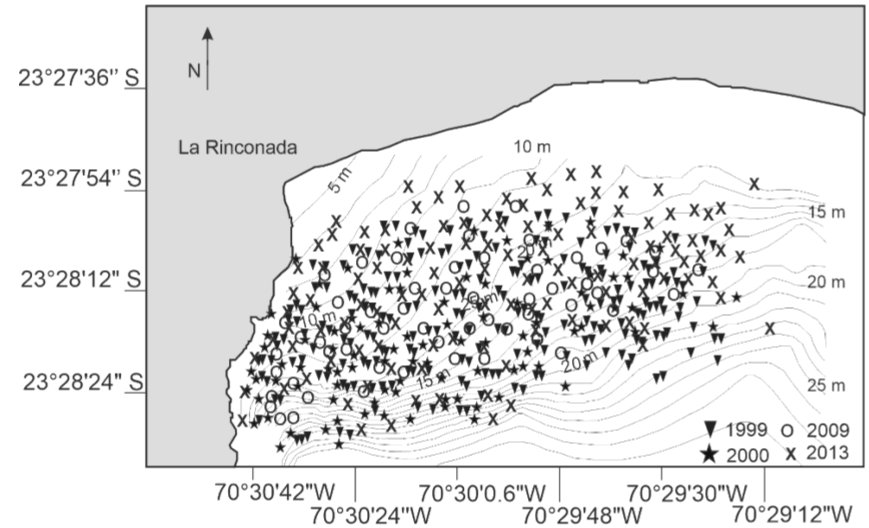

Figure 2. Location of sampling stations for each campaign (1999, 2000, 2009, and 2013).

were randomly selected, weighed, and sexed, obtaining an average weight for this species.

Resource density in SS2

Sampling was carried out in the SS2 subsystem to establish the size structure and density of *T. dombeii* (razor clam) and *T. pannosa* (clam): three samplings between 2005 and 2006 and two in 2009, following the methodology described by Ortiz et al. (2003). Divers surveyed nine transects of 5 m spread along the SS2, extracting samples from three 0.5×0.5 m quadrats (10 cm depth) from each transect (27 samples in total). These were sieved in the laboratory, and the organisms were collected and identified.

RESULTS

Substrate composition, algal coverage, and species inventory

The substrate of La Rinconada Marine Reserve consists of 70.45% medium and fine sand (Fig. 3), extending from areas close to shore to over 20 m depth. We found substrates with larger particle sizes in the adjacent strip, offshore and parallel to the coast, mainly shell remains and quartzite gravel mixed with fine and medium sand.

The algae *R. corallina* dominates the bottom at SS1, with a coverage of over 80% in the center of its distribution, decreasing to less than 20% towards the edges (Fig. 4).

We identified 106 species in the protected area, of which Actinopterygian fish and gastropod mollusks predominate, each with 25.5%, Malacostraca arthropods with 16%, and bivalve mollusks with only 6.6% (Table 1).

Resource abundance and size structure in SS1

The gastropod *T. chocolata* was present in 38% of the sampling stations in 1999, distributed between 6-19 m depth, with an average density of 0.21 ind m^{-2} (Table 2) and an estimated abundance of 567,000 ind. The resource maintained its presence in 2000, with a density of 0.77 ind m^{-2} (Table 2) and 760,000 ind. By 2009, *T. chocolata* was recorded in 71.5% of the stations, with 1.1 ind m^{-2}, an abundance of 2,285,490 ind, of which 39.1% were over the minimum legal size (MLS $\gtrsim$ 55 mm). In 2013, the average density was 1.01 ind m^{-2} (Table 2), with a projected abundance of 2,079,590 ind, 43.7 % above the MLS.

Size frequency analysis identified 3 to 4 cohorts for this species (Fig. 5). In 1999, three cohorts were observed, with C1 (large average size) accounting for 6.5%, C2 at 80.8%, and C3 (small average size) at 12.7% of the population (Fig. 5a). Three cohorts were also found in 2000, with C1 contributing at 67.7%, C2 at 23.6%, and C3 at 8.7% (Fig. 5b). In 2009, 4 cohorts were identified, with C1 accounting for 4.3% and C2 at 34.8%, while the smaller cohorts C3 and C4 with 47.7 and 13.0%, respectively (Fig. 5c). Finally, the analysis shows 3 cohorts in 2013, with C1 contributing 34.7%, C2 52.4%, and C3 12.9% to the population (Fig. 5d).

The crab *R. setosum* was present in 23% of the sampling stations in 1999, distributed between 5-27 m depth, with an average density of 0.06 ind m^{-2} (Table 2) and a projected abundance of 164,700 ind. In 2000, this

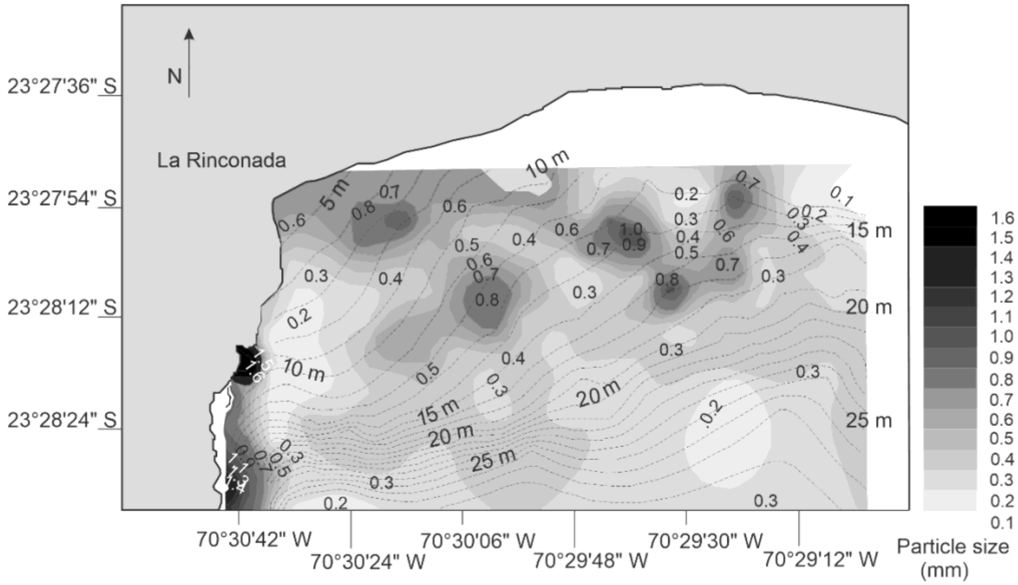

Figure 3. Spatial distribution of substrates (continuous lines) and depth isobaths (segmented lines) in La Rinconada Marine Reserve.

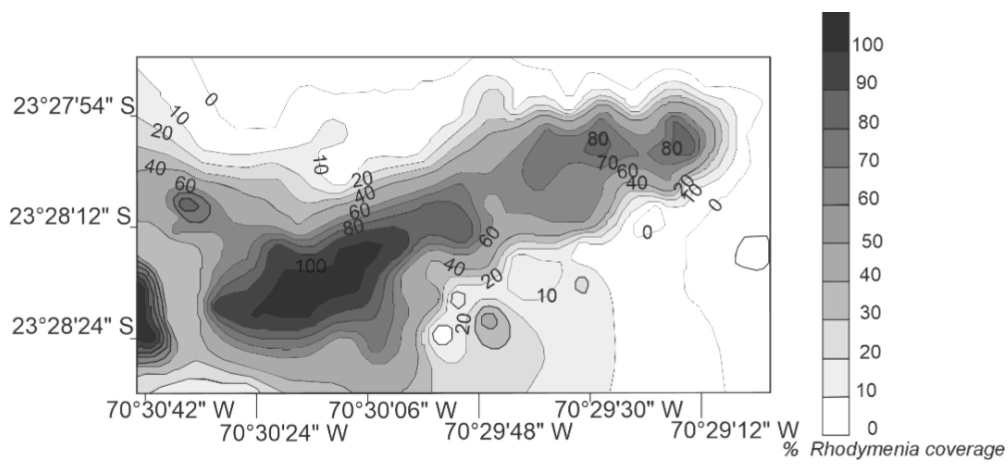

Figure 4. *Rhodymenia corallina* coverage in the protected area.

resource decreased its occupancy, found only at 11% of the stations, with a density of 0.056 ind m^{-2} (Table 2) and 145,000 ind. In 2009, *R. setosum* had an occurrence of 49.6%, with 0.28 ind m^{-2} (Table 2) and an estimated abundance of 627,760 ind.

Size frequency analysis identified 1 to 5 cohorts for this species (Fig. 6). In 1999, 2 cohorts were identified, with C1 (large average size) accounting for 51.5% and C2 (small average size) for 48.5 %, respectively (Fig. 6a). One cohort was found in 2000 (C1), contributing 100% (Fig. 6b). For 2009, the analysis showed 5 cohorts (from largest to smallest sizes): C1 account for 19.5%, C2 at 30.6%, C3 at 12.6%, C4 at 17.5% and C5 at 19.8% of the population (Fig. 6c).

The cephalopod *O. mimus* was only found in the 1999 campaign, occurring in 22% of the stations at depths of 5-24 m. Its mean density was 0.000419 ind m^{-2} (Table 2), with an average weight of 493 g per individual. The estimated abundance of this resource was 1,131 ind. Of those, 60% were females, and 40% were males. All sampled females were immature, and 66.7% carried spermatophores. All sampled males were mature specimens. Later that year, observations indicated that the species nested sporadically in shallow areas near the rocky shore, near the limit with SS2.

Table 1. Inventory of La Rinconada Marine Reserve biodiversity. Species are ranked as 1: frequent, 2: occasional, and 3: rare.

Major group	Class	Species	Observation frequency
Chordata	Mammalia	*Otaria byronia*	(1) Frequent on the surface and in the water column.
		Pseudorca crassidens	(2) Observed during diving activities.
		Stenella sp.	(3)
	Reptilia	*Chelonia mydas*	(1) Frequent on the surface and in the water column.
	Chondrichthyes	*Mustelus mento*	(2)
		Lamna nasus	(2)
		Others non-identified	Observed sporadically with ENSO conditions.
		Mobula tarapacana	(3) Single observation: a group of seven specimens feeding on *Transennella pannosa* and *Tagelus dombeii* in the sandy bottom.
		Discopyge tschudii	(2)
		Pseudobatos planiceps	(2)
	Actinopterygii	*Paralabrax humeralis*	(1)
		Hemilutjanus macrophthalmos	(1)
		Semicossyphus darwini	(1)
		Chirodactylus variegatus	(1)
		Pinguipes chilensis	(1)
		Prolatilus jugularis	(1)
		Anisotremus scapularis	(1)
		Girella laevifrons	(1)
		Aplodactylus punctatus	(1)
		Isacia concepcionis	(1)
		Scartichthys gigas	(1)
		Seriola lalandi	(2)
		Sardinops sagax	(2)
		Sarda chiliensis	(2)
		Scomber japonicus	(2)
		Trachurus murphyi	(2)
		Mugil cephalus	(2)
		Seriolella violacea	(2)
		Thyrsites atun	(3)
		Coryphaena hippurus	(2) During ENSO conditions.
		Labrisomus philippi	(1)
		Aphos porosus	(1)
		Hippoglossina macrops	(1)
		Paralichthys adspersus	(1)
		Leptonotus blainvilleanus	(1)
		Syngnathus macrobrachium	(1)
		Hippocampus ingens	(2) On post-ENSO conditions.
Molluscs	Gastropoda	*Annaperenna verrucosa*	(1)
		Thaisella chocolata	(1)
		Stramonita haemastoma	(1)
		Priene scabrum	(1)
		Felicioliva peruviana	(1)
		Sinum cymba	(1)
		Xanthochorus cassidiformis	(1)
		Polinices uber	(1)
		Tegula luctuosa	(1)
		Fissurella peruviana	(1)
		Alia unifasciata	(1)

Continuation

Major group	Class	Species	Observation frequency
		Nassarius gayii	(1)
		Crucibulum quiriquinae	(1)
		Chiton sp.	(1)
		Acanthina monodon	(1)
		Salitra bourguignati	(1)
		Xanthochorus buxeus	(1)
		Atrimitra orientalis	(1)
		Crepidula philippiana	(1)
		Crepipatella dilatata	(1)
		Aesopus aliciae	(1)
		Trigonostoma tuberculosum	(1)
		Bulla punctulata	(1)
		Agathotoma ordinaria	(1)
		Rissoina sp.	(1)
		Nudibranchs	Unidentified species inhabiting the algae *Rhodymenia corallina*.
		Aplysia sp.	(2) Common during ENSO conditions, feeding on *R. corallina*.
	Bivalvia	*Argopecten purpuratus*	(1)
		Transennella pannosa	(1)
		Tagelus dombeii	(1)
		Aulacomya atra	(1)
		Eurhomalea rufa	(1)
		Pteria sterna	(2) On post-ENSO conditions.
		Atrina (*Servatrina*) *oldroydii*	(2) During post-ENSO conditions. Found half-buried in sites of fine sand, reaching sizes of around 40 cm. It might correspond to an invasive species that arrives at the reserve as a larva.
	Cephalopoda	*Octopus mimus*	(1)
		Doryteuthis (*Amerigo*) *gahi*	(2) Occasionally observed during their egg-laying stage (over ropes and fronds of *R. corallina*).
Echinodermata	Asteroidea	*Heliaster helianthus*	(1)
		Meyenaster gelatinosus	(1)
		Luidia magellanica	(1)
	Echinoidea	*Arbacia* (*Echinocidaris*) *spatuligera*	(1)
Cnidaria	Octocorallia	*Renilla chilensis*	(1)
	Anthozoa	*Actinia* sp.	(1)
Annelida	Polychaeta	*Hydroides chilensis*	(1)
		Serpulidae	(1)
		Hesionidae	(1)
		Pisionidae	(1)
		Nereididae.	(1)
Arthropoda	Malacostraca	*Romaleon setosum*	(1)
		Platymera gaudichaudii	(1)
		Eurypanopeus crenatus	(1)
		Pilumnoides perlatus	(1)
		Hepatus chiliensis	(1)
		Eurypodius latreillii	(1)
		Paraxanthus barbiger	(1)
		Acanthonyx petiverii	(1)
		Cancer porteri	(1)
		Metacarcinus edwardsii	(1)
		Panopeus chilensis	(1)
		Panopeus convexus	(1)

Continuation

Major group	Class	Species	Observation frequency
		Pseudosquillopsis lessonii	(1)
		Pagurus villosus	(1)
		Propagurus gaudichaudii	(1)
		Pagurus edwardsii	(1)
		Tetralobistes weddellii	(1)
Tunicata	Ascidiacea	*Pyura praeputialis*	(1) Abundant in the rocky shore (intertidal and subtidal).
Rhodophyta	Rhodophyceae	*Rhodymenia corallina*	(1)
Ochrophyta	Phaeophyceae	*Lessonia trabeculata*	(1)
Chlorophyta	Ulvophyceae	*Ulva lactuca*	(1)
	Ulvophyceae	*Ulva rigida*	(1)

Table 2. Changes in density (abundance) and size (means ± standard deviation) for secondary resources in SS1 over the study period. *Wet weight (g).

		1999	2000	2009	2013
Thaisella chocolata	Density (ind m^{-2})	0.21 ± 0.40	0.77 ± 0.92	1.11 ± 1.18	1.01 ± 2.48
	Size (mm)	61.2 ± 13.2	70.1 ± 9.5	48.9 ± 21.0	52.1 ± 16.7
Romaleon setosum	Density (ind m^{-2})	0.06 ± 0.20	0.06 ± 0.07	0.28 ± 0.28	
	Size (mm)	68.2 ± 52.9	121.5 ± 21.4	76.6 ± 33.9	
Octopus mimus	Density (ind m^{-2})	0.00042 ± 0.0011			
	Size*	493.0 ± 175			

Resource density in SS2

The bivalve *T. pannosa* was distributed on a bottom of coarse calcareous sand interspersed with fine sand bars of 4 to 7 m width perpendicular to the coast, extending 700 to 900 m long in depths of 5-13 m. The density and mean sizes of *T. pannosa* in the SS2 subsystem for 2005, 2006, and 2009 are shown (Table 3). For spring 2005, sizes varied between 8.0-23.1 mm, with a population consisting of a single cohort (C1) whose mean size was 15.05 ± 2.80 mm (Fig. 7a). During summer 2006, the population fluctuated between 6.6-30.6 mm, with 2 cohorts: C1 (larger size) contributing 71.4% and C2 (smaller size) 28.6% (Fig. 7b). In autumn and winter 2006, sizes were 4.7-43.0 and 2.9-27.0 mm respectively, with 2 cohorts (Figs. 7c-d): C1 explaining 33.9 and 13.5% while C2 66.1 and 86.5% on each season. Finally, in 2009, the size of this resource was 8.6-26.9 mm during winter and 3.2-23.5 mm in spring, with the size-frequency analysis identifying 2 cohorts (Figs. 7e-f). C1 accounted for 13.3% and C2 86.7% in winter and 6.8 and 93.2% in spring this year.

The bivalve *T. dombeii* was found at depths of 4-15 m, over the sand to silty sand, interspersed with coarse sand and shells in an area inhabited by *T. pannosa*. Densities and mean sizes for this resource are presented in Table 3. Size frequency analysis identified 2 to 3 cohorts for this species (Fig. 8). In spring 2005, sizes ranged between 22.5 and 69.9 mm, with the population being composed of two cohorts: C1, contributing 96.3% and C2 at 5.4% (Fig. 8a). In summer, autumn, and winter 2006, the resources showed sizes of 15.0-72.3, 6.5-67.5, and 14.5-69.6 mm, respectively. This year, 3 cohorts were seen (C1, C2, and C3). In summer, C1 accounted for 48.1%, C2 at 46.2%, and C3 for 5.7%. In autumn, C1 explained 38.0%, C2 42.6%, and C3 19.4%, while in winter, C1 contributed 44.5%, C2 49.5%, and C3 6.0% (Figs. 8b-d). For winter and spring 2009, sizes for *T. dombeii* were between 15.3-69.9 and 14.7-67.8 mm, with individuals assigned in 3 different cohorts (Figs. 8e-f). During winter, C1 contributed with 82.3%, C2 at 12.2%, and C3 at 5.4%, while in summer, C1 accounted for 47.7%, C2 36.2%, and C3 16.7%.

On the other hand, in March 2000, in the area where *T. dombeii* and *T. pannosa* cohabit (parallel to the shore, between 7-12 m depth), we observed the presence of reproductive and feeding aggregations of *T. chocolata* in groups of 50-150 ind, preying on these bivalves, mainly on *T. pannosa*. Aggregations were also observed in June and July.

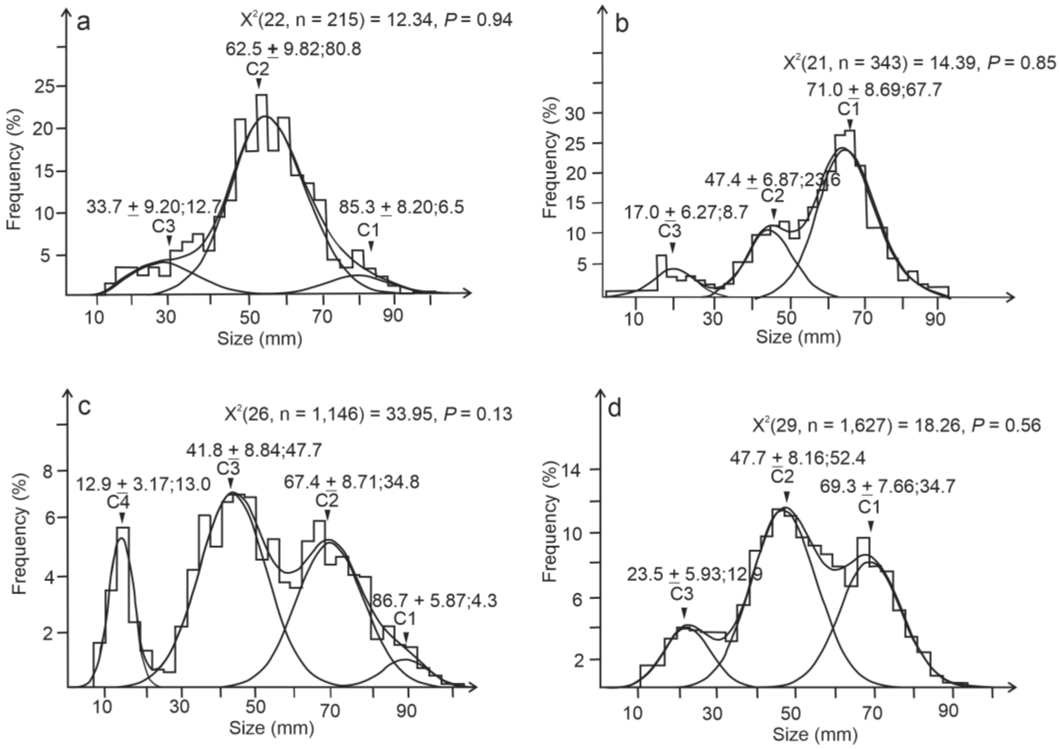

Figure 5. Size frequency distribution of the gastropod *Thaisella chocolata* for a) 1999, b) 2000, c) 2009, and d) 2013, with the components adjustment per cohort (Cn). Values indicate mean size ± standard deviation (mm); % cohort representation. The model fit equation is shown for each year.

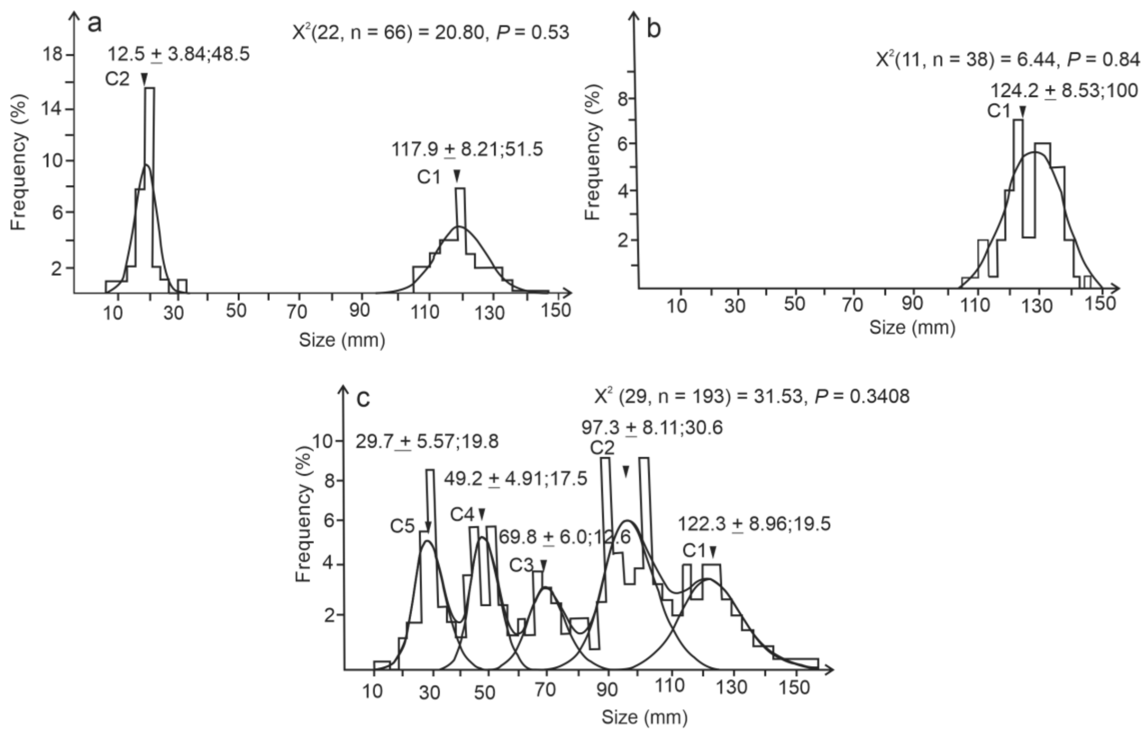

Figure 6. Size frequency distribution of the crab *Romaleon setosum* for a) 1999, b) 2000, and c) 2009, with the components adjustment per cohort (Cn). Values indicate mean size ± standard deviation (mm); % cohort representation. The model fit equation is shown for each year.

Table 3. Changes in density (abundance) and size (means ± standard deviation) for secondary resources in SS2 over the study period.

	2005			
	Spring		Summer	
	Density (ind m^{-2})	Size (mm)	Density (ind m^{-2})	Size (mm)
T. pannosa	2.49 ± 63.5	15.1 ± 2.9	29.6 ± 47.8	22.0 ± 5.5
T. dombeii	35.1 ± 44.0	55.5 ± 6.4	69.8 ± 66.8	41.8 ± 12.9
	2006			
	Autumn		Winter	
	Density (ind m^{-2})	Size (mm)	Density (ind m^{-2})	Size (mm)
T. pannosa	56.6 ± 167.2	8.3 ± 3.5	127.9 ± 235.0	8.8 ± 4.3
T. dombeii	52.7 ± 51.4	41.0 ± 15.7	30.8 ± 32.9	47.5 ± 11.9
	2009			
	Winter		Spring	
	Density (ind m^{-2})	Size (mm)	Density (ind m^{-2})	Size (mm)
T. pannosa	14.1 ± 32.8	16.2 ± 4.0	28.9 ± 8.2	11.7 ± 4.2
T. dombeii	36.7 ± 36.5	53.6 ± 10.1	27.1 ± 7.4	48.7 ± 13.4

DISCUSSION

Previous studies by Ortiz et al. (2009, 2010) have reported that *A. purpuratus* is preyed on by *T. chocolata*, *R. setosum*, and *O. mimus*. This last species also feeds on *R. setosum*, while *T. chocolata*, when aggregated in areas from 7 to 12 m depth, preys mainly on *T. pannosa* and, to a lesser extent, on *T. dombeii*, both of which are species of the same trophic level as *A. purpuratus* in the area.

Other organisms cohabiting in the reserve and considered as potential predators are the crustaceans *Metacarcinus edwardsii*, *Platymera gaudichaudii*, *Hepatus chiliensis*, *Paraxanthus barbiger*, *Eurypanopeus crenatus*, and *Pilumnoides perlatus*. The latter is an active predator of scallops postlarvae and seeds (Navarro et al. 1991, Avendaño et al. 2008b). Echinoderms are another important predator group in the area, including *Heliaster helianthus*, *Luidia magellanica*, and *Meyenaster gelatinosus.*

The density and size structure estimated in this work corroborated the presence of two subsystems (SS1 and SS2) previously described by Ortiz et al. (2009), with an assemblage of commercial (*T. chocolata*, *R. setosum*, *T. pannosa*, *T. dombeii*) and non-commercial species interacting with *A. purpuratus*, primarily through predator-prey relationships (Ortiz et al. 2009, 2010).

Previous physicochemical and biological data have allowed us to characterize this MPA and the conditions contributing to sustaining resource populations (Avendaño & Cantillánez 2008).

Our data show that *T. chocolata* is distributed between 5 and 22 m depth, with a greater abundance at 7-12 m, over coarse and fine sand, near SS2, where *T. pannosa* and *T. dombeii* (bivalves) are found, which serve as prey for this gastropod during reproductive periods (Avendaño et al. 1997, 2023b), as observed in 2000. Densities of *T. chocolata* increased from 0.21 ind m^{-2} in 1999 to 1.01 ind m^{-2} in 2013. In addition, the proportion of individuals above the minimum legal size went from 39.1% in 2009 to 43.7% in 2013, suggesting low anthropogenic intervention, such as illegal fishing, recognized as a threat to the primary resource (Avendaño et al. 2017, Avendaño & Cantillánez 2022b).

On the other hand, the permanent presence of juveniles of *T. chocolata*, represented by small cohorts, evidence the retention of larvae and the subsequent settlement of postlarvae in the area, adding new pre-recruits to the population (Cantillánez 2000, Avendaño et al. 2007, Cantillánez et al. 2011).

The crab *R. setosum*, distributed between 5 and 27 m depth, showed a marked increase in its mean density. Its size structure during the study period shows the contribution of pre-recruits, as was the case with *T. chocolata*, which indicates the reserve's positive effects on these species.

The cephalopod *O. mimus* was only recorded in 1999 in SS1 (distribution area of the primary resource),

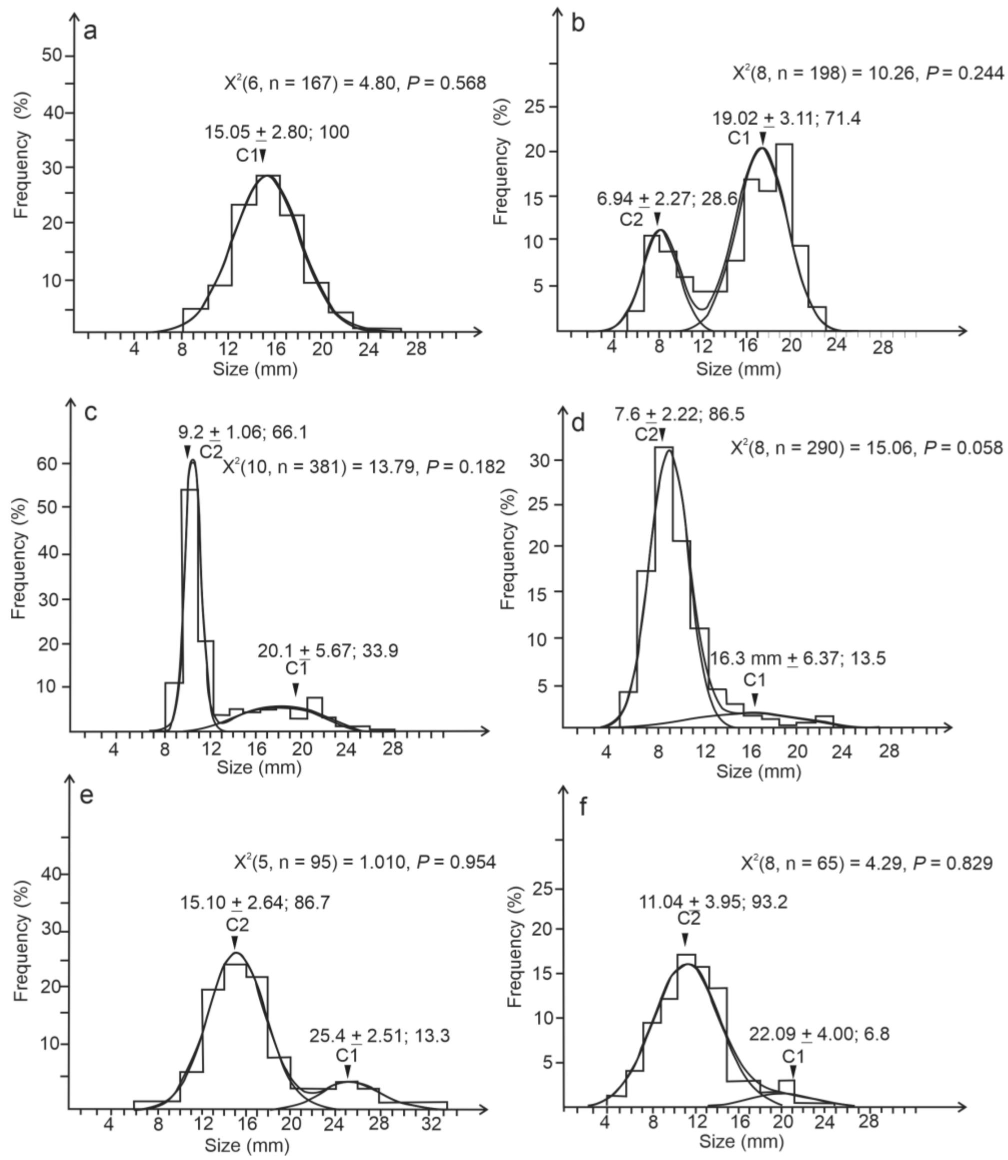

Figure 7. Size frequency distribution of the bivalve *Transennella pannosa* for a) spring 2005, b) summer, c) autumn and d) winter 2006, and e) winter and f) spring 2009. Values of the components adjustment per cohort (Cn) indicate mean size ± standard deviation (mm); % cohort representation. The model fit equation is shown in each case.

immediately after the ENSO 97-98 event (Cantillánez 2000), with juvenile specimens with an average weight of 493 g. Therefore, we hypothesize that SS1 is a breeding habitat for the species under warmer conditions. Higher temperatures may result in a shorter larval cycle and increased survival, as with *A. purpuratus* (Cantillánez et al. 2007). Reports on *O. mimus* fishery in Peru show increased landings during and after ENSO events (Arntz & Valdivia 1985, Carbajal et al. 2001). In northern Chile, catches are recorded almost exclusively after these events (Parada et al. 2013).

The variability observed in *T. pannosa* numbers in 2009 could be explained by increased *T. chocolata* abundance (Cantillánez et al. 2011). *T. pannosa* is not commercially exploited in Chile, and the reserve has no extraction records. Despite the recorded decrease in density during the winter of 2009, Ortiz et al. (2015) note that *T. pannosa* is the most abundant species in SS2, constituting 39.81% of the total benthic invertebrate biomass. The presence of pre-recruit cohorts reflects the reserve's capacity for larval retention and settlement (Avendaño et al. 2008c).

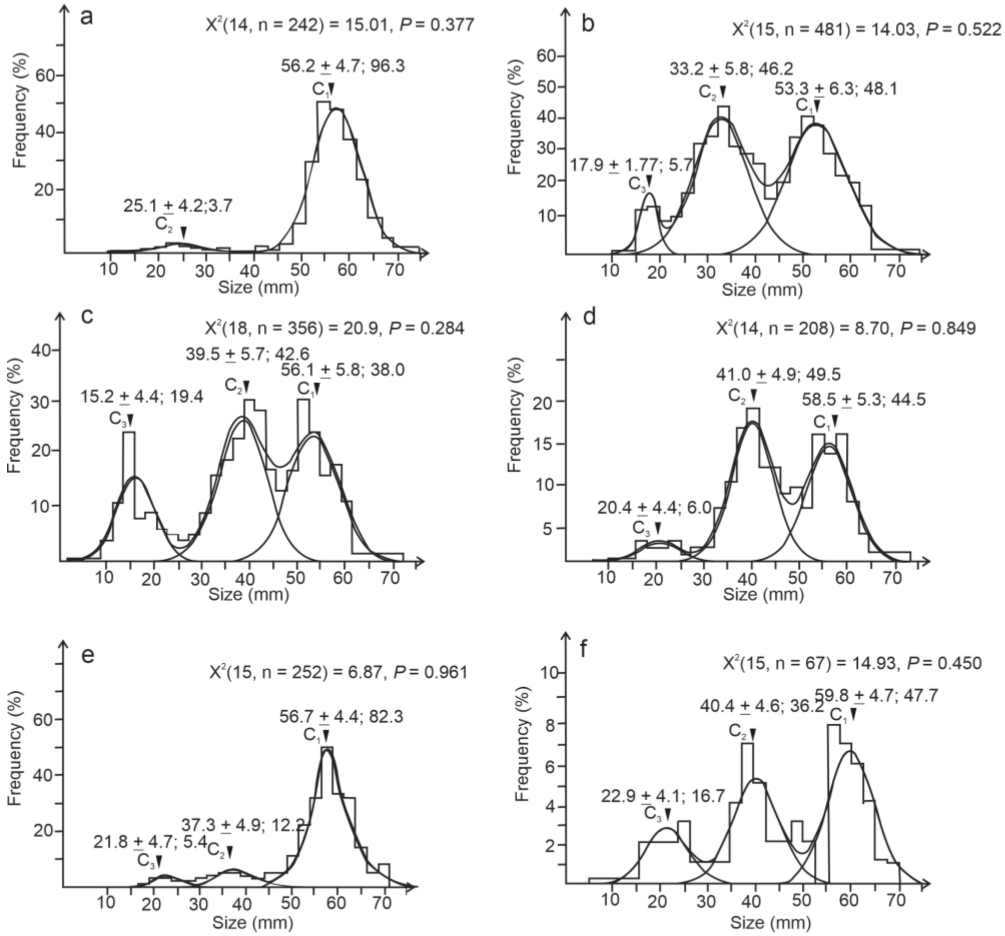

Figure 8. Size frequency distribution of *Tagelus dombeii* for a) spring 2005, b) summer, c) autumn and d) winter 2006, and e) winter and f) spring 2009. Values of the components adjustment per cohort (Cn) indicate mean size ± standard deviation (mm); % cohort representation. The model fit equation is shown in each case.

The hard razor clam *T. dombeii* is not subject to exploitation or illegal extraction (Ortiz et al. 2009), so the observed decrease in its abundance could be attributed to natural mortality, natural fluctuations in recruitment or predation, mainly by *T. chocolata*, and potentially by *Mobula tarapacana*, a ray observed on one occasion in the area. However, the diet of this animal primarily focuses on small fish and planktonic crustaceans (Bustamante 2022). The presence of early life stages suggests, as for the other resources, the capacity of the reserve to promote pre-recruitment.

As previously mentioned, the main goal of La Rinconada Marine Reserve is the conservation and sustainable use of *A. purpuratus* and, more broadly, any hydrobiological resources of commercial interest, considering factors such as genetic diversity, life cycle, as well as availability of substrates and favorable habitats, and oceanographic and ecological conditions (SUBPESCA 1997). However, an effectiveness analysis conducted in 2009 (Avendaño et al. 2010), applying three biophysical indicators (Avendaño & Cantillánez 2016) defined by Pomeroy et al. (2006), showed that neither the density nor the size structure of the primary resource had been improved. On the contrary, the analysis showed a decline in its population, which affects the availability of reproductive adults and seeds, hindering the achievement of the MPA's objectives (Avendaño & Cantillánez 2016, Avendaño et al. 2023a). Despite the above, our results showed positive effects for other coexisting resources (named here as secondary resources).

The results presented here for La Rinconada Marine Reserve showed positive effects at the community level, with the two subtidal systems containing diverse species. Except for the primary resource, no anthropic disturbances that alter the structure and complexity of benthic assemblages have been detected. This supports the role of MPAs as critical tools for the conservation of biodiversity and the functioning of ecosystems, with implications for the critical ecosystem services they provide.

In this case, our findings showed effective settlement and recruitment over the years and, consequently, the capacity of resource populations to persist.

Here, we offered a preliminary inventory (Table 1) of community composition, recognizing the need for further monitoring and evaluation. Despite this, new information is provided, adding to the background supplied by Avendaño et al. (2008a) and Ortiz et al. (2009, 2010) for both subsystems identified in the area.

Previous research cited here describes interspecific interactions, primarily feeding relationships, but other relevant ecological interactions may well be integrated into a framework to deepen our knowledge of the reserve (Avendaño et al. 2008a).

Within the effects propagated as a consequence of disturbances over different variables analyzed with Mixed Trophic Impact models (ECOPATH II MTI routine) (Avendaño et al. 2008a, Ortiz et al. 2009, 2010), it is observed that *A. purpuratus*, *T. chocolata*, and *Cancer* spp. are the species (variables) that generate the most remarkable changes in the system, standing out the consequences arising from perturbations on the asteroid *Luidia magellanica*, crustaceans (*Cancer* spp.) and Rhodophyta (dominated by *R. corallina*), with significant impacts in the other components. *R. corallina* is known to be important in the reserve's food web.

Finally, the data presented on the distribution, abundance, and size structure of La Rinconada Marine Reserve secondary resources and an inventory of the area's biodiversity may contribute to evaluating the reserve's long-term performance. This information can complement the current criteria, accounting for monitoring the state of the commercial resource of primary interest (scallops), the community, and the ecosystem, approaching conservation and management holistically.

Credit author contribution

M. Avendaño: formal analysis, funding acquisition, investigation (lead), methodology (lead), writing-original draft (lead), writing-review and editing (lead); M. Cantillánez: formal analysis, funding acquisition (lead), investigation (lead), methodology (lead), writing-review and editing, software (equal), writing-review and editing (supporting).

Conflict of interest

The authors declare no conflict of interest.

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