State of knowledge about the community of mollusks on both sides of the Baja California peninsula, Mexico: A comparative analysis

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Abstract: A bibliographic search, a compilation of collection data and recent sampling of deep-water mollusks (from 200 to 4200 m) in the Gulf of California (Talud IV-IX cruises, 2000-2005) yield a total of 685 records on both sides of the Baja California Peninsula, Mexico. Records were split into Gulf of California (GC) and the slope of Baja California in the influence zone of the California Current (Mexico only) records (CC) and a comparative analysis of β diversity for both fauna was made using depth and latitude records. Five commonly used similarity indices (Jaccard, Sørensen, Sokal and Sneath, Braun-Blanquet, and Ochiai-Barkman) were calculated for each cell of the latitude by depth matrix. A total of 281 species and 201 genera were recognized. Number of records and species richness were usually higher in the GC, but diversity profiles obtained on both sides of the Peninsula were similar. Using the Sørensen index, highest similarity between GC and CC fauna was observed at 23°N (species: 13%, genera: 23%) and at 200-699 m (species: 20%, genera: 33%). Based on data available and our present knowledge, the effect of the Baja California Peninsula and of the local currents pattern results in a low similarity between GC and CC fauna (86% of the species and 75% of the genera are distinct).

Résumé : Etat des connaissances des populations de mollusques des deux côtés de la péninsule de Basse Californie, Mexique : analyse comparée. Une recherche bibliographique et une compilation des données de capture de mollusques d’eau profonde (entre 200 et 4200 m), y-compris des séries d’échantillonnages obtenus dans le golfe de Californie (croisières Talud IV-IX, 2000-2005), ont permis d’obtenir 685 registres sur les deux côtés de la péninsule de Basse Californie, Mexique. Ceux-ci ont été divisés entre le golfe de Californie (GC) et le courant de Californie (portion correspondant au Mexique) (CC). Une analyse comparative de la β diversité pour les deux faunes a été faite en fonction de la profondeur et de la latitude. Des gradients de latitude (23°-31°N, divisés en neuf bandes égales) et de profondeur (de 200-4200 m, intervalles de 500 m) ont été définis. En tout, 281 espèces et 201 genres ont été reconnus pour la région et cinq indices de similarité (Jaccard, Sørensen, Sokal et Sneath, Braun-Blanquet et Ochiai-Barkman) ont été calculés. Le nombre de signalements et la richesse en espèces étaient généralement plus élevés dans le GC, mais la diversité des profils obtenus sur les deux côtés de la péninsule étaient similaires. La plus forte similitude en espèces entre le GC et le CC a été observée avec l’indice de Sørensen à 23°N (12,66%) et à 200-699 m (20,00%). Dans le cas des genres, la plus forte similitude a été observée à 23°N (22,54%) et entre 200-699 m (32,91%). Considérant les données actuellement disponibles, l’effet de la péninsule et des courants locaux semble à l’origine d’une faible similitude entre le GC et le CC (86% des espèces et 75% des genres sont distincts).

Keywords: Deep-water mollusks ● Baja California ● Mexico

Received 15 December 2009; accepted in revised form 25 August 2010.
**Introduction**

In spite of the fact that the deep-sea macroinvertebrates communities are characterized by high diversity (Hessler & Sanders, 1967; Sanders & Hessler, 1969; Grassle, 1989; Smith et al., 1998), it has been observed that species composition in benthic marine communities varies following geographic and bathymetric gradients. Species distribution, however, is a dynamic process known to have varied significantly over time due to strong modifications in the environmental conditions and geomorphology of the oceans and continents. Although world oceans are to some extent interconnected, the presence of physical and ecological distributional barriers (e.g., continental masses, currents, water fronts, water temperature, nature of substrate, availability of food) strongly limits species dispersion, thus favouring the existence of geographic distribution patterns and the recognition of zoogeographic provinces (Vermeij, 1978; Brown & Gibson, 1983; Camus, 2001).

The Baja California Peninsula started to form about 4-6 millions years ago, when a large strip of continental Mexico was separated from its west coast and slowly drifted in a northwesterly direction to unite with the Pacific Plate (Anderson, 1972; Brusca, 1980). Events subsequent to the formation of the Baja California Peninsula resulting from the drifting of a large strip of continental Mexico since the Miocene, have been described by Durham & Allison (1960) and Coney (1983). As far as plate tectonic and continental rifting is concerned, it is considered one of the most dynamic areas worldwide in the last 220 millions years. As for today, it represents one of the longest peninsular area in the world (ca 1200 km long), separating two different bodies of water well connected at southern end of Baja California. On the west coast, the superficial California Current which flows in a southerly direction, provides the area with a mostly warm-temperate character (< 23°C), with a Pacific Ocean-dependent hydrographic regime and a distinct warm-temperate fauna; on the east coast lies the Gulf of California, one of the largest enclosed-sea worldwide, characterized with warmer shallow water, a complex current pattern and a fauna with a very strong tropical affinity, and mostly under the influence of warm (> 25°C) water masses from the tropical eastern Pacific (Álvarez-Borrego & Schwartzlose, 1979; Brusca, 1980; Hendrickx, 1992; Fernández-Barajas et al., 1994; Espinosa-Carreón et al., 2001; Hendrickx et al., 2005). A small section of the marine extension along the west coast of Baja California (south of Magdalena Bay to Cabo San Lucas) is now considered as part of the Cortés Province that also includes the entire Gulf of California, while the rest of the Baja California Peninsula (north of Magdalena Bay) is part of the warm-temperate Californian Province that has its northernmost limit in Point Concepción, California (Garth, 1955; Hendrickx et al., 2005).

The purpose of this study is to evaluate the richness of the deep-water mollusks fauna on both sides of the Baja California Peninsula according to its latitudinal and bathymetric distribution.

**Material and Methods**

Records included in this study correspond to species of deep-water mollusks known to occur in > 200 m between 23°-31°N and 106°-119°W, an area that roughly includes the slope of Baja California in the influence zone of the California Current (CC) offshore Baja California and the Gulf of California (GC) (Fig. 1). Records were obtained from three major sources: published literature (see annex 1), material collected during the Talud IV-IX cruises in the SE Gulf of California (see Zamorano et al., 2007), and a subset of the data base of SCRIPPS Institution of Oceanographic corresponding to Mexican Pacific records for the defined area.

Nine latitudinal intervals of one degree each were defined. Similarly, eight depth intervals of 500 m range each were defined, from 200 to 4200 m, the latter corresponding to the deepest known record for mollusks in this area. Each interval is named after its numerically lower limit. Using the criteria of “presence-absence” of species and genera in the GC, the CC, and in each latitudinal or depth category, a series of five similarity index were calculated (i.e., Jaccard, Sørensen, Sokal and Sneath, Braun-Blanquet, and Ochiai-Barkman: Magurran, 1988) for each area (CC and GC) and between areas. The use of different indices will allow for future comparison with data resulting from similar analysis for other deep-water groups or geographic areas using any of those indices.

**Results**

Altogether, we were able to locate 685 records, with 177 from the CC and 508 from the GC. The highest number of records occurred in the 28° interval (41) in the CC area, and in the 27° interval in the GC (89); the number of records were always considerably higher for each latitudinal range in the GC, except for 30° and 31° (Fig. 2).

We found records of 281 species and 201 genera of deep-water mollusks for the study area. In order to calculate species and generic richness on both sides of the Peninsula, data obtained for the CC and the GC areas were compared. A total of 202 species (148 genera) are recorded for the GC and 118 (104 genera) for the CC, with only 39 species (51 genera) in common; similarity is 19% of total in species and 33% in genera.
When similar latitudinal intervals are compared, species compositions on both sides of the Baja California Peninsula are very dissimilar. Highest similarity corresponds to 23° (from 4 to 15%, depending upon index used); in 27° and 28°, similarity indices varied from 2 to 10 and from 3 to 10, respectively. There were no species in common when the CC and GC similar latitudinal intervals were compared (Table 1). Species richness on either sides of the Peninsula presents a rather similar pattern, with an apparent peak at 27-28°N (67-26 and 67-39 species; Fig. 3 & Table 1) with high values also observed at 23°. At all latitudes, except in the 30° interval, richness is higher on the GC side (Fig. 3).

When genera are compared, indices are higher than with species (Table 2), and there is at least one genus in common on both sides of the Peninsula for each latitudinal interval, except in 30°. Higher similarity is observed at 23° (indices: 7 to 26%) and 28° (6 to 21%).

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**Figure 1.** Study area indicating the geographic limits of the marine areas corresponding to the Baja California Peninsula (California Current, CC) and the Gulf of California (GC). The Gulf of California is included within an imaginary diagonal line running from Cape San Lucas to Cabo Corrientes, while the area identified as the California Current runs from Cabo San Lucas to the borders of Mexico and the United States.

**Figure 1.** Zone d’étude indiquant les limites géographiques des zones maritimes correspondant à la péninsule de Basse Californie (Courant de Californie, CC) et du Golfe de Californie (GC). Le Golfe de Californie est inclus dans une ligne imaginaire en diagonale allant de Cabo San Lucas à Cabo Corrientes, tandis que la zone identifiée comme le Courant de Californie va de Cabo San Lucas à la frontière entre le Mexique et les États-Unis.

**Figure 2.** Number of records of deep-water mollusks for latitudinal range (1° interval) off both coast of the Baja California Peninsula. CC, California Current; GC, Gulf of California.

**Figure 2.** Nombre de signalements de mollusques d’eau profonde par tranche de latitude (intervalle de 1°) au large des côtes de la péninsule de Basse Californie. CC, Courant de Californie; GC, Golfe de Californie.
The number of records by depth interval varies drastically, with a sharp decrease with depth increase (Fig. 4). Maximum number of records (265) is obtained in the 200 m interval in both the GC (265 records) and the CC (79 records only). All depth intervals shallower than 2700 m feature higher species richness in the GC than in the CC, but a reverse trend occurs in deeper water (Fig. 4). With respect to similar depth intervals, species composition on either sides of the Peninsula is very distinct; with 21 species in common, higher similarity is observed for the 3200 m depth interval (3 to 26%, depending upon the index used), followed by the 200 m interval (6 to 21%) (Table 3).

As observed with latitude, variation of species richness following the depth gradient presents a similar trend on both sides of the Peninsula, with maximum numbers of species in the 200-699 m depth range. In deeper water, species richness decreases steadily to 1700-2199 m, where a low, secondary-peak is observed. In the CC, a second, slight increase of richness is also observed in the 3200 and 3700 m depth intervals (Table 3 & Fig. 5). Species richness is higher in the GC in shallow intervals (i.e., 200 to 2200 m intervals), but below (2700 to 3700 m intervals) a reverse trend is observed. When genera are concerned, similarity increases in almost every depth compared to species (compare Tables 3 & 4), with higher values in the 200 m interval (10.92 to 34.14%, depending upon the index) and

### Table 1. Species richness (number of species) and similarity indices calculated for 1° of latitude range on both sides of the Baja California Peninsula. CC, California Current; GC, Gulf of California; JI, Jaccard; SI, Sørensen; SSI, Sokal and Sneath; BBI, Braun-Blanquet; OBI, Ochiai-Barkman.

<table>
<thead>
<tr>
<th>Latitude</th>
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<th>Common species</th>
<th>Similarity indices (%)</th>
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</thead>
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</tr>
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<td>60</td>
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<td>5</td>
</tr>
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<td>41</td>
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</tr>
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<td>20</td>
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</table>

**Figure 3.** Latitudinal gradient of deep-water mollusks richness (number of species) for latitudinal range (1° interval) off both coast of the Baja California Peninsula. CC, California Current; GC, Gulf of California.

**Figure 4.** Number of records of deep-water mollusks for each depth interval (500 m range) off both coast of the Baja California Peninsula. CC, California Current; GC, Gulf of California.
the 1200 m interval (9.80 to 31.50%). The Ochiai-Barkman index is also remarkably high (28.87%) in the 3200 m interval (Table 4). There are no species or genera in common (similarity = 0) in the same depths intervals (2200, 2700, and 3700).

**Discussion**

Most published informations related to deep-water mollusks off the Baja California Peninsula (both coasts) deal with taxonomy. Parker (1964) briefly analysed the slope mollusks fauna of the Gulf of California, including data from a few samples of the California Current area. He reported 33 species in 28 genera, of which 4 species (4 genera) were exclusively from the California Current (all from one station, ca 23°N-113°W; 3481-3518 m depth). The rest (29 species, 24 genera) was all collected from the Gulf of California in wide latitudinal and depth ranges. Escobar-Briones & Soto (1993) listed only four species of deep water (> 200 m) mollusks for the SW Gulf of California. In contrast, our data base includes 217 species in 148 genera for the Gulf of California and 139 species and 104 genera for the California Current, including the records provided by Parker (1964) and Escobar-Briones & Soto (1993).

Our 23°N interval features the highest similarity for both species and genera. This comes as no surprise because it represents the area of confluence between the typical temperate (north) and tropical-subtropical (south and Gulf of California) faunae of the northern hemisphere portion of

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**Table 2.** Genera richness (number of genera) and similarity indices calculated for 1° of latitude range on both sides of the Baja California Peninsula. CC, California Current; GC, Gulf of California; JI, Jaccard; SI, Sørensen; SSI, Sokal and Sneath; BBI, Braun-Blanquet; OBI, Ochiai-Barkman.

<table>
<thead>
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<th>Similarity indices (%)</th>
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<td>18</td>
<td>1</td>
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</table>

**Table 3.** Species richness (number of species) and similarity indices calculated for depth intervals of 500 m on both sides of the Baja California Peninsula. CC, California Current; GC, Gulf of California; JI, Jaccard; SI, Sørensen; SSI, Sokal and Sneath; BBI, Braun-Blanquet; OBI, Ochiai-Barkman.

<table>
<thead>
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<th>Depth interval (m)</th>
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<th>Common species</th>
<th>Similarity indices (%)</th>
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<td>137</td>
<td>21</td>
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<td>65</td>
<td>4</td>
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<tr>
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<td>2</td>
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<td>1</td>
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<td>3200-3699</td>
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the East Pacific, at least for shallow water species. In macroevolutionary terms (Goldberg et al., 2005), it can be seen that this area functions as a sink for a region that recruits taxa through immigration, making it a species accumulation center without a local source. Roy et al. (1998) came to a similar result while analyzing the distribution of gastropods, and they recognized the area of Cabo San Lucas (22.52°N, at the tip of the Baja California Peninsula) as the locality with the highest species turnover.

Among the collected species with a wide geographic distribution ranges are the gastropod *Bathybembix bairdii* (Dall, 1889), known from Alaska (Keen, 1971), the Gulf of California (Dall, 1895), the Gulf of Tehuantepec (McLean, 1996), and off El Salvador (Hendrickx & López, 2006), and the bivalve *Acharax johnsoni* Dall, 1891 known from Washington to Peru, including the SE Gulf of California (Keen, 1971; Zamorano et al., 2007). Although species and genera similarity between the CC and the GC for each latitudinal interval is low and species richness appears higher within the GC than in the CC area, a similar diversity gradient is observed on both sides of the Peninsula (see Fig. 3). Similarity indices using species records clearly tend to decrease with latitude increase (less species towards the north), but this is not clear with genera and similarity values are rather irregularly distributed along the latitude gradient. When both sides of the Peninsula are compared, lowest similarity was obtained in 29°, 30° and 31°N. One obvious reason for this is the significant reduction of areas where depth exceeds 200 m towards the northern Gulf of California. Indeed, the upper Gulf features a maximum depth of ca 450 m and most of it corresponds to continental platform depth (Santamaría-del Ángel et al., 1996) while there is no such limitation on the west side of the Peninsula, where depth regularly increases offshore. Another reason might be linked to a higher rate of endemic species at these latitudes in the Gulf. There are very few data related to the deep-water mollusks in the upper Gulf of California; our records (Zamorano & Hendrickx, 2009), however, indicate that only four species of endemic deep-water mollusks are recognized: *Vitrinella tiburonensis* Durham, 1942, *Trophonopsis diazi* (Durham, 1942), *T. lorenzoensis* (Durham, 1942), and *Vesicomya suavis* Dall, 1913, which represent less that 8% of the total number of species recorded from 29 to 31°N. Comparatively, there are four species of endemic deep water polychaetes and no species of deep-water decapod crustaceans on records for the upper

![Figure 5. Bathymetric gradient of deep-water mollusks richness (number of species) for each depth interval (500 m range) off both coast of the Baja California Peninsula. CC, California Current; GC, Gulf of California.](image)

**Figure 5.** Gradient bathymétrique de la richesse des mollusques d’eau profonde (nombre d’espèces) par tranche de profondeur (intervalle de 500 m) au large des côtes de la péninsule de Basse Californie. CC, Courant de Californie ; GC, Golfe de Californie.

<table>
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<th>Depth interval (m)</th>
<th>Genera richness CC</th>
<th>Genera richness GC</th>
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**Table 4. Genera richness (number of genera) and similarity indices calculated for depth intervals of 500 m on both sides of the Baja California Peninsula. CC, California Current; GC, Gulf of California; JI, Jaccard; SI, Sørensen; SSI, Sokal and Sneath; BBI, Braun-Blanquet; OBI, Ochiai-Barkman.**
Gulf of California (Hendrickx et al., 2005). Thus there is no clear link between species richness and proportion of endemics, as far as our knowledge of this fauna stands.

Both species and generic richness are higher within the Gulf of California than in the California Current. The influence of the wide, species-rich tropical area south of the Gulf of California (Mexico to northern Peru) as a source for species immigration towards the Gulf is well documented for shallow water (see Garth, 1960; Parker, 1964; Brusca, 1980; Hendrickx, 1992) and corresponds to the macro-evolutionary links (Webb et al., 2002; Goldberg et al., 2005; Allen & Gillooly, 2006; Roy et al., 2009). Speciation within biogeographic units along latitude, longitude and depth gradients also partly explains global diversity increase (Valentine, 1968). Yet, no clear explanation can be linked to the apparent lower richness in deep-water mollusks in the CC area until the deep-water currents patterns are fully understood, in particular in what concerns their interaction with the Gulf of California deep-water habitat.

When bathymetric distribution of species on both sides of the Baja California Peninsula is analysed, highest similarity indices for both species and genera are registered for the 200-699 depth interval. This could simply be due to the larger sampling effort of slope communities in shallower depths (i.e., upper slope). Variation in diversity indices along bathymetric gradient follows a similar pattern on both sides of the Peninsula, although similarity at species level never exceeds 30%. Higher species similarity was expected in deeper water but this was not observed with our results, although a slight tendency for similarity to increase with depth was observed with the Ochiai-Barkman index. Obviously, the lack of significant numbers of records in water deeper than 2700 m in the GC does not allow for an appropriate comparison. There are only few areas with depth > 3200 m in the GC and these are mostly found close to the Gulf’s mouth (Álvarez-Borrego & Schwartzlose, 1979; Castro et al., 2000).

Definition of zoogeographic units is generally based on species in common between contiguous areas and on degree of endemism of each area; thus, a lower similarity between two contiguous areas and a higher number of endemics will favour recognition of distinct zoogeographic units. Percentages of endemics needed to recognize a distinct zoogeographic unit has been subject of controversy, with extremes values such as 50% (see Woodward, 1856) and 10% (see Briggs, 1974). Our results indicate that global similarity between the CC and the GC deep-water mollusks faunae is relatively low, and that the number of species exclusive from the GC (Upper Gulf to the mouth) is 54 (ca. 27%) vs. 27 (ca. 23%) in the Mexican part of the CC.

Acknowledgements

This study was supported by CONACyT project 31805-N and partly supported by DGAPA project IN217306-3 (Mexico). Shiptime was granted by UNAM (Coordinación de la Investigación Científica). The authors thank all members of the scientific and technical crews for the help provided during the TALUD IV–IX cruises. We thank E. Coan and P. Valentich-Scott for their assistance with identification of difficult species, and the referees for their comments that enriched this contribution. The sampling and experiments comply with the current laws of the country in which they were performed.

References


Annex 1. Bibliographic sources from which information on deep-sea mollusks on both sides of the Baja California Peninsula was obtained.

Annexe 1. Sources bibliographiques concernant les mollusques d’eau profonde des deux côtés de la péninsule de Basse Californie.


Hoyle W.E. 1904. Reports on the dredging operations off the west coast of Central America to the Galapagos, to the west coast of Mexico and in the Gulf of California in charge of Alexander Agassiz, carried on by the U.S. Fish Commission (Reports on the Cephalopoda). Bulletin of the Museum of Comparative Zoology at Harvard University, 43: 1-71.


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