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Research Article

Mollusk freaks: new teratological cases on marine mollusks from the South Pacific Ocean

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ABSTRACT. The present study provides new documented cases of abnormalities on chitons (hypomerism and coalescence of shell plates), in addition to four new cases on keyhole limpets (closed apical opening), and one new teratologic case on internal organs in octopuses (missing gill). We assess the frequency of these abnormalities and discuss about its possible environmental, mechanic and genetic causes. Several of these findings represent the first of these cases reported in South Pacific Ocean.

Keywords: Mollusca, chiton, keyhole limpet, octopus, abnormalities, South Pacific.

INTRODUCTION

Teratologies are the abnormalities in the development of the body plan attributed to biotic and abiotic factors (Ujházy *et al.,* 2012). While many studies in marine invertebrates have shown abnormalities triggered in laboratory conditions on early life stages by pollutants and UV radiation (*e.g*., Schröder *et al.,* 2005; Chiarelli & Roccheri, 2014), the causes of these disorders in the wild are not entirely understood. On Mollusca, malformations on the class Polyplacophora have been described extensively (Dell'Angelo & Schwabe, 2010), while other classes have not been described in so much detail (*e.g*., Pelseneer, 1923; Mitov *et al.,* 2003; Brewer & Seitz, 2013). In the South Pacific there is little knowledge on abnormalities of mollusks, and for Chile, these reports have limited to Polyplacophora (Peña, 1977; Peña & Castro, 1982; Gálvez, 1991). Teratology cases in Mollusca, report abnormalities in the shell of these animals primarily; in chitons, for instance, these have been classified as "hypomerism" and "hypermerism" when specimens have fewer or more shell plates than the regular eight respectively, "coalescence" when two or more plates are merged together, and "splitting" when one shell plate is divided into two independent halves (Taki, 1932; Dell'Angelo & Schwabe, 2010). There could also be anomalies in the soft tissue of the bodies, which have been less documented (*e.g*., Pelseneer, 1923; Brewer & Seitz, 2013; Mitov, 2014). This study was done as the first report of abnormality cases in some mollusk species from the South Pacific Ocean. We document these abnormalities cases as semi-quantitative.

MATERIALS AND METHODS

While working on diverse projects, chitons, keyhole limpets and octopuses were examined over a period of three years, looking for morphological abnormalities, performed through fieldwork and reviewing the mollusk collection of the Museo Nacional de Historia Natural, Chile (MNHNCL). The samplings were carried out throughout the South Pacific coast, including the Juan Fernández Archipielago (JFA) and Rapa Nui (Eastern Island). In total, 290 specimens of *Tonicia fremblyana* (Kass, 1956) were inspected (283 from this study and seven from the MNHNCL), 750 of *Chiton magnificus* Deshayes, 1827 (612 from this study and 138 from the MNHNCL), 1108 of *Chiton granosus* Frembly, 1827 (930 from this study and 178 from the MNHNCL), 165 of *Plaxiphora mercatoris* Leloup, 1936 (63 from this study and 102 from the MNHNCL), 181 *Fissurella latimarginata* Sowerby, 1835 (121 from this study and 60 from the MNHNCL), 188 of

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Fissurella crassa Lamarck, 1822 (157 from this study and 31 from the MNHNCL), 383 of *Fissurella picta* (Gmelin, 1791) (152 from this study and 231 from the MNHNCL), 182 of *Fissurella peruviana* Lamarck, 1822 (125 from this study and 57 from the MNHNCL), and ten of *Octopus mimus* Gould, 1852 (seven from this study and three from the MNHNCL). Among these, we came across specimens with abnormalities, which were then qualitatively described, and their length measured. All measurements are expressed in millimeters. The abnormal specimens of chitons and limpets found for us were donated to the MNHNCL collection.

RESULTS

From the 290 individuals of *Tonicia fremblyana* examined, only one of them (0.34% of the total specimens of this species inspected) presented hypomerism (Table 1, Fig. 1a), collected at Pucusana, Peru on November of 2014. At first glance, this specimen seems to have only five plates, instead of the usual eight (hypomerism). Nevertheless, the last plate has some traits of both an intermediate plate and an anal plate, indicating coalescence between shell plates, that is, respectively, the presence of a pronounced apex in the middle of the last plate, and the curved shape of the posterior end of the plate (Fig. 2a). This specimen of *T. fremblyana* would have coalescence between the V-VI plates (Figs. 1a, 2a). From the 750 individuals examined of *Chiton magnificus* only one (0.13%), collected at Tres Playitas, Huasco, in January of 2015, presented anomalies (Table 1). In this specimen we found a considerable reduction of the plate IV, and coalescence between this and the plate III, and the atrophy of the plate II (Figs. 1b, 2b). One of the 165 specimens of *Plaxiphora mercatoris* (0.61%) presented hypomerism, collected at Tahai, Rapa Nui (Eastern Island). Although the individual was in poor conditions, with the left half of the VI and anal plates broken; however it was clear that this chiton had only seven plates. (Table 1, Fig. 1c). Even though the plates were broken, there were only two shell impressions on the mantle of where the last two plates used to be attached (Fig. 2b). Finally, from the 1108 specimens examined of *Chiton granosus*, a seven-plated specimen was found (0.09% of the total examined for this species), with one of the intermediate plates missing (Table 1, Fig. 1d). This specimen was collected at Maguillines port, near Constitución on 27 August 1990.

From the 181 specimens of *Fissurella latimarginata* examined, only one of them (0.55%) collected at El Frances, Coquimbo, in January of 2013, showed morphological abnormalities (Table 1). The apical region in this individual was heavily eroded with most of the outer calcitic layer of the shell worn out, and the inner aragonitic layer visible (Fig. 3a). Moreover, the distinctive hole in the apex was utterly missing, entirely closed by the white inner aragonitic layer (Figs. 2a-2b). Although closed, an outline of the foramen was visible from a dorsal view, but from a ventral view the surface of the apical region was smooth, with no such outline evidencing where the foramen was supposed to be (Fig. 3b). Furthermore, the dorsal opening on the mantle was closed as well, with a slight thickening where the opening was supposed to be (Fig. 3c). To assess any gill size compensation, we measured the length, width, and area of the gills, and compared them with individuals of the same species and similar size without abnormalities. Nevertheless, we did not find differences between them (Table 2). From the 188 individuals of *F. crassa* examined, one of them displayed a similar abnormality (0.53% of the total), collected from a shell pile on northern Cifuncho, Antofagasta, in 1993 (Table 1,

Table 1. Summary of the new documented teratologic cases on mollusks from the South Pacific reported. Repository numbers belong to the National Museum of Natural History of Chile, and the author's personal collection (*).

Species	Source	Locality	Coordinates	Observation	Total length (mm)	Repository
Tonicia fremblyana	Fondecyt 1130266	Pucusana	(12º28'47.7"S, 76º48'3.3"W)	Hypomerism (5 plates)	20.0	MNHNCL 401245
Chiton magnificus	Fondecyt 1130266	Huasco	(28º24'42"S, 71º11'44"W)	Coalescence	19.0	MNHNCL 401246
Chiton granosus	Museum collection	Constitución	(35°21'21"S, 72°27'34"W)	Hypomerism (7 plates)	25.0	MNHNCL 401243
Plaxiphora mercatoris	Museum collection	Eastern Island	(27°08'23"S, 109°25'38"W)	Hypomerism (7 plates)	23.0	MNHNCL 401244
Fissurella latimarginata	Fondecyt 3149610	Coquimbo	(30º5'42"S, 71º22'51"W)	Closed Apical Hole	52.0	MNHNCL 202712
Fissurella picta	Museum collection	Ipun Island	(44°36'21"S, 74°45'47"W)	Closed Apical Hole	58.7	MNHNCL 202715
Fissurella crassa	Museum collection	Cifuncho	(25°39'15"S, 70°37'59"W)	Closed Apical Hole	55.9	MNHNCL 202713
Fissurella peruviana	Museum collection	Chile		Closed Apical Hole	20.8	MNHNCL 202714
Octopus mimus	Fondecyt 3110152	R. Crusoe Island	(33°37'57"S, 78°49'44"W)	Only one gill	67.0	OSLK 9*

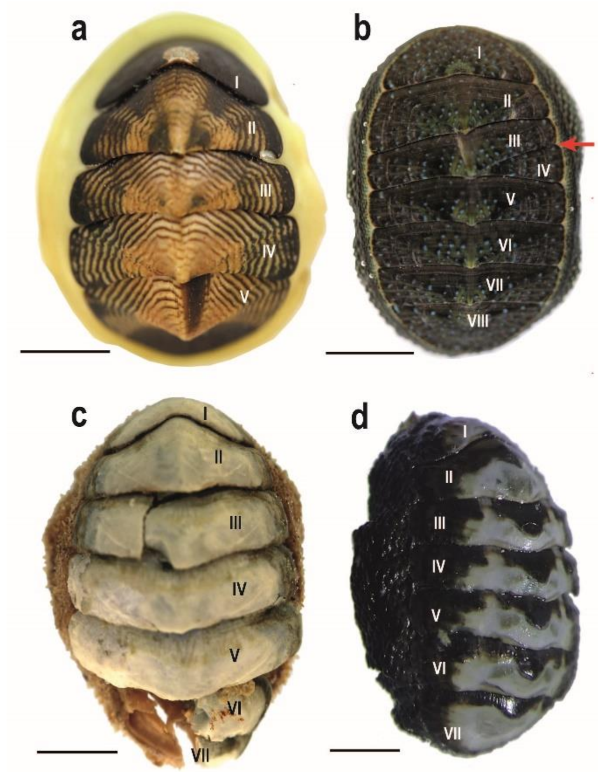

Figure 1. Polyplacophorans with abnormalities. a) *Tonicia fremblyana* from Peru with 6 plates, dorsal view, b) *Chiton magnificus* with reduction of the plate IV, and coalescence between the plates III and IV (red arrow), c) *Plaxiphora mercatoris* with hypomerism, d) *Chiton granosus* with hypomerism, dorsolateral view, since due preservation was curled, and straighten it could damage the specimen. Scale bars = 0.5 cm.

Figs. 3d-3e). Also, among the 383 specimens of *F. picta* examined, only one (0.26%) presented abnormalities, collected on Ipun Island, Aysén, in 1984 (Table 1, Figs. 2f-2g). From the 182 specimens of *F. peruviana*, only one (0.55%) was an abnormal individual, with no information about its sampling (Table 1, Figs. 3h-3i). These three latter specimens displayed an apical hole closed by the white aragonitic layer of the shell, with a visible outline from above, but imperceptible or hardly visible from a ventral view. These three specimens were found in the MNHNCL mollusk collection, and only their shells were preserved.

Regarding the octopuses, one out of the seven *O. mimus* specimens was found to have abnormalities, collected at Cumberland Bay in Juan Fernández Archipelago (Table 1, Fig. 4). Externally this specimen had no signals of any abnormalities (Fig. 4a), but once the mantle was dissected, it was revealed only one gill instead of the usual two, the left one missing (Fig. 4b). The gills are responsible for the oxygen exchange, hence it is possible this abnormality had affected the respiration of the specimen. We measured the length, width, and area of the gills and compared them with regular individuals with two gills, yet no differences were found (Table 2), discarding the idea of size compen-sation of the remaining gill.

DISCUSSION

Polyplacophora with six plates, as the specimen of *Tonicia fremblyana* reported here, are relatively rare, and merely around 40 cases worldwide have been previously documented (Dell'Angelo & Tursi, 1990; Dell'Angelo & Schwabe, 2010). This case of coales-cence and hypomerism is the first documented in Peru. The specimen of *Chiton granosus* reported here would be the second documented case of hypomerism for the species after the one described by Peña (1977), and overall the third documented case of teratology considering a case of coalescence described by Peña & Castro (1982). Chitons with seven plates are the most common type of hypomerism, and several hundred have

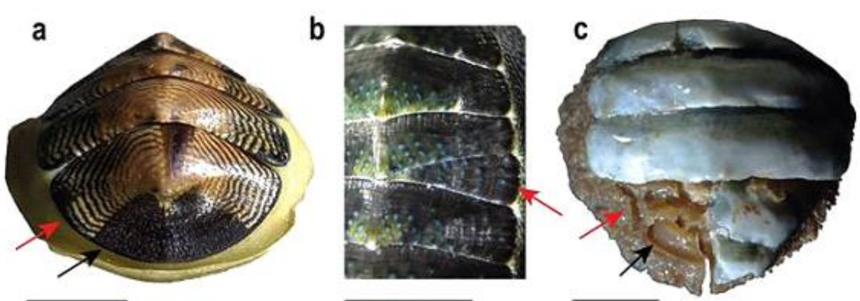

Figure 2. Close-up of the abnormalities found in chitons. a) Posterior view of *Tonicia fremblyana* from Peru, with the last intermediate plate (red arrow), fused with the anal plate (black arrow), b) dorsal view of *Chiton magnificus*, with a reduction of the IV plate (red arrow), and c) dorsal view of the posterior end of *Plaxiphora mercatoris* with hypomerism, the broken plates reveal the impression on the mantle for the last intermediate plate (red arrow) and the anal plate (black arrow). Scale bars = 0.5 cm.

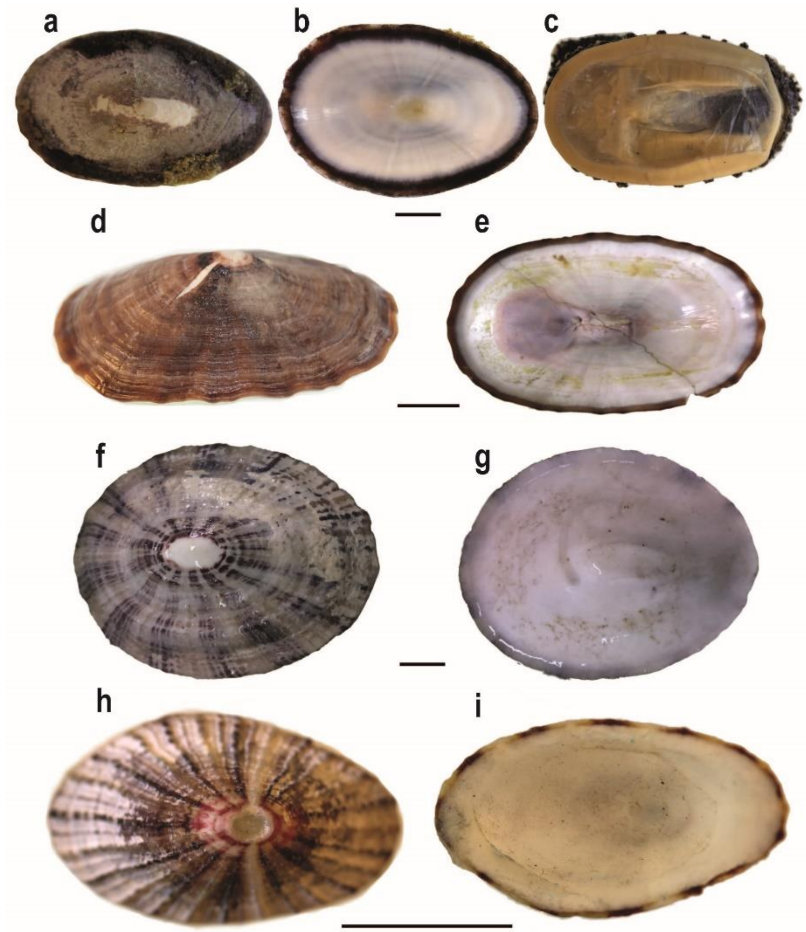

Figure 3. Keyhole limpets with a closed apical hole. a) *Fissurella latimarginata* dorsal view of shell, b) ventral view of shell, c) dorsal view of the mantle, with shell removed, d) *Fissurella crassa* dorsal view, e) ventral view, f) *Fissurella picta* dorsal view, g) ventral view of shell, h) *Fissurella peruviana* dorsal view, i) ventral view. Scale bars = 10 mm.

been described (Dell'Angelo & Tursi, 1990). Cases of abnormalities on chitons have been well documented since the beginnings of the XX century (*e.g.*, Crozier, 1919; Pelseneer, 1923; Taki, 1932). Nevertheless, in the Pacific Ocean, there are only a few documented cases (*i.e.*, Peña 1977; Peña & Castro, 1982; Gálvez, 1991; Dell'Angelo & Schwabe, 2010).

Teratologic cases on Fissurellidae have not been particularly well documented, and only two previous cases came to our attention, both on *Fissurella* (Carpenter, 1857; Mienis, 2002), but neither of them from the South Pacific Ocean. The present study reports four new documented cases of abnormalities. Finding a specimen of *F. latimarginata* with a closed foramen is bizarre, considering the role of this opening in keyhole limpets is to facilitate the excretion of waste products carrying it away through a unidirectional water flow (Voltzow & Collin, 1995). Thereby a keyhole limpet with a closed apical opening could require different mechanisms to supply its oxygen demand. We did not find differences in size between the gills of the abnormal specimen and other ones of the same species and similar size (Table 2). Therefore, this limpet might have had different ways of compensation. We observed the tip of the gills seemed had been brought forward next to the head, similar to what has been seen in experiments blocking of the shell opening on *Diodora aspera* (Rathke, 1833) (Voltzow & Collin, 1995). Although it has been noted that the process of tissue preparation causes the gills to shrink, and the vascular tissue to collapse, making it difficult to interpret the original size and position of the gills in the living gastropods (Voltzow, 2015).

Regarding cephalopods, the documented teratology cases mostly describe anomalies on the extremities: tentacle bifurcation on squids (*e.g.*, González & Guerra, 2008), and in octopuses bifurcation and even branching of arms (Okada, 1965; Brewer & Seitz, 2013) and bilateral hectocotylization (*e.g.*, Higashide *et al.*, 2007; Brewer & Seitz, 2013). We could not find documented

Table 2. Morphometric measurements of *Fissurella latimarginata* and *Octopus mimus* specimens. Asterisks (*) denote the abnormal individuals. Repository numbers belong to the National Museum of Natural History of Chile, and codes starting with FLHE and BOS belong to the authors' personal collection. All measurements are in millimeters (mm).

Repository	Length (TL)	Gill length (GL)	Gill width (GW)	Area of the gill
Fissurella latimarginata				
FLHE1	60.7	25.0	6.2	155.0
FLHE2	57.6	23.9	5.2	124.3
FLHE3	58.1	21.1	6.2	130.8
FLHE4	56.3	17.8	5.9	105.0
FLHE5	62.0	20.6	8.2	168.9
MNHNCL 202712*	52.0	20.8	5.1	106.1
Octopus mimus				
MNHNCL 6637	54.5	17.3	10.8	186.8
MNHNCL 6631	38.7	11.3	9.1	102.8
MNHNCL 300049	59.3	18.2	14.6	265.7
BOS6	66.0	12.1	10.1	122.2
BOS7	61.0	17.8	11.7	208.3
BOS8	46.0	10.5	11.0	115.5
BOS9*	67.0	19.9	14.8	294.5

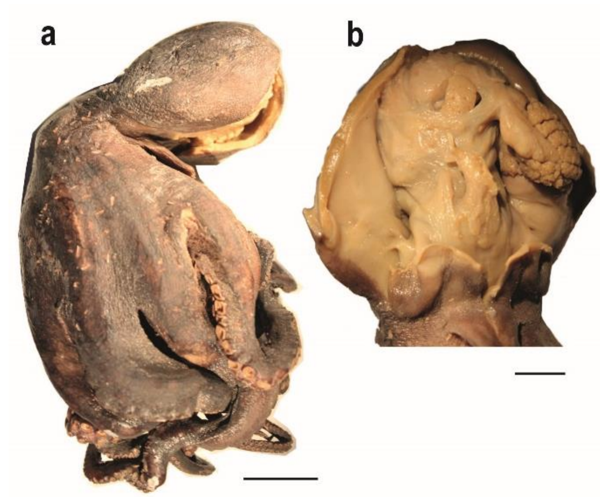

Figure 4. A specimen of *Octopus mimus* lacking one gill. a) External view, b) mantle opened on a dorsal view revealing the missing gill and the right one. Scale bars = 10 mm.

cases of any abnormal cephalopod in the South Pacific, nor any documented case of this kind of abnormality. Could be theorized that lacking one-gill row meant some kind of compensation in size of the remaining gill row, yet this was not found in the present study. In octopuses have been registered changes in the behaviour to supply extra oxygen, such as strong contractions of the mantle, and even forcing the gills halfway out of the mantle cavity (Ghiretti, 1966), so it is possible to think something like this was done by this specimen to survive, to increase its oxygen exchange.

Even though there are no conclusive explanations for the origin of these anomalies on mollusks, some studies have pointed out the importance of specific environmental variables which led to the interruption of the proper development of larvae during the early development, both natural (*e.g.*, temperature, salinity) and anthropogenic (*e.g.*, pesticides, pharmaceutical residues) (Sirenko & Kashenko, 1990; Mitov *et al.*, 2003; Mottier *et al.*, 2013; Di Poi *et al.*, 2014). In bivalves, exposure during embryo-larval development to antidepressants and pesticides lead to hinge and mantle abnormalities (Mottier *et al.*, 2013; Di Poi *et al.*, 2014). Vijai *et al.* (2015) posit that temperature on embryonic development might explain some malformations in cephalopods. On their study, embryos reared at low temperature (16°C) showed abnormal organogenesis; however, normal development resumed when transferred to 22 or 24°C after blastoderm formation. In all the cases described here, these abnormalities represented a tiny percentage of all inspected specimens. Thus, these probably were not related to environmental forces, which would have affected a higher proportion of the population, making these cases more frequent. Instead, these might be due to other causes, such as mechanical injuries or genetic anomalies (Mitov *et al.*, 2003). Following mechanical damage or non-lethal predatory attacks, shell regeneration can lead to morphological abnormalities at any time of life (Peel, 2015; Da Silva *et al.*, 2016). Although shell regeneration might explain the coalescence between the plates of the chiton, or the closed apical holes in *Fissurella* spp., it is not clear how regeneration could have led to the complete absence of up to three shell plates of chitons. The random gene expression of specific genes could explain some of these anomalies, as well as the low frequency they are found. In mollusks, Lee *et al.* (2003) and Fritsch & Wanninger (2016) recorded the expression of several Hox and ParaHox genes regulated the body plans of chitons and cephalopods, while the engrailed gene played a critical role in shell formation of gastropod shells and polyplacophorans plates (Jacobs *et al.*, 2000; Wanninger & Haszprunar, 2001; Nederbragt *et al.*, 2002). Therefore, the interruption of these genetic pathways during ontogeny could be a significant approximation on explaining some of these abnormalities.

Finally, this study presented the first documented cases of abnormalities for *Fissurella*, several species of chitons, and overall octopuses from the South Pacific, and the first recorded case on abnormalities in internal organs of cephalopods. In the future, new approaches should be carried out to elucidate the origin of these anomalies. It would be necessary to carry out experiments recreating natural conditions in a controlled environment, to conclude the factors causing the teratology in mollusks in the wild.

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