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Gastropods (Mollusca) of the priority marine region to conserve biodiversity No. 31 “Tlacoyunque”, Mexico, associated with the rocky intertidal

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Gastropods (Mollusca) of the priority marine region to conserve biodiversity No. 31 "Tlacoyunque", Mexico, associated with the rocky intertidal

Abstract

Mexico has 70 priority marine regions to conserve biodiversity, three located in the state of Guerrero and have large areas with rocky intertidal, which is one of the most structurally complex and diverse habitats in the marine environment. This research examined ecological characteristics of gastropods, which inhabit the rocky intertidal zone of the Marine Region 31, considering richness, abundance, local geographic distribution, hierarchical distribution, species diversity, and the similarity between sites. Gastropods collected in 2015, 2016, and 2018 were analyzed in nine sites. Per site, an area of 10 m^2 was sampled. 103 species were identified. An inventory completeness of 78.41 % to 89.40 % was estimated. In five families, 52.42 % of the species richness and 84.8 % of the abundance were estimated. Nine species are new records for Guerrero. The value of H' was 4.57 bits/individuals and J' was 0.684. 38 species were dominant and 53 occasional. This research reports the greatest richness of gastropods in the rocky intertidal zone of Marine Region 31, increasing the list from 216 to 236 species. Sites with a more heterogeneous habitat, greater stability, and less exposure to waves showed greater richness, diversity, and abundance. Therefore, they must be prioritized for the protection and conservation of the biodiversity and ecosystem.

Key words: Gastropoda, community, mollusks, new records, hierarchical distribution, similarity.

Introduction

The rocky intertidal zone is one of the most diverse habitats in the marine environment, in which there are different microenvironmental conditions conducive to the establishment of a great

diversity of invertebrates. The rocky environment intertidal persists for a long time, so it can be considered as a system with temporary stability (Tait and Dipper 1998; Vassallo et al. 2014).

Many species of marine gastropods are permanent or occasional inhabitants of the rocky environment and can be used as bioindicators of pollution or to determine the degree of environmental stress (Ramírez 2009). On the other hand, they are also a resource that provides a supply of high quality protein and economic income. As with any natural resource, it must be managed and used in harmony with nature. For this to be possible, studies must be conducted to evaluate biodiversity in order to support sustainable management and the recovery of species and their habitat (Ríos-Jara et al. 2008).

Among some works carried out on the American Pacific coast that provide information on diversity and abundance, as well as on seasonal, spatial, and biogeographic patterns in marine mollusks, including information on the class Gastropoda, are those of Keen (1971), Aldea and Rosenfeld (2011), Nieto-Bernal et al. (2013), Ojeda et al. (2014), Tejada-Pérez et al. (2018) and Sánchez et al. (2020).

In Mexico, in addition to reports in different regions of the Mexican Pacific, which have generated illustrated guides exclusively for the class Gastropoda (González-Villarreal 2005; Penagos-García 2013), inventories have been carried out in coastal areas of the Gulf of California, Sinaloa, Jalisco, Colima, Michoacán, and Oaxaca (Contreras et al. 1991; Villarroel et al. 2000; Hendrickx and Brusca 2002; López-Uriarte et al. 2009; Ríos-Jara et al. 2009, 2020; Landa-Jaime et al. 2013; Flores-Rodríguez et al. 2014; Hendrickx et al. 2019). Likewise, there are studies that analyze the biogeographic scope (Ríos-Jara et al. 1996; Olabarría and Vega 2000), space-time variation (González-Medina et al. 2006), community composition and structure (Tripp-Quezada et al. 2018), and commercial importance and exploitation (Ríos-Jara et al. 2008).

By contrast, in the coasts of the state of Guerrero, studies on mollusks, where reference is made to the class Gastropoda, have generated systematic lists, and aspects of community

composition, relative abundance, density, diversity, and zonation have been addressed (Flores-Rodríguez et al. 2007; Barba-Marino et al. 2010; Flores-Garza et al. 2011, 2014; Torreblanca-Ramírez et al. 2012, 2017; Castrejón-Ríos et al. 2015; Ahumada-Martínez et al. 2016; Cerros-Cornelio et al. 2017). New records have been documented in the geographic distribution (Torreblanca-Ramírez et al. 2014a; Flores-Garza et al. 2018), and studies have been conducted on species with commercial importance and economic potential (Flores-Garza et al. 2012a; Torreblanca-Ramírez et al. 2014b; Castro-Mondragón et al. 2016; Galeana-Rebolledo et al. 2018), as well as analyses on reproduction and fisheries (Castrejón-Ríos et al. 2022; Cerros-Cornelio et al., 2025).

Priority Marine Region 31 (Tlacoyunque) is an area located in Costa Grande of the state of Guerrero, with a great deal of influence from tourism, agriculture, and livestock farming. Because of this, it is under pressure, making it extremely important to carry out studies for the conservation of natural resources, especially if it is a region classified as a priority for the conservation of biodiversity. Studies, carried out in different sites of this region, reported inventories of marine gastropods, which include aspects of ecological relevance, address the relationship of the association of mollusks with marine macroalgae, the report of new records, and report the species composition of commercially important mollusks, as well as economic and social aspects of coastal fishermen (Salcedo-Martínez et al. 1988; Flores-Rodríguez et al. 2012; Aguilar-Estrada et al. 2017; Cerros-Cornelio et al. 2017, 2021; Barrientos 2018; Gama-Kwick et al. 2021).

However, knowledge of this marine region is still elementary even though it is a region with a high diversity, which makes it a priority for conservation. Therefore, the present study aimed to analyze the composition of the Gastropoda class associated with the rocky intertidal zone of PMR 31 (Tlacoyunque), considering the richness, diversity, abundance, and hierarchical distribution of species, and similarity between sites.

Material and methods

Study area

The Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO) delimited 70 Priority Marine Regions (PMRs) for Mexico, which arose from the need to conserve biodiversity. Three PMRs (31, 32, and 33) are located on the coast of the state of Guerrero. The problem in PMR 31 is the lack of knowledge regarding species diversity and conservation, sea turtle smuggling, the introduction of exotic species, as well as the lack of knowledge on current regulations for the sustainable use of resources (Arriaga et al. 1998).

The present study was conducted at nine sites with rocky shoreline, distributed over 83 linear km of coastline in PMR 31 (17°40'12" to 17°13'48" N, 101°43'12" to 101°1'48" W) located in Costa Grande, Guerrero; Mexico (Fig. 1). The selection of the sampled sites was made considering spatial heterogeneity, as well as how easy the access to these sites was. Each site was georeferenced and classified according to its exposure to waves, and type and stability of the substrate, taking as a reference the criteria of Flores-Garza et al. (2012b). Finally, the rock type was determined according to the descriptions of the geological chart of the Instituto Nacional de Estadística, Geografía e Informática Costa Grande E14-7, 1:50 000 (INEGI 2021) and field observations (Table 1).

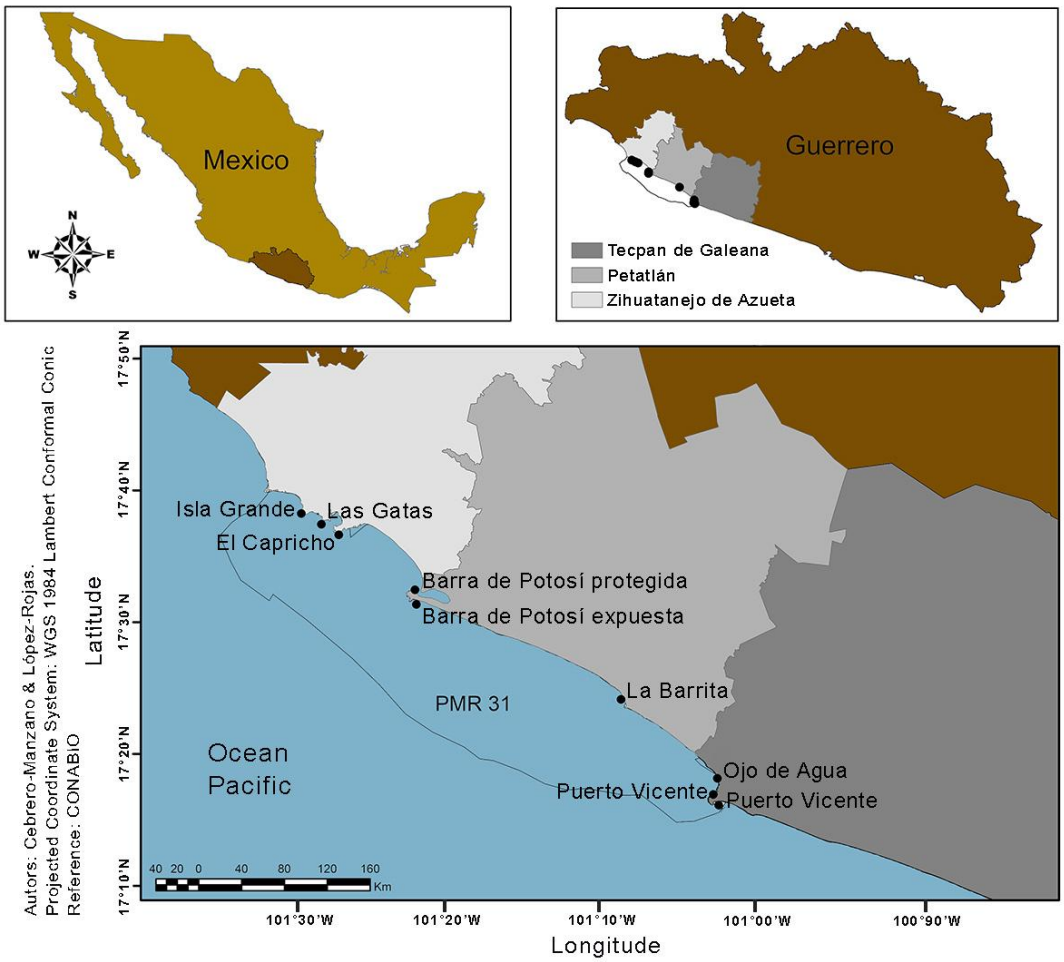


Fig. 1 Geographic location of the collection sites in the rocky intertidal zone of PMR 31, Guerrero, Mexico.

Table 1 Geographical location and the most relevant characteristics of the habitat in the sampled sites.

Sites	Coordinates	Type of rock and substrate	Substrate stability	Wave Exposure
Isla Grande	17º40’36.86’’N 101º39’16.78’’W	Sedimentary rocks. Substrate of rock masses, blocks and boulders. It presents complex relief due to the high number of cracks.	Middle	Low
Las Gatas	17º37’17.52’’N	Metavolcanic rocks from the	Middle	Low

	101º33’14.26’’W	Lower Cretaceous Ki, with porphyritic andersites, volcaniclastic deposits. Boulders and rock masses, with intermediate breccia and tuffs.		
El Capricho	17°37’23.53’’N 101°32’50.74’’W	Metamorphic rocks. Boulders and rock masses	Middle	Low
Barra de Potosí Protegida	17º40’36.86’’ N 101º39’16.78’’ W	Metamorphic metavolcanic rocks from the Lower Cretaceous. Smooth boulders, less than a meter in diameter.	Middle	Middle
Barra de Potosí Expuesta	17º31’43.51’’ N 101º27’08.22’’W	Some boulders, mostly blocks and rock masses.	High	High
La Barrita	17º24’32.74’’ N 101º10’51.36’’W	Rock masses, some blocks and boulders, which together form tide pools.	High	Middle
Ojo de Agua	17º18’01.80’’ N 101º03’05.83’’W	Rock masses and boulders that form tide pools.	High	Middle
Puerto Vicente Guerrero	17º16’34.29’’ N 101º03’19.27’’W	Rock masses, some blocks, boulders, gravel and sand.	High	Middle
Piedra de Tlacoyunque	16°19’35.49’’N 98°34’12.65’’W	Blocks, discontinuous rock masses and sandy areas between them.	High	High

Gastropod samples, obtained in 2015, 2016, and 2018 from the nine sites, were analyzed. Sampling was conducted at low tide and on new moon days. An area of 10 m^2 was sampled for each site. The type of sampling was systematic (Scheaffer et al. 1987). The starting point of the sampling was selected randomly using a 30 m long rope, which was placed parallel to the coast over the intertidal zone, defining the sampling area. The collection unit was 1 m^2, which was delimited by a frame made of PVC pipes. All specimens found alive within the sampling unit were collected. After collecting the first sampling unit, a space of 2 m was left following the rope, and the frame was placed. This procedure was repeated until 10 replicates were completed. At the end of the sampling, the collected specimens were identified; only some specimens, where there were doubts of identification, were preserved in 96% ethyl alcohol and transferred to the laboratory. Conchyliological identification, nomenclatural updating, and analysis of their geographic

distribution of the species were carried out using specialized literature and databases such as: Keen (1971), World Register of Marine Species (WoRMS 2025), Global Biodiversity Information Facility (GBIF 2025) and Discover Life (2025).

Data analysis

Species richness (observed) was considered as the number of gastropod species present, and the expected species richness was estimated using the Chao 1 and 2 and Jackknife 1 and 2 estimators and compared against the observed richness in order to assess how complete the inventory carried out in the region was.

Abundance was considered as the number of organisms of each species, and relative abundance was considered as the percentage of organisms of each species with respect to total abundance. The degree of occurrence of the species (hierarchical location) was determined by the Olmstead-Tukey correlation method, represented by quadrats (Sokal and Rohlf 1995). This method uses the calculation of two estimators: one is the average of the species abundances, transformed using Log +1, and the other is the average frequency of occurrence of the species calculated as a percentage, which consists of averaging the percentage of the number of samples in which each species is present. The dominant species (D) was classified as the one whose relative abundance and frequency of occurrence values exceeded the average calculated from both estimators. Species, whose abundance value did not exceed the value of the estimator for abundance but exceeded the value calculated for frequency of occurrence, were classified as constant species (C). Numerous little frequent (NLF) were those whose abundance value was greater than the average estimated abundance value, and the frequency of occurrence value did not exceed the average estimated value for this variable. Finally, occasional species (O) were those whose abundance value and frequency of occurrence did not exceed the arithmetic mean estimated for frequency of occurrence and abundance (Flores-Garza et al. 2012).

Species diversity was determined by applying the Shannon-Wienner index (H') using $\log_2$, and evenness was evaluated using the Pielou evenness index (J'). To examine similarity, based on abundance and species richness among sampling sites, a cluster grouping analysis was performed using the Bray-Curtis index (transforming data to log + 1), and to identify the species responsible for the clustering pattern based on average similarity within the group, a SIMPER similarity percentage analysis was used, both analyses were performed using the statistical program PRIMER V6 (Clarke and Gorley 2001).

Results

A total of 10,272 specimens were collected, of which 103 species included in 59 genera, and 35 families were identified. The species richness estimated was 115.25 by Chao 1, 118.36 by Chao 2, 126.1 by Jackknife 1, and 131.36 by Jackknife 2, so that, according to the results of observed species richness, completeness is estimated in the range of 78.41 % (Jackknife 2) to 89.40 % (Chao 1).

Five families accounted for 52.42 % of the species richness (Columbellide13.59 %, Fissurellidae 11.65 %, Muricidae 10.67 %, Calyptraeidae 8.73 %, and Lottiidae 7.76 %). There were 18 families represented by one species. By site, the highest species richness was found in Ojo de Agua (83 species), followed by La Barrita (64 species). The lowest species richness (13 species) was recorded in Las Gatas (Table 2).

Table 2 Families, species, abundances, and degree of occurrence of the Gastropods associated with the rocky intertidal zone of the PMR 31 (Tlacoyunque).

Families/ Species	**Abundance**									**n/s**	**d/o**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		
Fissurellidae											
Diodora digueti (Mabille, 1895)							3			3	O
Diodora alta (C. B. Adams, 1852)							1			1	O
Diodora inaequalis (G. B. Sowerby I, 1835)							8			8	O

Fissurella morrisoni J.H. McLean, 1970	2						3	3		8	O
Fissurella asperella G. B. Sowerby I, 1835	2		5	4		8	2		8	29	D
Fissurella decemcostata J.H. McLean, 1970		2						1		3	O
Fissurella gemmata Menke, 1847				2	25	22	9	28	68	154	D
Fissurella microtrema G. B. Sowerby I, 1835			4			1	1		4	10	C
Fissurella nigrocinta P. P. Carpenter, 1856	37			65	51	46	17	54	81	351	D
Fissurella obscura G. B. Sowerby I, 1834						1	2			3	O
Fissurella rubropicta Pilsbry, 1890		1	2				1			4	O
Fissurella spongiosa P. P. Carpenter, 1857	1							1		2	O
Tegulidae											
Agathistoma globulum (P. P. Carpenter, 1857)			146	76	38	117	213	756		1346	D
Trochidae											
Monilea patricia (R. A. Philippi, 1851)			27			3	4	32		66	D
Areneidae											
Arene hindsiana Pilsbry & H. N. Lowe, 1932					1					1	O
Turbinidae											
Uvanilla unguis (W. Wood, 1828)	2		13			2				17	NLF
Uvanilla olivacea (W. Wood, 1828)							7		1	8	O
Phasianellidae											
Eulithidium perforatum (R. A. Philippi, 1849)	2					2	1			5	O
Eulithidium tessellatum (Potiez & Michaud, 1838)						1				1	O
Lottiidae											
Lottia pediculus (R. A. Philippi, 1846)	6		27			1	30	18		82	D
Lottia mitella (Menke, 1847)	6			5	17		14	7	29	78	D
Lottia mesoleuca (Menke, 1851)			5	1	6	53	9	10		84	D
Lottia acutapex (S. S. Berry, 1960)			2		11		3		36	52	D
Lottia fascicularis (Menke, 1851)		75	85	58	19	216	85	231		769	D
Lottia discors (R. A. Philippi, 1849)				187	31	23	57	425		723	D
Lottia strongiana (Hertlein, 1958)	15				1	35		1		52	D
Lottia dalliana (Pilsbry, 1891)						20	2			22	NLF
Eoacmaea semirubida (Dall, 1914)						2	1			3	R
Neritidae											
Nerita scabricosta Lamarck, 1822	6			2			32	21	1	62	D
Nerita funiculata Menke, 1851							15		1	16	O

Littorinidae										
Echinolittorina aspera (R. A. Philippi,1846)	3			6	3	14	8		34	D
Echinolittorina modesta (R. A. Philippi, 1846)					1	2			3	O
Rissoinidae										
Rissoina stricta (Menke, 1850)					1	2	2		5	O
Turritellidae										
Vermicularia frisbeyae J. H. McLean, 1970					1				1	O
Cerithiidae										
Cerithium gallapaginis A. Adams, 1855					87	7			94	NLF
Bittium watsoni (Jeffreys, 1885)					1	3			4	O
Cerithium menkei P. P. Carpenter, 1857					8				8	O
Planaxidae										
Supplanaxis obsoletus (Menke, 1851)			1	1		3			5	O
Epitoniidae										
Epitonium cookeanum Dall, 1917					1	1			2	O
Eulimidae										
Melanella townsendi Bartsch, 1917						1			1	O
Hipponicidae										
Hipponix panamensis (C. B: Adams, 1852)		1		3	4	13			21	D
Hipponix delicatus Dall, 1908		6		6		10			22	NLF
Pilosabia trigona (Gmelin, 1791)				1	2	7	22	1	33	D
Calyptraeidae										
Bostrycapulus aculeatus (Gmelin, 1791)						1	10		11	O
Crepidula excavata (Broderip, 1834)							3		3	O
Crepidula incurva (Broderip, 1834)		51	15	2		3			71	D
Crepidula striolata Menke, 1851		3				3			6	O
Crucibulum umbrella (Deshayes, 1830)	13			13	1	4		23	1	55	D
Crucibulum subactum S. S. Berry, 1963			1	4					5	O
Crucibulum scutellatum (W. Wood, 1963)			2						2	O
Crucibulum concameratum Reeve, 1859			1	2		5			8	O
Trochita trochiformis (Born, 1778)	1				40	21	5		67	D
Triviidae										
Niveria pacifica (G. B. Sowerby II, 1832)						1			1	O
Cypraeidae										

Macrocypraea cervinetta (Kiener, 1844)			1			5	3			9	O
Pseudozonaria arabicula (Lamarck, 1810)	1		1		1	1	11	1		16	C
Ovulidae											
Jenneria pustulata (Lightfoot, 1786)						1	1			2	O
Cymatiidae											
Monoplex vestitus (Hinds, 1844)							1			1	O
Turritriton gibbosus (Broderip, 1833)							1			1	O
Cassidae											
Cypraecassis coarctata (G. B. Sowerby I, 1825)						2	1			3	O
Muricidae											
Acanthais brevidentata (W. Wood, 1828)					1	3	7	4		15	C
Penethais triangularis (Blainville, 1832)	75	36	9	100	113	80	91	360	40	904	D
Vasula speciosa (Valenciennes, 1832)	14	16	2	8	6	30	133	3	7	219	D
Vasula melones (Duclos, 1832)							1			1	O
Plicopurpura columellaris (Lamarck, 1816)	56	3			6	70	87	117	23	362	D
Stramonita biserialis (Blainville, 1832)	10	6	7	47	188	72	71	17	22	440	D
Zetecopsis zeteki (Hertlein & A. M. Strong, 1951)							1			1	O
Vitularia salebrosa (P. P. King, 1832)						1				1	O
Homalocantha oxyacantha (Broderip, 1833)								1		1	O
Tripterotyphis fayae (Keen & G. B. Campbell, 1964)						2				2	O
Trachypollia lugubris (C. B. Adams, 1852)	4	7	11	2	4	9	29	28	2	96	D
Mitridae											
Strigatella tristis (Broderip, 1836)	4					2	11			17	NLF
Neotiara rupicola (Revee, 1844)			3							3	O
Pisaniidae											
Gemophos sanguinolentus (Duclos, 1833)	4		6	2	13	33	75	72	1	206	D
Engina tabogaensis Bartsch, 1931	8		4			3	1			16	C
Engina pulchra (Reeve, 1846)								38	1	39	NLF
Columbellidae											
Columbella aureomexicana (F. B. Howard, 1963)	17			6		4	2	1		30	D
Columbella fuscata G. B. Sowerby I, 1832			28	63	147	544	622	53	19	1476	D
Columbella major G. B. Sowerby I,	30		5			1	32			68	D

1832											
Columbella sonsonatensis (Mörch, 1860)	6					2	2	12		22	D
Cosmioconcha palmeri (Dall, 1913)	4			36	6	11	6			63	D
Anachis nigrofusca P. P. Carpenter, 1857	23		36	2	1	37	7	5		111	D
Anachis menaletta (Duclos, 1846)						2	2			4	O
Anachis scalarina (G. B. Sowerby I, 1832)							3			3	O
Anachis spadicea (R. A. Philippi, 1846)								1		1	O
Mitrella ocellata (Gmelin, 1791)			32	1	50	89	204	383	24	783	D
Mitrella xenia (Dall, 1919)	2		8		39	51	114	108		322	D
Mitrella baccata (Gaskoin, 1852)							4			4	O
Parvanachis pygmaea (G. B. Sowerby I, 1832)	4									4	O
Mazatlania fulgurata (R. A. Philippi, 1846)						2	1			3	O
Fasciolariidae											
Leucozonia cerata (W. Wood, 1828)			11		1	18	75	32		137	D
Opeatostoma pseudodon (Burrow, 1815)	5		1	1		52	7	18		84	D
Harpidae											
Morum tuberculosum (Reeve, 1842)						1	3	1		5	O
Olividae											
Olivella dama (W. Wood, 1828)							1			1	O
Cystiscidae											
Persicula imbricata (Hinds, 1844)							2			2	O
Conidae											
Conus purpuracens G. B. Sowerby I, 1833						1	7	1		9	O
Conus gladiator Broderip, 1833							24		2	26	NLF
Conus nux Broderip, 1833				1		12	21			34	NLF
Pseudomelatomidae											
Pilsbryspira garciacubasi Shasky, 1971	1					1				2	O
Crassispira cerithoidea (PP Carpenter, 1857)						1	5			6	O
Siphonariidae											
Siphonaria gigas G. B. Sowerby I, 1825	24	5	59	26		20	35	1		170	D
Siphonaria maura G. B. Sowerby I, 1835			30	1		14	30	13		88	D
Siphonaria palmata Carpenter, 1856			6	1		8	14	3		32	D
Trimusculidae											
Trimusculus stellatus (G. B. Sowerby I, 1835)							2			2	O
Total abundance	388	21	59	72	78	189	236	293	37	1027	

				2	6	6	6	1	
7	4	2	2						

1) Isla Grande; 2) Las Gatas 3) El Capricho; 4) Barra de Potosí Protegida 5) Barra de Potosí Expuesta; 6) La Barrita; 7) Ojo de Agua; 8) Puerto Vicente Guerrero; 9) Piedra de Tlacoyunque; n/s) Abundance by species; d/o) Degree of occurrence; D) dominant; C) common; NLF) numerous less frequent; O) occasional.

Five families accumulated 84.8 % of the abundance (Columbellidae 28.17 %, Muricidae 19.87 %, Lottiidae 18.12 %, Tegulidae 13.1 %, and Fissurellidae 5.6 %). The families with the lowest relative abundance were: Triviidae, Ranellidae, Olividae, Areneidae, and Cymatiidae, all with 0.01 %. The species with the highest relative abundance were *C. fuscata* (14.36 %), followed by *A. globulum* (13.10 %), and *P. triangularis* (8.80 %). Relative abundance greater than 1 % was observed in 16 species. The sum of the abundances of these 16 species together reached 82.48 %. The minimum abundance value occurred in 14 species (singletons), and eight were represented by two specimens (doubletons). By site, the highest abundance of gastropods was found in Puerto Vicente Guerrero (2934 specimens), followed by Ojo de Agua (2367 specimens), and La Barrita. The lowest abundance was recorded in Las Gatas (212 specimens).

Nine new gastropod records are reported for the state of Guerrero (Table 3), and 11 species extend their geographic range within the state (*E. semirubida*, *C. gallapaginis*, *M. townsendi*, *E. cookeanum*, *C. incurva*, *T. gibbosus*, *N. rupicola*, *A. gaskoini*, *A. spadicea*, *O. dama*, and *C. cerithoidea*), resulting in 20 new gastropod species records for PMR 31.

Table 3 New records for the State of Guerrero, known distributions and new distribution.

Species	States with registration of the species	References	Localities with new records of the species
D. alta	Jalisco, Colima y Nayarit	Ríos-Jara et al., 2002; Barrientos 2018.	Ojo de Agua
U.	Jalisco y Colima,	Ríos-Jara et al. 2002;	Ojo de Agua; Piedra de

olivacea	Oaxaca	Gonzales-Villarreal 2005; Bastida-Zavala et al. 2013.	Tlacoyunque
E. tessellatum	Isla Socorro, Revillagigedo, Manzanillo, Colima	Pagaza et al. 1994.	La Barrita
L. discors	Jalisco, Colima y Oaxaca	Contreras et al. 1991; Ríos-Jara et al. 2002; Flores-Rodríguez et al. 2012; Bastida- Zavala et al. 2013.	Barra de Potosí Protegida, Barra de Potosí Expuesta, La Barrita, Ojo de Agua, Puerto Vicente Guerrero
L. dalliana	Jalisco, Colima, Guaymas y Golfo de California	Ríos-Jara et al. 2002; Landa-Jaime et al. 2013; Hendrickx et al. 2019.	La Barrita, Ojo de Agua
V. frisbeyae	Oaxaca, Jalisco, Colima, Guaymas y Golfo de California	Rodríguez-Palacios et al. 1988; Ríos-Jara et al. 2002; Corgos et al. 2013; Michel-Morfín et al. 2013; Hendrickx et al. 2019.	La Barrita
M. baccata	Isla Socorro, Revillagigedo, Colima, Oaxaca, Jalisco y Colima	Pagaza et al. 1994; Bastida-Zavala et al. 2013; Corgos et al. 2013; Barrientos 2018.	Ojo de Agua
M. fulgurata	Jalisco y Colima	Ríos-Jara et al. 2002; Landa-Jaime et al, 2013; Gonzales-Villarreal 2005; Corgos et al. 2013.	La Barrita, Ojo de Agua
C. coarctata	Jalisco, Colima y Oaxaca	Ríos-Jara et al. 2002; Ríos-Jara et al. 2009; Barrientos 2018; Bastida- Zavala et al. 2013; Landa-Jaime et al. 2013.	La Barrita, Ojo de Agua

38 species were estimated to be dominant, four constant, eight numerous little frequent, and the occasional category was reached by 53 species. Within the dominant species, *A. triangularis*, *S. biserialis*, *T. lugubris*, *V. speciosa*, and all members of the family Muricidae occurred in 100 % of the sites and accounted for 3.8 % of the species richness and 16.15 % of the abundance. 26.21 % of the species richness (27 species) were observed as unique, and 21.35 % (22 species) were recorded as duplicates.

The Shannon-Wiener diversity index value (H') calculated for PMR 31 was H' = 4.57 bits/individual while the Pielou evenness or fairness index value (J') was 0.684. The site with the

highest species diversity index value was Ojo de Agua with H' = 4.39 bits/individual, and the site with the lowest value was Las Gatas with H' = 2.63 bits/individual. The highest equitability was estimated in Isla Grande (J' = 0.812) and the lowest in Vicente Guerrero (J' = 0.655) (Table 4).

Table 4 Species richness, abundance, diversity, and degree of occurrence of gastropods in the sites of the priority marine region 31 (Tlacoyunque).

Sitios	**S (%)**	**N (RA %)**	**H'**	**J'**	**D (%)**	**C (%)**	**ALF (%)**	**R (%)**
Isla Grande	32 (31)	388 (3.77)	4.06	0.812	23 (60.5)	2 (50)	2 (25)	5 (9.43)
Las Gatas	13 (12.6)	212 (2.06)	2.632	0.711	9 (23.7)	-	1 (12.5)	3 (5.66)
Capricho	34 (33)	596 (5.80)	3.891	0.765	23 (60.5)	3 (75)	1 (12.5)	7 (11.3)
Barra de Potosí Protegida	30 (39.1)	726 (7.06)	3.477	0.709	26 (68.4)	-	2 (25)	2 (3.77)
Barra de Potosí Expuesta	28 (27.2)	786 (7.65)	3.486	0.725	24 (63.1)	2 (50)	-	2 (3.77)
La Barrita	64 (62.1)	1891 (18.40)	4.148	0.691	34 (89.5)	4 (100)	5 (62.5)	21 (39.62)
Ojo de Agua	83 (80.6)	2367 (23.04)	4.399	0.69	36 (94.7)	4 (100)	6 (75)	37 (69.81)
Puerto Vicente Guerrero	45 (43.7)	2934 (28.56)	3.596	0.655	32 (84.21)	2 (50)	1 (12.5)	10 (18.86)
Piedra de Tlacoyunque	21 (20.4)	372 (3.62)	3.389	0.772	16 (42.1)	1 (25)	2 (25)	2 (3.77)
PMR 31	103	10272	4.577	0.684	38	4	8	53

S= species richness, N= abundance, RA= relative abundance, H'= diversity, J'= equity, D= dominant, C= constant, ALF= abundant little frequent, R= occasional.

According to the cluster analysis, using 50 % similarity, the formation of two groups was estimated. The first group was formed by the sites La Barrita, Ojo de Agua, and Puerto Vicente Guerrero, reaching a similarity of 64.36 %. In this group, 95.14 % of the total species richness of PMR 31 was observed (Fig. 2). 33 common species were found for the three sites and these contributed 90 % of the similarity. The second group consisted of the sites Tlacoyunque, Barra de Potosí Exposed, and Barra de Potosí Protegida, with an estimated similarity of 54.45 %. In this

group, 44.66 % of the species richness found for the entire PMR 31 was recorded. 11 common species were found in the sites composing this group, and they contributed 81 % of the similarity (Table 5). Of the total number of species recorded in the first group, 38 occurred at only one site, and, of the second group, 24 were recorded at only one site. The other sites (Isla Grande, Las Gatas, and Capricho) were located as isolated entities.

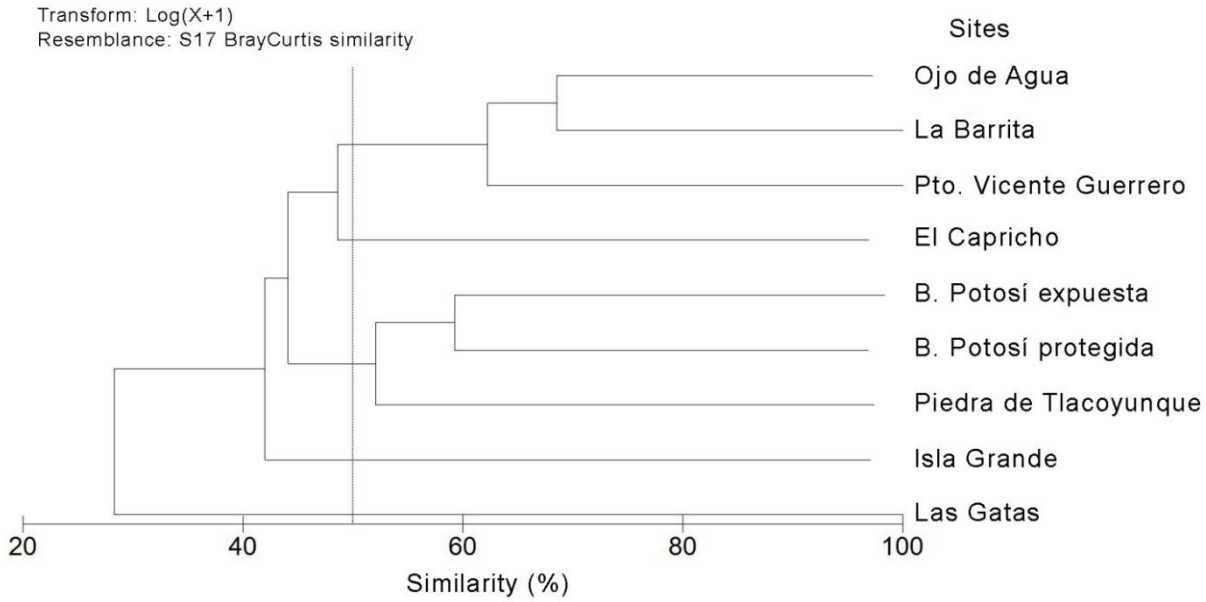


Fig. 2 Grouping dendrogram based on the Bray Curtis index, of the gastropod communities at the sites of PMR 31 (Tlacoyunque), Guerrero, Mexico

Table 5 Species that influence the grouping pattern based on average similarity within groups.

Group I La Barrita, Ojo de Agua, and Puerto Vicente Guerrero				**Group II Tlacoyunque, Barra de Potosí Expuesta, and Barra de Potosí Protegida**	
Dominant species	**%**	**Dominant species**	**%**	**Dominant species**	**%**
A. globulum	5.32	*T. trochiformis*	2.34	*F. nigrocinta*	12.81
L. fascicularis	5.14	*V. speciosa*	2.15	*P. triangularis*	12.63
M. ocellata	5.11	*A. nigrofusca*	2.01	*S. biserialis*	10.64
C. fuscata	5.03	*E. aspera*	1.77	*C. fuscata*	10.60
P. triangularis	4.75	*S. palmata*	1.75	*L. mitella*	6.90
P. columellaris	4.64	*M. patricia*	1.56	*V. speciosa*	6.3
M. xenia	4.49	*A. brevidentata*	1.56	*F gemmata*	5.87
G. sanguinolentus	4.04	*L. pediculus*	1.52	*M. ocellata*	4.99
L. discors	3.71	*P. trigona*	1.52	*T. lugubris*	3.49
S. biserialis	3.55	*S. gigas*	1.51	*A. globulum*	3.45
F. nigrocinta	3.48	*C. sonsonatensis*	1.18	*L. discors*	3.27
L. cerata	3.35	*N. scabricosta*	1.07		
S. maura	2.85	*R. stricta*	0.88		
T. lugubris	2.84	*C. aureomexicana*	0.88		
F. gemmata	2.80	*C. nux*	0.84		
O. pseudodon	2.57	*P. arabicula*	0.74		
L. mesoleuca	2.51				

%= percentage that contributes to the similarity.

Discussion

Reports of gastropod species, associated with the rocky intertidal zone in different localities of the Mexican Pacific, excluding the Guerrero coast, range from 26 to 87 species (Contreras et al. 1991; Esqueda et al. 2000; Ríos-Jara et al. 2006; Vega et al. 2008; Zamorano et al. 2008; Flores-Rodríguez et al. 2012; Landa-Jaime et al. 2013; Hendrickx et al. 2019).

In the state of Guerrero, the species richness of gastropods reported by Torreblanca-Ramírez et al. (2017) in PMR 32 (108 species), was slightly higher than that found in PMR 31. Other

studies, carried out in the state, not located in PMR 31, report species richness values of 34 to 67 species (Flores-Rodríguez et al. 2007; Barba-Marino et al. 2010; Flores-Garza et al. 2011; Torreblanca-Ramírez et al. 2012). Within the geographical limits of PMR 31, but different site and sampling area (subtidal, intertidal, sandy, rocky and coral), the works of Salcedo-Martínez et al. (1988) and Barrientos (2018), report the finding of 122 and 70 species, respectively. Other research conducted exclusively in the rocky intertidal of PMR 31, including those addressing only one family of marine gastropods, report species richness ranging from 10 to 55 (Flores-Rodríguez et al. 2012; Aguilar-Estrada et al. 2017; Cerros-Cornelio et al. 2017; Barrientos 2018; Gama-Kwick et al. 2021). 24 species of gastropods caught by artisanal fisheries were also reported (Cerros-Cornelio et al. 2021).

The report of species richness in this research is only surpassed by the work of Salcedo-Martínez et al. (1988); however, they cover more habitat types in their study. Currently, this work reports the highest species richness recorded in the rocky intertidal zone of PMR 31 and increases the list of marine gastropods recorded in Guerrero from 216 to 236 species, including 11 new additions for PMR 31 and nine for the state of Guerrero.

Different works have analyzed the use of non-parametric estimators of species richness, the results are diverse and depending on the taxon or group analyzed, the bias and precision of these vary; nonetheless, they are still a good indicator to evaluate the sampling effort and completeness of the inventory (Escalante 2003; González-Oreja 2010; Bautista-Hernández et al. 2013). We used four of the most recommended, and the analysis of the inventory found and the sampling effort signaled that at least 78% (Jackknife 2) of estimated species were reached, indicating that the sampling effort carried out in this research achieved a good representativeness of species.

Regarding the species richness and abundance of the gastropod families that have been reported as best represented in the rocky intertidal zone of Oaxaca and Guerrero, they are similar to those reported in this work (Flores-Garza et al. 2011; Flores-Rodríguez et al. 2012; Torreblanca-

Ramírez et al. 2012, 2017) although they may present another arrangement, but the families Columbellidae and Muricidae always occupy the first two places in richness and abundance. At other latitudes, such as Venezuela, the most representative families in terms of species richness are also reported to be Fissurellidae, Muricidae, and Columbellidae (Capelo et al. 2014). It was observed that variations in richness and abundance depend on the conditions of wave exposure and substrate stability. In this regard, Tait and Dipper (1998) reported that each level of the intertidal is occupied by different species; each species predominates in a certain zone where conditions are more favorable. Outside this zone, the number of specimens is reduced because environmental conditions are less appropriate, and other competing species are better adapted to these conditions.

The number of families found in this work is similar to that found by Landa-Jaime et al. (2013) for Jalisco, and slightly higher than that reported by Torreblanca-Ramírez et al. (2014b) and Flores-Garza et al. (2011) for PMR 32. In other latitudes, Fernández and Jiménez (2006) found 18 families and 41 species. This study reports an important number of new records of gastropod species for the state of Guerrero, as well as for PMR 31.

Substrate heterogeneity as an aspect promoting a wide range of species richness has already been mentioned by classic works such as Spight (1977), Brusca (1980), Levinton (1982) and Tait and Dipper (1998). In addition, this research focused exclusively on the inventory of a single taxonomic group, but, due to the characteristics of the sampling method and the meticulous review at each of the sites, a significant number of small organisms were recorded. Some authors consider that, in order to obtain a more complete species inventory, more considerable efforts are required in the search for less conspicuous species and those of smaller size, such as micromollusks, and for a more exhaustive inspection of the sampling areas (Ríos-Jara et al. 2020; Gama-Kwick et al. 2021). Likewise, Lozano-Guzmán et al. (2020), recommend carrying out more faunistic reviews of these and other invertebrate groups, given the ecological value of the geographic area and the degree of anthropogenic disturbance present.

The proportion of species hierarchically placed as dominant and occasional is similar to those reported by Torreblanca-Ramírez et al. (2014b), in PMR 32 (Acapulco). Other studies on the coast of Guerrero, where they sampled a single site, found dominant species proportions of 25.37 % and 37.22 % (Torreblanca-Ramírez et al. 2012; Flores-Garza et al. 2014). Another research, carried out in the Mexican North Pacific that includes this aspect, determined that the dominant species reached the proportion of 15.9 % (Hendrickx et al. 2019). Similarly, Hendrickx et al. (2019) reported a similar proportion of rare species in Guaymas, Sonora (53.1 %) with studies conducted in the state of Guerrero, indicating that the behavior of occasional species of intertidal gastropods is similar in the Mexican Pacific.

Regarding the diversity indexes H' and equity J' found in reports published about the Mexican Pacific where most include the classes Gastropoda, Bivalvia, and Polyplacophora, gastropods contribute a considerable number of species. Reported values of H' for mollusks in the rocky littoral range from 2.86 to 3.80 (Barba-Marino et al. 2010; Capelo et al. 2014). In the state of Oaxaca, Zamorano et al. (2008) reported high diversity values in the infralittoral zone (H' = 4.584 and J' = 0.867). A study done on the Guerrero coast in the rocky intertidal zone, exclusively in gastropods, reported values of H' = 3.39 bits/ind and J' = 0.65 (Torreblanca-Ramírez et al. 2012). These values reflect what corresponds to a tropical, heterogeneous zone, such as the rocky intertidal substrate of the coast of Guerrero. Our results are in line with what is expected in a tropical region; however, despite being a single class, they are among the highest values reported in literature. Variations in H' and J' were evidenced at each site, which can be related to the type of wave exposure and the heterogeneity of the substrate, allowing a greater accommodation of species. It has already been mentioned that sites with firmer substrates provide better conditions to harbor greater diversity and equity than less firm or smooth substrates (Brusca 1980; Brower et al. 1998). This allows us to consider that the sites studied, which presented high values of diversity and equity, are more stable ecosystems, with less alteration and better established communities.

The greatest similarity was observed in La Barrita, Ojo de Agua, and Puerto Vicente Guerrero. Among the similarities in the physical characteristics of the habitat of the sites, the following stand out: the presence of a similar substrate composed of rocky massifs, discontinuous blocks and sandy areas, the stability of the substrate determined as high and the exposure to waves medium. On the other hand, with respect to the ecological characteristics related to the attributes of the communities analyzed, it was found that these are the sites with the highest abundance and richness of species, the highest diversity index, and the highest percentage of dominant and occasional species. It has already been mentioned in several works that species composition is a response to the environmental conditions present at each site (Pagaza et al. 1994; Barba-Marino et al. 2010; Tripp-Quezada et al. 2013; Flores-Rodríguez et al. 2017; D'Souza et al. 2022).

The second group consisted of Piedra de Tlacoyunque, Barra de Potosí Expuesta, and Barra de Potosí Protegida. The first two sites are formed by a substrate consisting of rocky massifs, blocks and some boulders, high substrate stability and high wave exposure; however, the composition and substrate stability and wave exposure in Barra de Potosí Protegida are different from the other sites that make up the group. Nonetheless, the locations of these sites are very close to Barra de Potosí Protegida, and the similarity may be due to the displacement of species between them. This phenomenon has already been considered in other studies as a factor that influences the similarity (Garcés and Angher 2006). The abundances and richness of the sites and the percentage of dominant species are lower than those found in group 1, but they are not the lowest in PMR 31. The behavior of the occasional species is similar since the three sites presented the same percentage, and it is the lowest of the sites analyzed in the region. The high wave exposure of two of the sites the substrate type of one of them are factors impacting the lower species richness and high heterogeneity, (Brusca 1980; Tait and Dipper 1998; Barba-Marino et al. 2010; Flores-Rodríguez 2017; D'Souza et al. 2022). Cox (2002) mentions that it has been observed that mature communities with a stable environment typically have high species richness, and those that are stressed have

lower species richness. Therefore, our study demonstrates that the gastropod community associated with the rocky intertidal zone is a mature community.

According to the results of the similarity analysis, which showed the formation of two groups, and with the information obtained from the SIMPER analysis, it was evident that there are similar species shared between the groups; however, the group integrated by La Barrita, Ojo de Agua, and Puerto Vicente Guerrero (group 1) showed a greater composition of species, which were responsible for the separation between groups 1 and 2.

Conclusions

The species richness found in PMR 31 corresponds to what is expected in a tropical zone with a heterogeneous habitat, such as the rocky intertidal zone of the region. The increase in the list of species, for Guerrero, as for PMR 31, has to do with the sampling effort combined with the different forms and types of rocky substrate and its complexity, which gives rise to a heterogeneity of habitats.

The habitat with greater heterogeneity, greater stability, and less exposure to waves showed greater richness, diversity, and abundance of gastropods. Consequently, the sites that make up group one, in the event that activities are developed, whose purpose is the protection and conservation of biodiversity and the ecosystem, should be considered initially for the planning of these activities.

The finding of new records demonstrate the need to focus even more research efforts on the study of marine diversity, as suggested by CONABIO, especially in the regions that have been defined as priority regions for the conservation and use of biodiversity in Mexico.

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Conflict of interest

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