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Marine Biodiversity Gastropods Surveys as a Model for Early Detection of Exotic-Invaders Species

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Abstract

In this paper we address the importance and transcendence of biodiversity surveys to detect early arrival of exotic species that could become ecological invaders. We used qualitative-intensive surveys of gastropods benthic fauna in high energy beaches as a model for the detection of exotic species. Between 2009-2010, four beaches belonging to the Venezuelan Gulf were sampled every three month through the standard transepts and quadrants methodology using a Ekman grab. We identified 105 gastropods species, 35 of which were new addition to the Venezuelan malacofauna. Ten of these species are new for the Atlantic Ocean, which means, they are introduced species. These species are: *Bittium rugatum* Carpenter, 1864; *Cerithiopsis bakeri* Bartsch, 1917; *Diastoma fastigiatum* Carpenter, 1864; *Odostomia* astricta Dall and Bartsch, 1907; *Odostomia aepynota* Dall and Bartsch 1909, *Odostomia excolpa* Bartsch 1912; *Triphora catallinensis* Bartsch, 1907; *Triphora hemphilli* Bartsch, 1907; *Rissoina burragei* Bartsch, 1915; and *Cyclostremiscus xantusi* Bartsch, 1907. We discussed their geographic origin, transportation way, the status as invaders following currents models and the implication and transcendence of biodiversity baseline studies for the future monitoring of exotic and/or invaders species around the american continent.

Keywords: Biodiversity surveys; Exotic species; Gastropoda; Oil tankers

Introduction

Gastropods are the most diverse mollusks class with 15.000 fossil and more 35.000 living species [1]. In Venezuela the malacofauna, as in the majority of tropical countries, is varied and highly diversified but has been mainly studied along the eastern coasts [2-11]. In contrast, the western coasts and especially the northern portion of the Maracaibo System, the Venezuelan Gulf (Figure 1), has been relatively ignored despite its importance as a heavy maritime route for oil tanker ship. The malacofauna of this mixed aquatic ecosystem was primarily studied along difficult access marine zones [12,13] representing only the mollusks fauna of deep or off shores waters (118 species). However, in an increasing effort to know the invertebrate fauna of coastal areas, a 10 year census was done [14] along the marine and estuarine water of Maracaibo System, reporting 58 mollusks species, none of them reported before. These surveys allowed to estimate the invertebrate mortality and ecological damage due to a 25.000 barrel oil spill that covered 40Km of high energy beaches [15].

Using the experience and the usefulness of having pre-spill malacofaunal census, additional efforts were done to extend the invertebrate faunal surveys up to the most northern portion of the Venezuela Gulf, covering more than 150Km of high energy marine coast with unknown malacofauna. These surveys showed an amazing unreported Venezuelan malacofauna, such as 66 bivalve mollusks species [16], but also new additions to the Atlantic Ocean, suspiciously suggesting that some of these species could be exotic arriving to the Maracaibo System, likely associated to the heavy traffic of oil tanker traveling from distant latitudes. To test this statement in this paper we present and discuss the results of a geographically extended gastropod surveys that detected exotic species and visualize the importance of these kind of studies in order to have updated the continued introduction of those species, in a world with strong and growing maritime commercial traffic

Materials and Methods

The upper west northern coast of Venezuela Gulf is part of the Peninsula Goagira, a natural limit between Venezuela and Colombia. This area has more than 150km of high energy sandy beaches along which we set four sampling station: Neima, Cojoro, Porshoyle y Castilletes (Figure 1). We sampled these four stations, every three months during two years (2009-

2010), with a Ekman grab (sampling surface area = 0.022m^2) using the standard methodology of quadrants and transepts [15]. In each station we set a 50m transept, at right angle to the coast line during low tide. Each 10m, we took three samples perpendicular to the transect, each spaced 2m aparts. In the laboratory, each sample was passed through a 600µm sieve, and the collected gastropods identified to the species level with classical malacological taxonomy literature [17-21] using a stereomicroscope and in some cases a binocular microscope. The specimens were fixed with 10% formalin and preserved in 70% ethanol. Then, they were deposited and cataloged in the Section of Aquatic Invertebrates of the Museum of Biology of the University of the Zulia (MBLUZ), Maracaibo, Venezuela. Pictures were taken with a digital camera Lumix Panasonic (10mp).

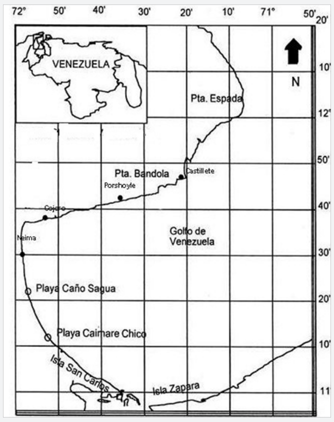

Figure 1: Maracaibo System (Sistema de Maracaibo) map showing sampling stations.

Results

In the whole period of sampling, there were obtained 11.798 gastropod specimens belonging to 105 species, distributed in 30 families, being the most representative, Piramidellidae, Cerithidae and Vitrinellidae with 19, 13 and 8 species respectively (unpublished authors data). The beach with the highest diversity was Castilletes with 76 species, followed by Cojoro and Porshoyle with 60 and 55 species respectively, and finally Neima with 47. As it is seen, there is a southward reduction in diversity, a fact that has been discussed as a consequence of increasing northward sand grain size and a southward increasing of organic matter content of the sediment [22]. Most species collected in the present study (75%) are common dweller of the western portion of the Atlantic ocean and the Caribbean region [17, 19], Many of them, very abundant, have been reported in previous studies along Venezuela coast [7,23], such as *Diastoma varium* and *Caecum pulchellum*, among other.

From the gastropods species previously mentioned [12,13] for the Venezuelan Gulf, only six had been reported along other Venezuelan coast [7,23]: *Neritina virginia*, *Caecum pulchellum*, *Persicula* (*Marginella*) *lavalleeana, Retusa candei, Seila adamsi* and *Turbonilla interrupta*. This fact is interesting because tell us about the importance of performing periodic monitoring in order to follow up temporal changes in biodiversity, specially in these kind of environments prone to ecological impacts (oil exploitation, commercial fishing and heavy traffic of international ships) and biotic invasions. Last formal study was performed 34 years ago [13] and many changes must have occurred. In addition, the present study also confirms the presence of species reported as missing [15] after the huge oil spill happened in 1997 along part of these high energy beaches (*Olivella minute, Diastoma varium, Eulima bifasciata, Cerithiopsis latum* and parasitical *Cochliolepis* sp.).

More interesting, from the 35 new species being reported for Venezuelan waters (Table 1), we must highlight ten species found for the first time in the Atlantic Ocean and their importance as an early detection of possible invasive species, a fact we analyze in the lines below. The new species for the Atlantic Ocean are the following:

Table 1: List of new species for Venezuela and Atlantic Ocean waters.

Estacion	Neima	Cojoro	Porshoyle	Castillete
Cerithiidae				
*Alabina cerithidioides**				X
*Bittium rugatum***				X
*Cerithiopsis. abruptum**			x	
*C. bakeri***	x		x	X
*C. berryi**		x	x	
*C. trumcatum**	x		x	
*Cerithiella witheavesii**			x	X
*Diastoma fastigiatum***	x	x	x	X
Triphoridae				
*Triphora catalinensis***	x	x	x	X
*T. hemphilli***		x	x	X
*T. compsa**			x	X

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Piramidellidae				
*Odontomia. astricta***		x		X
*O. aepynota***		x	x	
*O. impressa**			x	
*O. callimorpha**			x	
*O. excolpa***				X
*O. pocahontase**				X
*O. franciscana**			x	
*O. barkleyensis**		x		
*Fargoa bushiana**	x	x	x	X
Turbinidae				
*Arene cruentata**			x	X
Rissoidae				
*Rissoina burragei***				X
Vitrinellidae				
*Cyclostremicus xanthusi***	x			X
*C. pentagonus**		x		X
*Parviturboides interruptus**		x	x	X
*Anticlímax athleenae**				X
Eulimidae				
*Balcis intermedia**				X
Turridae				
*Ithicytara lanceolata**				X
Acteonidae				
*Acteon puntostriatus**	x	x		X
Cymatiidae				
*Cymatium poulseni**				X
Caecidae				
*Caecum. tornatum**		x	x	X
*C. clava**		x		X
Columbellidae				
*Colus pygmaeus**			x	
Trochidae				
*Euchellus gutarosea**		x		
Stiliferidae				
*Athleene burrii**				X

*New for Venezuela. **New for Atlantic Ocean.

Bittium rugatum Carpenter [24], Figure 2A, Cat # MBLUZ 2400

This is a common fossil species along the western coast of North America [25]. Living populations are known from San Pedro, California, USA, up to Baja California, México [19,25]. It has been mentioned as member of the malacofauna of some pacific Mexican marine coastal lagoons [26] and several specimens have been recorded from beaches of San Diego, Santa Monica and Timms Pt., California, USA (University of Florida Malacology database Cat # 191563, 191574 and 236116). It was named originally as *Bittium asperum* and reported for the western coast of USA [24]. The present record is the first for the Atlantic Ocean and the Caribbean Sea.

Cerithiopsis bakeri Bartsch 1917 [27], Figure 2B, Cat. # MBLUZ 2403

Described from South Coronado Island, Baja California, Mexico [27], is the only known locality [19]. WoRMS and ITIS

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databases also mention this species but without specific geographic distribution. An unpublished record of this species exists at the Florida Museum of Natural History (University of Florida Malacology database Rec. # UFMO349655) from material collected in 1979 from Little Torch Key, Florida, USA, in the Atlantic Ocean. Thus, this record confirms our finding of this species in Venezuelan waters.

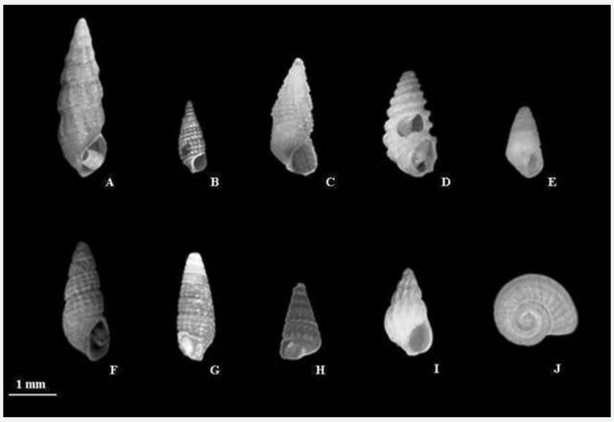

Figure 2: New Gastropods species for the Atlantic Ocean. See text for details.

Diastoma fastigiatum Carpenter 1864 [24], Figure 2C, Cat. # MBLUZ 2409

Originally described as *Bittium fastigiatum*, it is also a species coming from USA western shores, collected from Santa Barbara, California, but its geographic range was defined from Southern California to The Gulf of California [19]. Recent data loaded into the Gulf Invertebrate Macrofauna Database of the Arizona-Sonora Desert Museum set the range of this species from Santa Barbara California, USA, to Smith Island, Baja California, México. This range defined, grossly, a previous endemic distribution but the present record clearly represents an introduction in the Atlantic Ocean and Venezuela waters.

Odostomia aepynota Dall and Bartsch [28], Figure 2D, Cat # MBLUZ 2420.

Another previously endemic species of Californian Gulf western coast, it was described from 31 specimens collected along San Pedro beach, California [28]. Later, its geographic range was set from Palos Verdes, California to Baja California, México [19]. Mentioned as a member of the subgenus *Miralda*, is considered a common dweller along the Pacific coast of California [20,29]. *Odostomia aepynota* var. *planicosta* is considered a synonym [19]. This species is registered in the USNM data base Figure 2E (Cat.# 199365) as collected in San Pedro, California, USA [30]. Before finishing the present article, we found two recent citations of this species. The first was done in a short article related to intertidal micromolluscs of southern California [31] and the second by the Mexican Government [32] about the biota of the Los Pulmo Cabos National Park, located at the very southern end of Californian peninsula. Up to the present time, there is not report or specimens collected inside the Atlantic Ocean. *Odostomia* astricta Dall & Bartsch [33], Figure 2F, Cat # MBLUZ 2419

This species was first cited [33] but fully described later [28] from specimens collected at Monterrey, California, USA. Confirmed later to the same locality, there were set several synonyms: *O. cooperi, O. montereyensis, O. lucca* and *O. oldroydi* [19]. Remarkable, *Odostomia* astricta is one of the few species well covered by the Wikipedia web site, where it is used the original description dated back in 1909 [28]. Here it is reported only for "Pacific Ocean off California". The GBIF Database has two records. One is from Redondo Beach, California and the other for Baja California, México, without specific locality. This species is also registered in WoRMS [34] and ITIS Database without locality citation. There is no previous report of *O. astricta* for the Atlantic Ocean.

Odostomia excolpa Bartsch 1912 [35], Figure 2E, Cat # MBLUZ 2421

This third species of the Genus *Odostomia* also cited as endemic from the Californian Gulf [19] was described as *Odostomia* (Besla) *excolpa* (Holotype Cat. No. 198903, U.S.N.M.) from a single specimen collected by Dr. Edward Palmer at the head of the Gulf of California. This species is also cited by Wikipedia, unfortunally both the figure and the description belong to *O. convexa* Carpenter 1856. It is also registered by ITIS and WoRMS databases [20]. In addition, two new web sites, ADW [36] and EOL (http://eol.org/pages/455545/overview) also mention this species without any geographic information. There is not report or specimens collected of this species along the Atlantic Ocean.

Triphora catallinensis Bartsch 1907 [37], Figure 2H, Cat. # MBLUZ 2412

Originally described as *Triphoris catallinensis*, is another endemic species along the pacific coast of California, USA, reported initially only from Catalina Island, California [38]. Its geographic range is actually extended up to Laguna Beach. Unpublished records at the National Museum of Natural History, Invertebrate Zoology Collection, Cat. # 800630 and 474699, extends its distribution based on specimens collected in 1977 at Channel Islands, Santa Rosa Island and Johnson's Lee, California, USA. This distribution was confirmed recently [39]. However, in the same situation as C. bakeri, there is also an unpublished record for the Atlantic Ocean. Specifically, from the University of Florida Malacology database (Rec. # UFMO349662) where there are specimens collected in 1985, along the beach of Fiesta Americana Hotel, Cancun Island, Quintana Roo, México. Thus, this unpublished report, confirms the validity of our records from Maracaibo System, Venezuela.

Triphora hemphilli Bartsch 1907 [37], Figure 2G, Cat. # MBLUZ 2414

Originally described as *Triphoris hemphilli* [37] from Point Abreojos, Baja California, México, it is a common fossil species

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since Pliocene times along the Mexican pacific coast [40]. Abbott [19] only reports this species from the type locality, however, the WoRMS Data Base sets Texas, Gulf of México, as actual distribution based on a list of species names [41] about the diversity of the Gulf of Mexico [42]. This report in WoRMS is due to the description of new benthic algae found in the Gulf of México [43]. *T. hemphilli* was found on the leaves of this macro alga. Thus, also in this case, this unpublished report confirms our finding of *T. hemphilli* in the Atlantic Ocean, and suggests that interoceanic transport of gastropods is also possible through long distant traveling floating macro algae.

Rissoina burragei Bartsch 1915 [44], Figure 2I, Cat. # MBLUZ 2448

Originally reported from San Francisquito Bay, Gulf of California [44], but with additional specimens from the head of Concepcion Bay, Mulege and Agua Verde Bay. Its distribution was confirmed [19] as a species broadly dispersed in the Gulf of California. The geographic range for this species, following the Global Biodiversity Information Facility (GBIF) Database, goes from Espiritu Island, Gulf of California, USA, to San Juanico, Baja California, México. In Mexican waters has been reported in Punta Peñasco, Sonora [45]. Several data base (ITIS, WoRMS, and BioLib) cite this species but none reports geographic ranges. The most recent list of Costa Rica species [46] indicates that *R. burragei* is present in the Pacific Panamiam provinces, specifically in Isla del Coco, Puntarenas, Costa Rica. Apparently, out of the 10 species being presented in this paper, this is the one with the broadest geographic range covering USA, México and American Central coasts. Up to the present time, there is no report of *R. burragei* for the Atlantic Ocean.

Cyclostremiscus xantusi Bartsch 1907 [47], Figure 2J, Cat. # MBLUZ 2451

A very small species, reaching no more than 3mm, usually less than 2, it was described as *Cyclostrema* xantusi from one unique specimen collected is Cape San Lucas, Baja California, México [47]. Later, also reported as *Cyclostrema*, another single specimen was collected from the northeast Anchorage, Monserrate Island, Gulf of California, and other four taken at Cape San Lucas, also the type locality. In the 70s, this species was relocated in the Genus *Cyclostremiscus* [19]. Very recently it also appears listed in the fauna of Humedales of Ramsar, specifically in the Parque Nacional Bahía de Loreto, Mar de Cortez, Baja California Sur [48]. *C. xantusi* is also referred by WoRMS, ITIS and BioLib but without specific locality. There is no report of this species for the Atlantic Ocean.

Discussion

The presence of exotic gastropod mollusks is not new in Venezuelan waters. The first exotic gastropods in Venezuela likely arrived with the first Spanish colonizers in the XV and XVI centuries [49], as apparently was the case of the slugs of Arionidae family. In recent times, even thought many species were considered, at first look, as new autochthonous species not being reported before for Venezuelan waters, later it was realized that in fact those species were not autochthonous but exotic species introduced in some way from other latitudes. The first documented exotic gastropod in Venezuela, *Agriolimax reticulate* [50] was a pulmonate slug that was originally from Europe. It has been pointed out that these kinds of gastropods were introduced by immigrating farmer that arrived to Venezuela in the XIX century [49]. In the XX century, *Arion subfuscus* was reported as a species that came from paleartic waters [51]. These species were all terrestrial, therefore their introduction was very likely anthropogenic. Introduced aquatic gastropod in Venezuela began in early 70's with *Thiara (Tarebia) granifera*. This estuarine-freshwater species, originally from the Indo-Pacific Ocean was brought into the United States and sold widely as an aquarium snail. Its anthropogenic spreading indicates [52-54] that left from Florida to Puerto Rico in 1953 and then followed a continues invasion of Dominican Republic (1967), Grenada (1970), Venezuela (1970), Haiti (1972), Antigua (1980), and Costa Rica (1983). Around the 90's T. *granifera* was spread into continental northern waters along central Venezuelan together another freshwater gastropod, *Melanoides tuberculata* [54] originally from Asia [49]. We have found huge populations of both species at the very southern water of Maracaibo Lake (author unpublished data). In a revision of the status of exotic species in the Andean region [49] there were added two new exotic aquatic gastropods for Venezuelan waters, *Pomacea canaliculata* and *P. bridgesi*, both coming from cold water of South America.

The concept of cryptogenic species was introduced into Venezuelan terminology [55] as species that look like exotics but with uncertain status due to lack of scientific information. At this respect, there have been several exotic species initially not reported as such: *Babylonia aerolata* (from Indopacific) [23], *Fusinus barbarensis* (from Pacific ocean) [56], *Fusinus marmoratus* (from Mediterranean Sea) [23,56], *Modulos cerodes* (from Pacific oriental) [23,56], *Vasum ceramicum* (from Indic ocean) [23,56] and *Umbraculum plicatulum* (from the Mediterranean Sea) [23,56]. At present, these species are considered exotic but we really do not know whether or not they are reaching the status of invasive species.

Several ways of introduction of these exotic species to the Atlantic ocean could be postulated, however, due to the nature of the main economic activities going through the Venezuelan Gulf [57], it is very likely that several events of ballast water expulsion, containing larval stages of gastropods, should be mainly the responsible process for the introduction. Being the Venezuelan Gulf an area of marine influence, it is very prone to be colonized successfully by some species that can find inside the ballast water tanks favorable conditions to survive. We postulate that this event probably took place through several ships that traveled from the Californian Gulf, or nearby areas, to Venezuela through the Panama Channel, a very usual interoceanic route

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for ships. The transportation could take more than one step, one up to the Panamian area, and a second crossing the Panama Channel, since that two out the nine exotic species have been reported for the Central American Pacific water.

Based on the finding of unpublished record of the exotic species reported in this paper, we may postulate that the earliest introductory even could has been take as early as 1970. In effect, *T. hemphilli* was added to the Atlantic marine biota indirectly (not as a publication) by Rosenberg from a report of new macro algae from the Mexican Gulf [39]. *C. bakeri* also has an unpublished record dated in 1979. These reports mean that, out the species being reported in this paper, the first one entered into the Atlantic Ocean no later than 35 years ago.

However, more interesting to discuss, is the presence of *T. hemphilli* fossils in Florida and Texas Miocene sediments, a fact that could generate two contrasting hypothesis. In both we need to postulate that before the Miocene this species had a broad interoceanic geographic range around the Panamá Channel. After its lift up, two splitting events could happen. Under the first scenario, the Panamian bridge created two allopatric populations of the same species. Both populations decreased dramatically because of the strong environmental changes cause by the lifting itself, becoming very small populations, endemic and rare. This would be the scenario that explains the presence of the same species in both oceans, and if it is the case *T. hemphili* is not a exotic species. A second hypothetical scenario would be that in which after the raising of Central America, the Atlantic population became extinct and in nowadays the mankind reintroduced the species in the Atlantic Ocean.

Some authors [58] have discussed the concept of invasive species respect to the concept of exotic one, and have proposed an operational framework to define the stage of an exotic species since its first successful arrival. Following this framework, we may classified the exotic species being reported in the present study as stage III (localized and rare) or IVa (broad distribution but rare). Within this context, rare means low abundance and not dominant. Only *Bittium rugatum* and *Rissoina burragei* fall within stage III. The other species are distributed southward covering more than 100Km from the likely first settlement inside the Maracaibo System (Castilletes beach) since their arrival as stage II (effective survival and reproduction). We may expect that these exotic species can continue their dispersal southward as long as they can find suitable marine habitats and could reach stage V (broad distribution and abundant). Once this stage is gotten, an exotic species may become an invasive species capable of producing ecological competition, displacement of autochthonous species and changes at trophic level.

Considering the above statements and that the ten exotic species reported here are autochthonous of the same region, the Gulf of California in USA, Pacific Ocean, is likely to state that all these species colonized the Atlantic Ocean in no more than two event, ie. Ballast water of ships "contaminated" with gastropods larvae coming from the pointed Pacific Ocean region. This also may explained why broad malacological taxonomic inventories covering the Gulf of Mexico, Florida Peninsula, Atlantic Costa Rica beaches, the Colombian Caribbean and Venezuelan coast [15,23,59-63] did not find any of the species mentioned, before this report.

We must emphasize the significance of periodical biodiversity surveys that, as in the present case, allow to detect early arrival of exotic species and try to impede, if possible, damaging spreading and ecological destruction of resources and fisheries. In the worse case, at least be prepared. These kinds of surveys are imperative for those countries which are obligate steps for international ship routes, not only oil but also any kind of goods. Additionally, this surveys are crucial for countries with unknown invertebrate aquatic fauna because exotic invader may destroy existing fauna without knowing them before its disappearance. In our todays globalize world, the prevention and facing of rapidly growing exportation of exotic species will be critical for the maintenance of the global ecological equilibrium of the planet [64-67].

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