

Holoplanktonic mollusks (Mollusca: Gastropoda) from the Gulf of California, México

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ABSTRACT: We compiled a checklist of holoplanktonic mollusks obtained from seven oceanographic surveys performed between 2005 and 2007 in the Gulf of California, México. The checklist comprises five orders, 15 families, 28 genera and 62 species, including 39 new records and two range extensions within the Gulf.

INTRODUCTION

The true holoplanktonic mollusks are represented by the Class Gastropoda, in which the species are not large enough or powerful enough swimmers to be classified as nektonic. Of the approximately 40,000 marine species of gastropods, only 244 are holoplanktonic (Spoel *et al.* 1997), and live in the open oceans of the world, primarily at tropical and subtropical latitudes (Bé and Gilmer 1977). Another characteristic of this group is its affinity for certain water masses (Fager and McGowan 1963), which has resulted in their use as zoogeographic markers (Spoel and Pierrot-Bults 1979), and also as indicators of climate change and ocean acidification (Fabry *et al.* 2008).

The holoplanktonic mollusks are comprehended in two major groups according to Spoel *et al.* (1997); Pterotracheidae (including Atlantidae, Carinariidae, and Pterotracheidae) and Ophistobranchia (including Thecosomata, Gymnosomata and Nudibranchia).

Few faunistic surveys of holoplanktonic mollusks have been completed in the North Pacific related to holoplanktonic mollusks. McGowan and Fraundorf (1966) recorded 34 species south of Cabo San Lucas; McGowan (1967), reported 33 species from the California Current between November 1949 and October 1952; Sánchez-Hidalgo (1989), recorded eight species from Bahía Magdalena between May and June of 1984. In the Gulf of California not a single formal study of holoplanktonic mollusks has been made. However, sporadic records were done by Abbott (1974) whom reported two species. Poorman and Poorman (1988) recorded four species in Pto. San Carlos (Sonora), Fernández-Alamo (1996) found one species in the mouth of the Gulf; and Angulo-Campillo (2005) recorded two species near La Paz. The first paper that deals specifically with the heteropods of the Gulf was Seapy and Skoglund (2001), who recorded 10 species. In summary, 19 species of holoplanktonic mollusks have been reported from the Gulf of California. The present study extends the previous studies, reporting 63 species.

MATERIALS AND METHODS

The Gulf of California is a semienclosed basin, located between 32°00' – 24°40' N and bounded by the continental coast of México and the Baja California Peninsula (Figure 1). One of the most important features of the Gulf is the wide range of sea surface temperatures (SST). In the northern region, the annual SST range is 9 to 38°C, while in the southern region is 22 to 31°C (Soto-Mardones *et al.* 1999).

The Gulf of California is hydrographically complex, including local upwelling on the continental coast caused by north-west winds during winter and low intensity upwelling on the peninsular coast associated with south-east winds during summer (Alvarez-Borrego 1983). Water masses are warm but the Gulf water has high salinity (>34.9) and flows southward along the peninsular coast, while tropical Pacific water has lower salinity (34.65 < to >34.85) and flows northward along the mainland coast (Alvarez-Borrego 1983; Lavín *et al.* 1997)

Seven oceanographic surveys were conducted in the Gulf of California between March 2005 and August 2007. Four of those surveys (March, May, September 2005 and March 2006) were named CGC (for Circulación en el Golfo de California) and the remaining three (November 2005, January and August, 2007) were called GOLCA (for Golfo de California). The station codes in Figures 1 A-B consist of either CGC or GOLCA, followed by two digits indicating the year in which the survey was done and the two denoting the month. The GOLCA surveys were completed onboard the oceanographic vessel "El Puma" from the Universidad Nacional Autónoma de México (grants CONACyT-SAGARPA S007-2005-1-11717 and CONACyT-FOSEMARNAT 2004-4-01-144). The CGC surveys were conducted onboard the vessels "Alejandro de Humbolt and Altair" from Secretaría de Marina Armada de México (grant CGPI-2005053).

A total of 246 plankton samples were obtained with oblique tows using Bongo nets with 505-µm mesh size, to a maximum depth of 220 m, following the sampling

method detailed by Smith and Richardson (1979). The holoplanktonic mollusks were removed from the net samples, fixed and preserved in 96% ethanol to avoid deterioration of the shell. The specimens were identified using Seapy (1990), Spoel and Boltovskoy (1981), Richter and Seapy (1999), Spoel and Dadon (1999), Seapy and Lalli (2007), Spoel *et al.* (1997). Also, specimens of heteropods and some gymnosomes were selected for dissection, and particularly the radula was prepared for examination for scanning electron microscopy (SEM) following the method by Geiger *et al.* (2007). The specimens were deposited in the "Colección Científica de moluscos holoplanctónicos del Pacífico Mexicano" at CICAMAR-IPN.

The systematic list of species was made following Spoel and Dadon (1999), above family level according to Bouchet and Rocroi (2005).

RESULTS AND DISCUSSION

A total of 25,404 organisms were identified, grouped in five orders, four suborders, 15 families, 28 genera and 62 species (Table 1). The Heteropoda contained 25 species (39.7%), the Cephalaspidea one species (1.6%), the Thecosomata 21 species (33.3%), the Gymnosomata 13 species (20.6%) and the Nudibranchia three species (4.8%).

Thirty-eight new records were found in the Gulf of California. Of those 11 were heteropods, 16 thecosomes, 10 gymnosomes, and one nudibranch; these comprehends

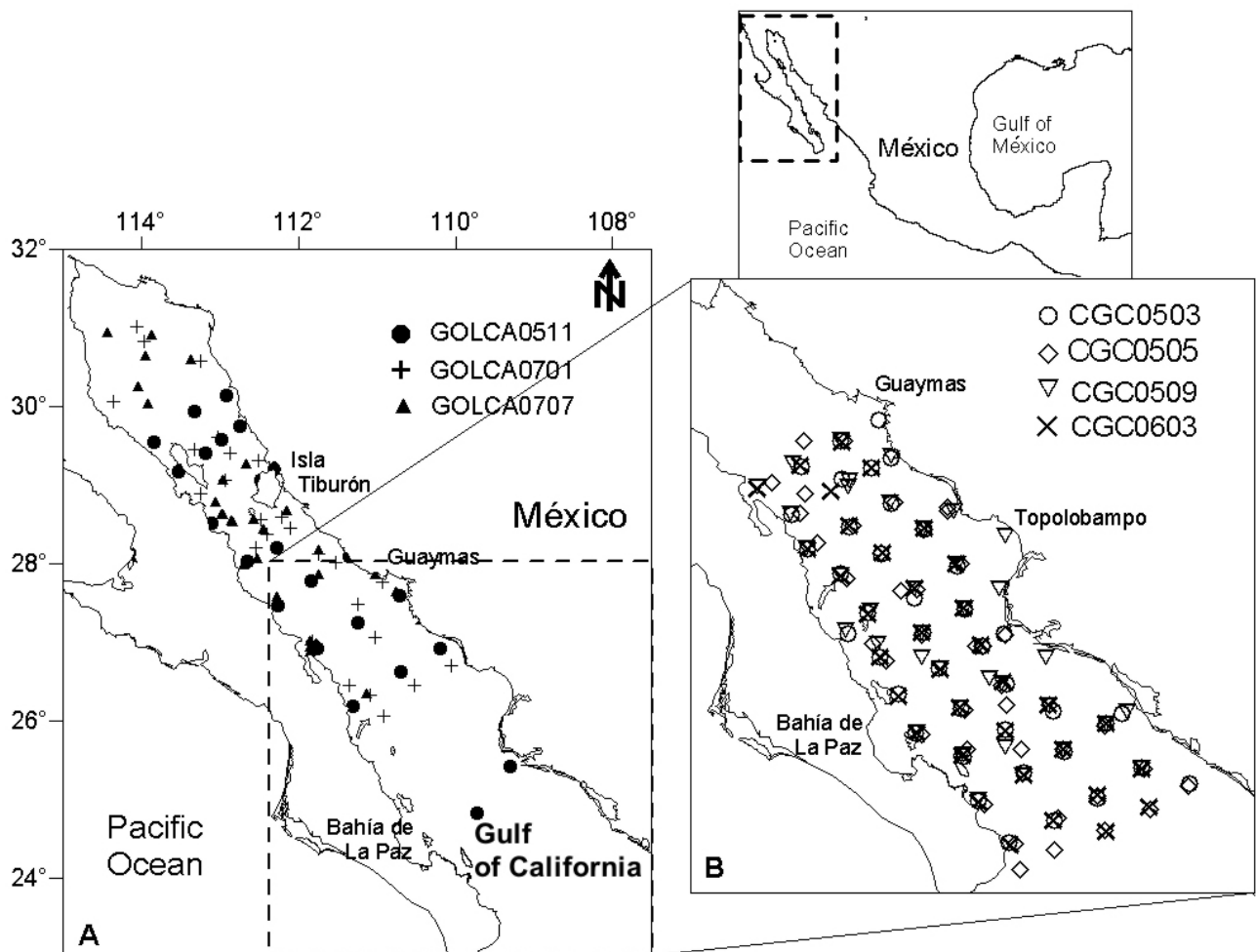
57% of the total richness recorded during the study (Table 1). There were two northward range extensions (*Firoloida desmaresti* and *Phylliroe bucephala*). The thecosomes were most abundant (61.4%) followed by the heteropods (37.3%), the gymnosomes and nudibranchs were uncommon (>1.3%). Only 14 species represented together 90% of the total abundance, whose individual abundances each exceeded 2% of the total (Table 1).

The taxonomic list of holoplanktonic mollusks from the Gulf of California given here is the most extensive yet presented. The 62 taxa identified represent approximately 30% of the holoplanktonic mollusk world fauna. The present species list is undoubtedly incomplete due to the fact that the selectivity of the sampling technique did not allow catches of some neustonic species (*e.g.* janthinids).

Within the Pterotracheoidea, the family Atlantidae was the best represented in the Gulf of California. There are 19 valid species worldwide, from which 17 occurs in the Pacific Ocean (Seapy 2010) and they are included now in the Gulf of California. This finding is relevant since although the smallest area of this enclosed sea, its high environments and diversity allows the presence of all the species found in the Pacific Ocean.

The Carinariidae contain nine species of which four were recorded and Pterotracheidae, three species of the four known.

The cephalaspidean *Gastropterum pacificum* is the only known member of its order to be considered as a semi-



planktonic species, a result of its being a benthic species with young “individuals” spending more time in the water column (Wrobel and Mills 1998).

There are 122 valid shelled pteropods species, and 66 valid gymnosomes species (Spoel *et al.* 1997; Cummings and Seapy 2003; Suárez-Morales *et al.* 2009). These groups have representatives in several habitats, such as those found in polar waters (*e.g.* *Limacina australis* and *Clione antarctica*). When comparing the number of species recorded for the Eastern Pacific (Thecosomata 32 species, Gymnosomata nine species), with the ones recorded during this study (Thecosomata 21, Gymnosomata 13), we collected more than the 50% of the recorded species, including new records for the Eastern Pacific (*Diacavolinia longirostris*, *Gleba cordata*, *Desmopterus papilio* and *Pneumodermophis canephora*). The Nudibranchia has the lowest number of true planktonic species (five species with circumtropical distribution), of which three were recorded here (*Phylliroe bucephala*, *Cephalopyge trematoides* and *Glaucus atlanticus*).

Of the 62 recorded species, two heteropods, *Atlanta californiensis* (Seapy and Richter, 1993), *Carinaria japonica* (Seapy, 1974) and the thecosome *Limacina helicina* (McGowan, 1963) are considered endemic to the Transition Zone waters of southern California and the California Current. The presence of *A. californiensis* and *C. japonica* implies that their exclusivity to the California Current must be reconsidered and their presence in the Gulf of California could be related to the intrusion of the California Current to the Gulf or to a vicariant population as in the case of many others species coming from the San

Diego province. The hypothesis that the holoplanktonic mollusk community could be a remnant of when the Gulf of California was connected with the Pacific Ocean is supported for other groups for example as a plausible explanation of the similitude between the fish fauna in the northern portion of the Gulf of California and the adjacent western North Pacific (Aceves-Medina *et al.* 2003).

When comparing the species richness of holoplanktonic mollusks with other marine regions (Table 2), differences between the North Pacific and South Atlantic, due to the historic research background in such areas are clear. In contrast with relatively recent new areas of study of holoplanktonic gastropods such as the Gulf of México-Caribbean (Parra-Flores and R. Gasca 2009) and Costa Rica Dome area (Suárez-Morales *et al.* 2008), the numbers of species registered in the Gulf of California is relatively high.

The Gulf of California is considered one of the most diverse ecosystems in the Eastern Pacific (Walker 1960; Thompson *et al.* 1979; Castro-Aguirre *et al.* 1995; Aceves-Medina *et al.* 2003; Hendrickx *et al.* 2007). Hendrickx *et al.* (2007) reported that the mollusk fauna of the Gulf of California contained 2,194 recorded species (belonging to 217 families), with the gastropods contributing 1,530 species (153 families). With the new records obtained in this study, the number of mollusk species for the Gulf of California increases to 2,229 species (230 families), which supports the conclusion that the Gulf of California is one of the most or the most biologically diverse marine ecosystem at warm-temperate latitudes.

TABLE 1. Species of holoplanktonic mollusks found in the Gulf of California during the 2005-2007 surveys. (CGC) for Circulación en el Golfo de California, (GOLCA) for Golfo de California, (%) relative abundance, (X) denotes the presence on each cruise, (*) denotes new records (+) range extensions, (Ref.*) previous records in the Gulf of California: (1) Abbott 1974, (2) Poorman and Poorman 1988, (3) Fernández-Alamo 1996, (4) Seapy and Skoglund 2002, (5) Angulo-Campillo 2005, (6) Hermosillo *et al.* 2006

TAXON	%	CGC cruices	GOLCA cruices	Ref.*
ORTHOGASTROPODA				
CAENOGASTROPODA				
PTEROTRACHEOIDEA				
ATLANTIDAE				
<i>Atlanta californiensis</i> Seapy and Richter, 1993*	<0.1	X	X	
<i>Atlanta echinogyra</i> Richter, 1972	3.4	X	X	4
<i>Atlanta frontieri</i> Richter, 1993	0.3	X	X	
<i>Atlanta brunnea</i> Gray, 1850	<0.1	X		4
<i>Atlanta gaudichaudi</i> Gray, 1850	2.3	X	X	4
<i>Atlanta helicinoidea</i> Gray, 1850*	<0.1	X	X	
<i>Atlanta inclinata</i> Gray, 1850	<0.1	X		4
<i>Atlanta inflata</i> Gray, 1850	<0.1	X		4
<i>Atlanta lesueurii</i> Gray, 1850	2.2	X	X	4
<i>Atlanta meteori</i> Richter, 1972*	<0.1	X		
<i>Atlanta oligogyra</i> Tesch, 1906*	0.4	X	X	
<i>Atlanta peronii</i> Lesueur, 1817	16.1	X	X	4
<i>Atlanta plana</i> Richter, 1972	2.3	X	X	4
<i>Atlanta tokiokai</i> van de Spoel and Troost, 1972	<0.1	X	X	4
<i>Atlanta turriculata</i> d'Orbigny, 1836	<0.1	X	X	4

TABLE 1. CONTINUED.

TAXON	%	CGC cruices	GOLCA cruices	Ref*.
<i>Protoatlanta souleyeti</i> (Smith, 1888)*	0.1	X	X	
<i>Oxygyrus keraudrenii</i> (Lesueur, 1817)*	<0.1	X		
CARINARIIDAE				
<i>Carinaria galea</i> Benson, 1835*	<0.1	X		
<i>Carinaria japonica</i> Okutani, 1955*	<0.1	X		
<i>Cardiapoda richardi</i> Vassière, 1904*	<0.1	X	X	
<i>Cardiapoda placenta</i> (Lesson, 1830)	<0.1	X	X	
PTEROTRACHEIDAE				
<i>Firoloida desmaresti</i> Lesueur, 1817+	5.5	X	X	1
<i>Pterotrachea coronata</i> Niebuhr, 1775	0.1	X	X	1
<i>Pterotrachea hippocampus</i> Philippi, 1836*	<0.1	X	X	
OPISTHOBRANCHIA				
CEPHALASPIDEA				
GASTROPTERIDAE				
<i>Gastropteron pacificum</i> Bergh, 1894	<0.1	X	X	6
THECOSOMATA				
EUTHECOSOMATA				
CAVOLINIIDAE				
CAVOLINIINAE				
<i>Cavolinia inflexa</i> (Lesueur, 1813)*	0.2	X	X	
<i>Cavolinia uncinata</i> (Rang, 1829)	<0.1			
<i>Cavolinia tridentata tridentata</i> (Niebuhr, 1775)*	<0.1	X	X	2
<i>Diacavolinia longirostris</i> (Blainville, 1851)*	1.5	X	X	
<i>Diacria quadridentata quadridentata</i> (Blainville, 1821)	1.8	X	X	2
CLIONINAE				
<i>Clio pyramidata lanceolata</i> Linnaeus, 1767	2.6	X	X	2
<i>Creseis chierchiae</i> (Boas, 1886)*	0.7	X	X	
<i>Creseis acicula acicula</i> Rang, 1828*	4.1	X	X	
<i>Creseis acicula clava</i> Rang, 1828*	2.2	X	X	
<i>Creseis virgula conica</i> Rang, 1828*	13.0	X	X	
<i>Creseis virgula virgula</i> Rang, 1828*	25.9	X	X	
<i>Hyalocylis striata</i> (Rang, 1828)	2.7	X	X	2,5
LIMACINIDAE				
<i>Limacina helicina</i> (d'Orbygni, 1836)*	0.1	X	X	
<i>Limacina inflata</i> (d'Orbygni, 1836)*	<0.1	X		
<i>Limacina trochiformis</i> (d'Orbygni, 1836)*	6.8	X	X	
PSEUDOTHECOSOMATA				
PERACLIDIDAE				
<i>Peracles apicifulva</i> Meisenheimer, 1906*	0.8	X	X	
CYMBULIIDAE				
<i>Corolla spectabilis</i> Dall, 1871*	<0.1	X		
<i>Corolla</i> sp.	<0.1		X	
<i>Gleba cordata</i> (Niebuhr, 1775)	<0.1	X		
DESMOPTERIDAE				
<i>Desmopterus pacificus</i> Essenberg, 1919*	2.1	X	X	
<i>Desmopterus papillo</i> Chun, 1889*	0.3	X	X	

TABLE 1. CONTINUED.

TAXON	%	CGC cruices	GOLCA cruices	Ref*.
GYMNOSOMATA				
PNEUMODERMATIDAE				
<i>Pneumoderma atlanticum pacificum</i> (Dall, 1815)*	0.4	X	X	
<i>Pneumoderma</i> sp.*	<0.1	X	X	
<i>Pneumodermophis canephora</i> Pruvot-Fol, 1924*	<0.1	X	X	
<i>Pneumodermophis ciliata</i> (Gegenbaur, 1855)*	<0.1	X		
<i>Pneumodermophis macrochica</i> Meisenheimer, 1905	<0.1	X	X	
<i>Pneumodermophis</i> sp.	<0.1	X	X	
NOTOBRANCHAEIDAE				
<i>Thliptodon diaphanus</i> (Meisenheimer, 1903)*	<0.1	X	X	
<i>Thliptodon gegenbauri</i> Boas, 1886*	<0.1	X		
<i>Spongiobranchaea australis</i> d'Orbigny, 1863*	<0.1		X	
CLIONIDAE				
<i>Clione limacina</i> (Phillips, 1774)*	<0.1	X	X	
<i>Clione</i> sp.	<0.1	X		
CLIOPSISIDAE				
<i>Cliopsis krohni</i> Troschel, 1854*	<0.1	X	X	
<i>Cliopsis modesta</i> Troschel, 1854*	<0.1	X		
NUDIBRANCHIA				
DENDRONOTINA				
PHYLLIROIDAE				
<i>Cephalopyge trematoides</i> (Chun, 1889)*	<0.1	X	X	
<i>Phylliroe bucephala</i> Pèron and Lesueur, 1810*+	<0.1	X	X	3,5
AEOLIDIINA				
GLAUCIDAE				
<i>Glaucus atlanticus</i> Foster, 1777	<0.1	X		2,6

TABLE 2. Number of holoplanktonic molluscs species from the World Oceans (Spoel et al. 1997), western North Pacific (Seapy and Lalli, 2007), South Atlantic (Boltovskoy et al. 2005), Gulf of México and Caribbean (Parra-Flores and R. Gasca, 2009), the Costa Rica Dome area (Suárez-Morales et al. 2008) and the present study. () indicate the percentage of the world total, NA = Not Available.

	Worldwide	North Pacific	South Atlantic	Gulf of México and Caribbean	Costa Rica	Present Study
Pterotracheoidea	35	28(80)	26 (74)	4 (11)	17(48)	23 (68)
Thecosomata	122	32(26)	91 (74)	40 (32)	11(9)	21 (17)
Gymnosomata	66	9(13)	12(18)	NA	NA	13 (19)
Nudibranchia	6	4(66)	NA	NA	NA	3 (50)
Janthinidae	15	3(20)	NA	NA	1(6)	NA
	244	76 (31)	134 (54)	44 (18)	29(11)	62 (25)

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