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INDIRECT EVIDENCES ON THE CONNECTIVITY OF CORAL REEFS OF THE GULF OF MEXICO AND THE MEXICAN CARIBBEAN

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Abstract. Coral reef connectivity results from the export and import of species or reproductive product between localities. Possible exchange pathways between the reef ecosystems in the country are not known; such knowledge about coral reef connectivity could contribute to its management and conservation. The connectivity between reefs of the Gulf of Mexico and Mexican Caribbean was evaluated based on patterns of similarity. Information for 48 stony coral species in 19 localities was compiled from different sources. Species richness suggests that the highest coral biodiversity is located around Cozumel on the Caribbean with 33 species. Cluster analysis based on biological similarity between localities shows that the Veracruz Reef System (VRS) is more similar to the reefs of the Mexican Caribbean than those on the Campeche Bank. Correlation (Mantel test) of biological similarity with geographical distance, days of transport by currents and environment variables, was negative and highly significant, corroborating that biological similarity decreases with increasing distances. The hypothesiss that the reefs of the VRS and the Caribbean are more similar because these areas are less affected by hurricanes is proposed. This environmental stability would lead to an accumulation of Caribbean coral species that makes VRS more similar to the Caribbean than to those reefs in the Northern Veracruz or those in the Yucatan shelf.

Key words: Connectivity, Dispersion, Coral reefs, Similarity

Introduction

Coral reefs are open systems that exchange organisms, nutrients and reproductive products, wholly or partly mediated by water flow (Sale, 2004). The density of populations occupying the reef ecosystem depends in part on reproductive effort of the species in remote areas where gametes are released, on the eficiency of mechanisms of transport in terms of larval viability and level of connectivity, and on the own reproductive capacity and recruitment of local populations (Roberts 1997). Most coastal marine species have limited adult movement, so the relative short-lived pelagic larval stages represent the primary opportunity for dispersal. Following the pattern of surface currents, some attempts have been made to try and define the transportation routes that are followed by larval stages, resulting in the recognition of general pathways of connectivity amongst the different areas where coral ecosystems occur (Cowen et al. 2006).

Connectivity in the marine environment can also be constrained by biogeographic barriers as seen in terrestrial environments, which are not easy to discern, due to the short duration of larval stages and dispersal mechanisms by currents (Thorrold 2006). One way to infer connectivity from the ecological point of view, is to determine the similarity of ecosystems from background information such as species richness, number species shared, the similarity of environment and their relationship to geographical distance. In general, those communities that are farthest from each other should be the less similar due to their lower connectivity (Nenkola and White 1999; Steinitz et al. 2006). Such relationships between the reef ecosystems of the Gulf of Mexico and Mexican Caribbean is unknown, so better knowledge should contribute to improve decision-making in management and conservation.

Material and methods

Records of species of corals of the Gulf of Mexico and Mexican Caribbean (Fig. 1) were compiled from seven different sources with comparable methodology (Table 1). Data were organized in tables according to species abundance, dominance, and Shannon-Wiener diversity (Magurran 1988).

Depending on the parameters of the community, analysis of qualitative biological similarity was carried out first with data on presence/absence by applying the Jaccard and/or Sorensen indices (Nenkola and White 1999; Steinitz et al. 2006). Similarity was determined with the Manhattan distance as a measure of affinity and the method of Ward as a strategy of agglomeration.

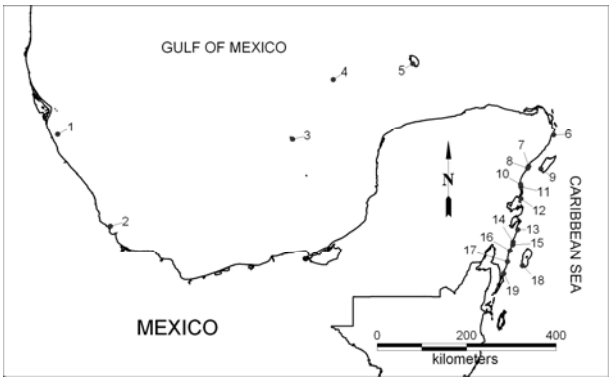

Figure 1. Corals reefs considered in the Gulf of Mexico and Mexican Caribbean: 1. Tuxpam, 2. Veracruz Reef System, 3. Triángulos, 4. Cayo Arenas, 5. Alacranes, 6. Punta Nizuc, 7. Akumal, 8. Chemuyil, 9. Cozumel, 10. Boca Paila, 11. Punta Yuyum, 12. Punta Allen, 13. Tampalam, 14. El Placer, 15. Chaguay, 16. Mahahual, 17. Xahuayxol, 18. Chinchorro Bank, 19. Xcalak.

Table 1. Coral reef localities and source of data included in this study. A = abundance data; P = presence data

Data	Locality	Source
A	Akumal	1, 3
P	Alacranes	4, 7
A	Boca Paila	1
A	Cayo Arenas	4, 7
A	Chaguay	1
A	Chemuyil	3
A	Chinchorro Bank	1, 4
A	Cozumel	3
A	El Placer	1
A	Mahahual	1, 2, 3
A	Punta Allen	1
A	Punta Nizuc	5
A	Punta Yuyum	1
A	Veracruz System	5, 6, 7
A	Tampalam	1
A	Triángulos	4, 7
P	Tuxpam	6, 7
A	Xahuayxol	1
A	Xcalak	1

Source: 1. Marks and Lang (2005); 2. Aguilar-Ontiveros (1998); 3. Borges-Souza & Chávez (2007); 4. Chávez et al. (1985); 5. Gutiérrez et al. (1993); 6. Pérez-España (2007); 7. Horta-Puga et al. (2007)

Similarity was also explored using other indices (Legendre & Legendre, 1998). Correlation of biological similarity with the geographical distance, the days of transport by currents and environmental similarity was assessed using simple and partial Mantel test (Fortin and Gurevitch 1993). Geographical distances were estimated using a geographic information system (GIS), to construct the matrix of distances and the matrix of days of larvae drifting being transported by currents (mean annual velocity, Mariano et al., 1995). A matrix of environmental similarity was calculated using mean annual environmental factors (sea surface temperature, salinity, oxygen, nitrates, phosphates and silicates) obtained from the NOAA World Ocean Atlas 2005 (http://www.nodc.noaa.gov).

Results

Coral communities had the highest species richness (S) in Mahahual, with 37 species. The highest ecological diversity (Shannon-Wiener) was found in Cozumel, with 4.05 bits/ind. Exploration of presence/absence data did not allow us to find any clear pattern defining how biological similarity declines with increasing geographic distance; for this reason, the following analysis was performed using quantitative data of relative abundances of coral species.

Classification of sites allowed to identify a pattern of grouping the reef localities. Veracruz Reef System (VRS), in the southern Gulf of Mexico, shows higher similarity with localities in the Mexican Caribbean than with localities in the Northern Gulf of Mexico or with those on the Yucatan shelf (Fig. 2)

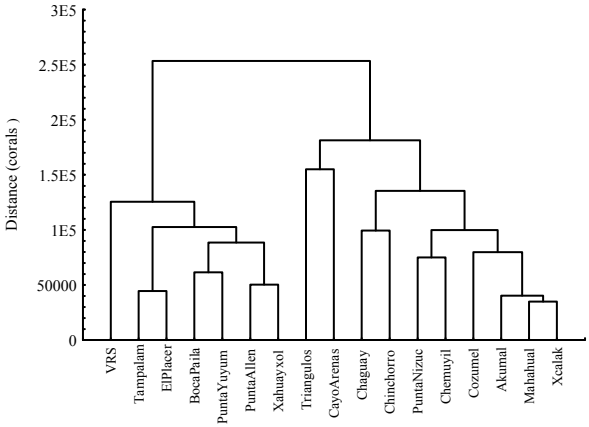

Figure 2. Cluster analysis (Manhattan distance, Ward method) for coral reef localities.

The first two Principal Components based on environmental variables explained 78.6 % of the total variance, with nitrates (0.98) and silicates (0.88) correlated positively with the first component. In the second component, the salinity showed positive correlation (0.89) whereareas sea surface temperature correlated negatively (-0.94).

The arrangement of localities in ordination space depicts a gradient of variability, with the reefs from the south and central Mexican Caribbean and the reefs from the Gulf of Mexico caracterized by low concentration of nitrates and silicates and relatively high concentration of phosphates (Fig. 3). According to the second principal component, the Mexican Caribbean localities were caracterized by warmer surface waters, but less salinity, while the Gulf of Mexico localities were more salty and waters with lower temperature (Fig. 3).

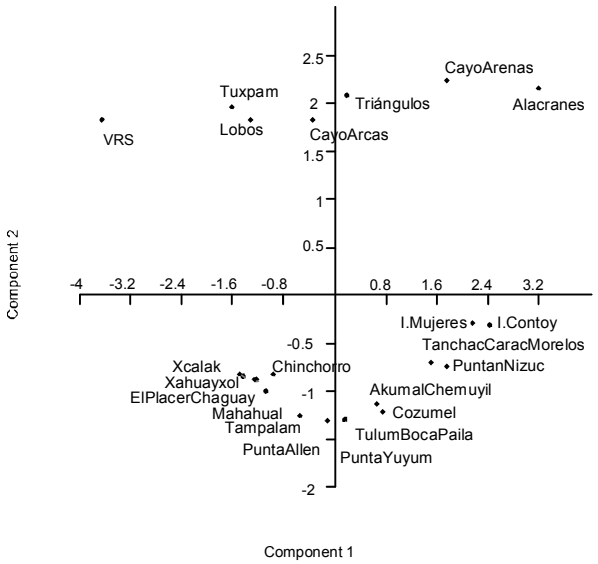

Figure 3. Principal Component analysis using components 1 and 2 as gradients of environmental variability (78.6% of total variance explained.)

A simple Mantel test was used to test the correlation of coral reef similarity with geographical distance, with the distance in days of transport as effect of current and with the environmental similarity showing negative correlations in all cases, except for biological similarity and days of transport by oceanic currents. In such statistical significant tests, the biological similarity between localities decreases as the geographical distance between them increases (Table 2).

Table 2. Simple Mantel test correlation between similarity and relevant distances matrices for coral reef localities. Correlation *r* and statistical significance (*p*) after 10,000 randomizations.

Simple Mantel test	*R*	*p*
biological similarity vs. distance (km)	-0.514	0.018*
biological similarity vs. days of transport	-0.384	0.076
biological similarity vs. environmental factors	-0.615	0.003*
distance (km) vs. days of transport	0.962	0.001*
environmental factors vs. distance (km)	0.885	0.001*
environmental factors vs. days of transport	0.751	0.001*

(*) statistical significance p<0.05

Prior to the partial Mantel test, the simple correlations between the matrices of the independent variables were obtained. All the combinations between them were positive, higher than 0.75 and highly significant (Table 1).

Table 3. Partial Mantel test for relevant matrix combination (vs.) with fixing effects from the third matrix (and) for coral reef localities. Correlation *r* and statistical significance (*p*) after 10,000 randomizations.

Partial Mantel test	*r*	*p*
biological similarity vs. distance (km) and days of transport	-0.572	0.003 *e*
biological similarity vs. days of transport and distance (km)	0.469	0.006 *e*
biological similarity vs. distance (km) and environmental factors	0.084	0.324 *e*
biological similarity vs. environmental factors and distance (km)	-0.402	0.019*
biological similarity vs. days of transport and environmental factors	0.150	0.219 *e*
biological similarity vs. environmental factors and days of transport	-0.537	0.008*

(*e*) spurious correlations, sensu Cramer (2003); (*) statistical significance p<0.05

A partial Mantel test indicated that the correlation of biological similarity with environmental factors, controlling the geographical distance and controlling for distance in days of transport, was negative and significant in both cases (Table 3). The other possible combinations were spurious according to Cramer (2003).

Discussion

Results obtained with the use of different techniques of classification and ordination enabled us to identify patterns of relationship between reef localities by their geographic range and to find results matching our working hypothesis, namely that closer localities are more similar to each other because they share a higher number of species rather than remote locations.

Cluster analysis showed an unexpected similarity between the Veracruz Reef System (VRS) with some more geographical distant reefs of the Mexican Caribbean. This is contrary to the expected idea that the VRS should be more similar to coral reef localities such as those in the Yucatan shelf or those in Northern Veracruz like Tuxpam or Lobos reefs, which are closer. One of the obvious reasons for this similarity is the number of shared species: of the 16 species of stony corals in the VRS, 14 of them are common or shared with Akumal and Mahahual in the Mexican Caribbean, while Cayo Arenas and Triangulos in the Yucatan platform, share only eight and five species with the VRS, respectively.

Higher similarity with the VRS, as well as the higher diversity of coral species at the regional level in the Mexican Caribbean, may indicate in the first case a historical accumulation of species richness in the context of higher stability associated with lower frequency of hurricanes in the Southwest Gulf of Mexico, whereas in the latter case, the recurrent impact of hurricanes in the Caribbean has caused a series of events of destruction and variable pulses of recruitment over time that have produced a diverse regional fauna

but a relatively low richness and low similarity scenario at the local level.

In the last 157 years (National Hurricane Center, 2008), the hurricane frequency as well as the accumulated impacts (frequency weighted by their intensity according to Saffir-Simpson scale) shows differences between regions in the study area. In the Gulf of Mexico, 17 hurricanes of a total of 28, had impacted the coral reefs on the Yucatan shelf, most of them with H1 category. Coral reefs in Northern Veracruz (Tuxpam and Lobos Island) had been impacted by twelve hurricanes, mainly H1 hurricanes, whereas the VRS has received only two impacts by hurricanes. On the Mexican Caribbean, coral reefs have been impacted by a total of 48 hurricanes, with the highest frequency in its northern portion with 28 hurricanes.

In the case of the coral reefs of the Mexican Caribbean and despite the observed patterns of association, there is a high heterogeneity in species composition, indicating that fewer coral species are shared among the sites in that region.

Within each geographic region, similarity between localities decreases with geographical distance, which is generally accepted by the current theory. Our results provide some evidence of the main patterns of connectivity amongst the reefs examined, concluding that ocean currents are the main driving factors responsible of the patterns shown; details of how other factors interact with interconnections of species and reefs are still unknown.

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