Coral Similarity and Connectivity of Some Reefs of the Gulf of Mexico and the Mexican Caribbean

ALEJANDRA CHÁVEZ-HIDALGO, GUSTAVO DE LA CRUZ-AGÜERO, and ERNESTO CHÁVEZ
Centro Interdisciplinario de Ciencias Marinas, I. P. N.
Av. Instituto Politécnico Nacional s/n, Col. Sta Rita, Playa El Conchalito La Paz, B.C.S., 23096 México

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 55 stony coral species in 17 localities. Species richness suggests that the highest coral biodiversity is located in Mahahual on the Caribbean with 37 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 in the Yucatan shelf. 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 hypothesis 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, similarity

Similitud Coralina y Conectividad de Algunos Arrecifes del Golfo de México y Caribe Mexicano

La conectividad de los arrecifes coralinos es el resultado de la exportación de una zona e importación por otra, de fases de propagación de especies que conforman estos ecosistemas. Se desconoce la posible relación entre los ecosistemas arrecifales de nuestro país, por lo que el conocimiento de su conectividad podría contribuir a su manejo y conservación. Con base en los patrones de similitud se evaluó la conectividad entre los arrecifes del Golfo de México y Caribe mexicano. Se compiló información de diferentes fuentes con 55 especies de hexacorales en 17 localidades. Mahahual tuvo la mayor riqueza con 37 especies. Los análisis de agrupamiento, muestran que los arrecifes del Sistema Arrecifal Veracruzano (SAV) son más similares a los arrecifes del Caribe mexicano que a aquellos de la plataforma yucateca. La correlación (prueba de Mantel) de la similitud biológica con la distancia geográfica, los días de transporte por las corrientes y las variables ambientales, arrojaron resultados significativos, corroborando que la similitud biológica disminuye al incrementarse las distancias. Se establece la hipótesis de que los arrecifes del SAV y los del Caribe son mas parecidos debido a que el sur de Veracruz es ambientalmente mas estable ya que es menos afectado por los huracanes, propiciando una acumulación progresiva de especies caribeñas que hace al SAV más similar al Caribe que al norte de Veracruz o la plataforma yucateca.
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PALABRAS CLAVES: Conectividad, dispersión, similitud

Evidences de Connectivite des Recifs Coralliens du Golf du Mexique et des Caraïbes Mexicaines

La connectivité de récif corallien provient de l'exportation et de l'importation d'espèces ou de produit reproducteur entre les localités. Les sentiers d'échange possibles entre les écosystèmes de récif au Mexique ne sont pas connus; une telle connaissance de la connectivité de récif corallien pourrait contribuer à sa direction et conservation. La connectivité entre les récifs du Golfe du Mexique et des Caraïbes mexicaines a été évaluée sur la base de modèles de similarité. Les renseignements pour 55 espèces de corail rocailleuses dans 19 localités ont été cueillis. La richesse d'espèces a reçu la plus haute diversité biologique de corail dans Mahahual avec 37 espèces. L'analyse par grappes basée sur la similarité biologique entre les localités montre que le Veracruz Reef System (VRS) est plus semblable aux récifs des Caraïbes mexicaines que ceux dans le plateau du Yucatan. La corrélation (le test de Mantel) de la similarité biologique avec la distance géographique, les jours de transport par les courants et les variables d'environnement était négative et extrêmement significative, en corroborant que la similarité biologique diminue avec les distances grandissantes. On propose l'hypothèse que les récifs du VRS et des Caraïbes sont plus semblables parce que VRS est moins affecté par les ouragans. Cette stabilité de l'environnement mènerait à une accumulation d'espèce de corail antillaise qui rend VRS plus semblable dans les Caraïbes qu'à ces récifs dans Veracruz du Nord ou ceux dans de le plateau du Yucatan. On propose un modèle conceptuel qui expose la connectivité de récifs dans le Golfe du Mexique et les Caraïbes mexicaines. Ce modèle est basé sur l'analyse de similarité biologique et approuve le modèle général de circulation océanique dans le Golfe du Mexique.

MOTS CLÉS: Connectivité, dispersion, similarité ,

INTRODUCTION

Coral reefs, considered one of the most diverse ecosystems in the world, are open systems, exchanging organisms, nutrients and reproductive products, among themselves and with other reef systems, all of them are wholly or partly mediated by the 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-living pelagic larval stages represent the primary opportunity for dispersal. Following the pattern of surface currents, some attempts have been made trying to 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 effect of currents (Thorrold 2006). One way to infer ecological connectivity, is determining the similarity between ecosystems from background information as the species richness, the number species that are shared, from the similarity of environment and their relationship to geographical distance. In general, those communities that are farthest from each other are the less similar due to their lower connectivity (Nenkola and White 1999, Steinitz *et al*. 2006). The degree of existing relationship between the reef ecosystems of the Gulf of Mexico and Mexican Caribbean is unknown, so their knowledge should contribute to improve decision-making in management and conservation.

METHODS

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

Depending on the community parameters, analysis of biological similarity was determined with the Manhattan distance as a measure of affinity and the method of Ward as a strategy of agglomeration. Eventually, similarity was explored using other indices (Legendre and Legendre 1998). Finally, 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 infor-

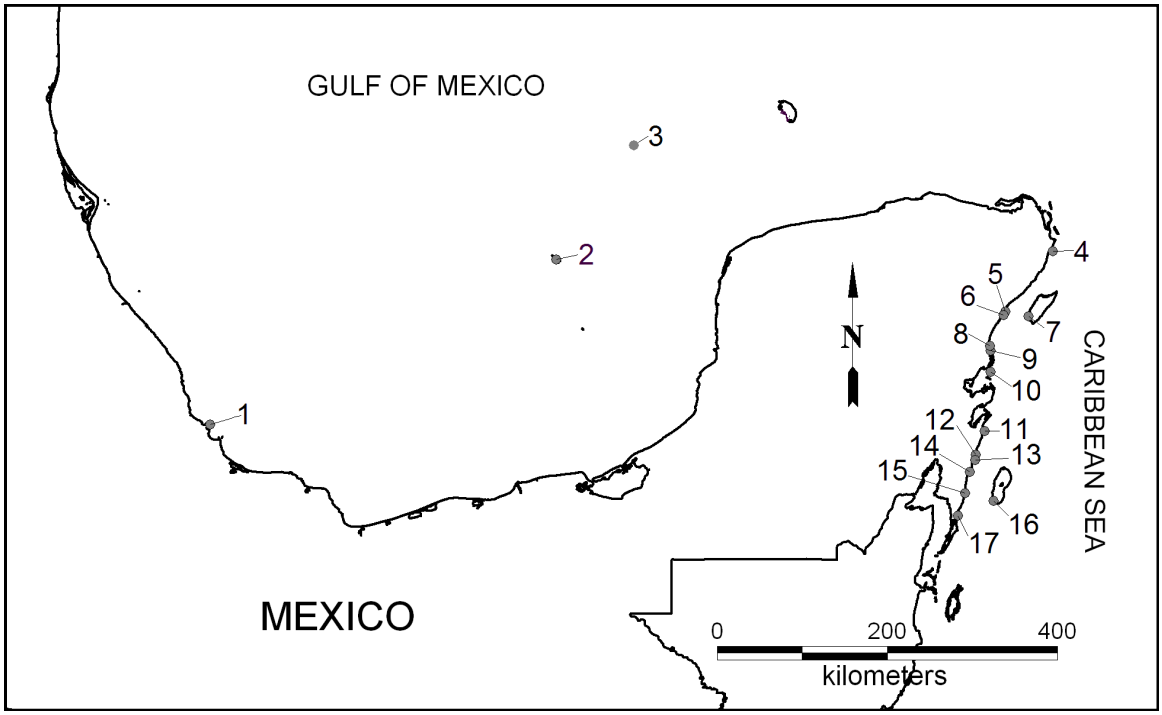

Figure 1. Corals reefs considered in the Gulf of Mexico and Mexican Caribbean: 1. Veracruz Reef System, 2. Triángulos, 3. Cayo Arenas, 4. Punta Nizuc, 5. Akumal, 6. Chemuyil, 7. Cozumel, 8. Boca Paila, 9. Punta Yuyum, 10. Punta Allen, 11. Tampalam, 12. El Placer, 13. Chaguay, 14. Mahahual, 15. Xahuayxol,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

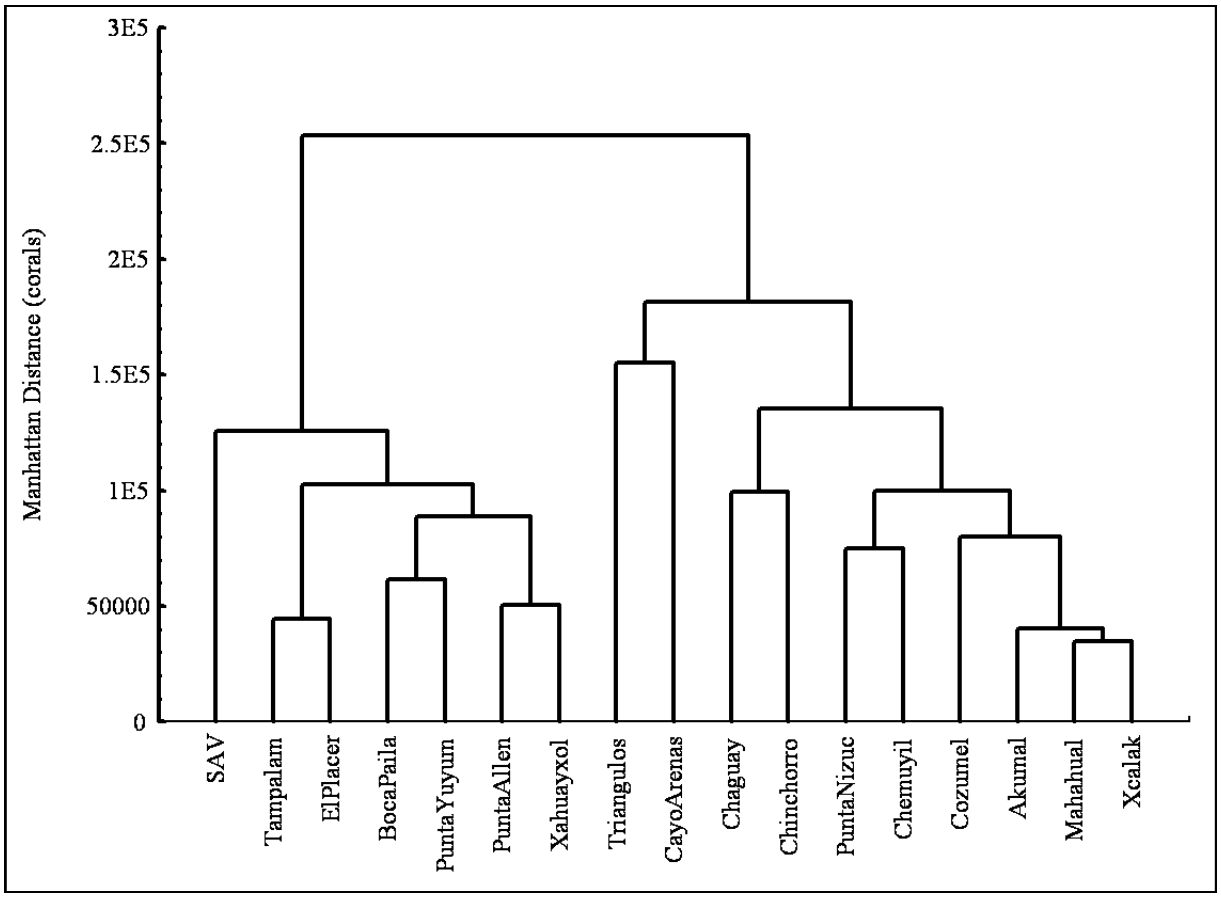

Figure 2. Cluster analysis (Manhattan distance, Ward method) for coral reef localities.

mation 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). 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. Being *Montastraea annularis, Diploria strigosa, Montastraea cavernosa* and *Montastraea faveolata* the most abundant species with *M. annularis* present in all localities. The less abundant species were *Diploria strigosa, Montastraea cavernosa* and *Montastraea faveolata,* only presented in one locality.

The dominant species (Sander's Index) were *Montastraea annularis, Diploria strigosa, Montastraea cavernosa* and *Montastraea faveolata*, contributing together more than 50% of the whole community. The highest ecological diversity (Shannon-Wiener) was found in Cozumel, with 4.05 bits/ind.

Classification of sites allowed to identify a pattern of grouping the reef localities examined. 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 in the Yucatan shelf (Figure 2)

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 does negatively (-0.94).

The arrangement of localities in ordination space depicts a gradient of variability, with the reefs from south and central Mexican Caribbean and the reefs from Gulf of Mexico caracterized by low concentration of nitrates and silicates and relatively high concentration of phosphates (Figre 3). According 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).

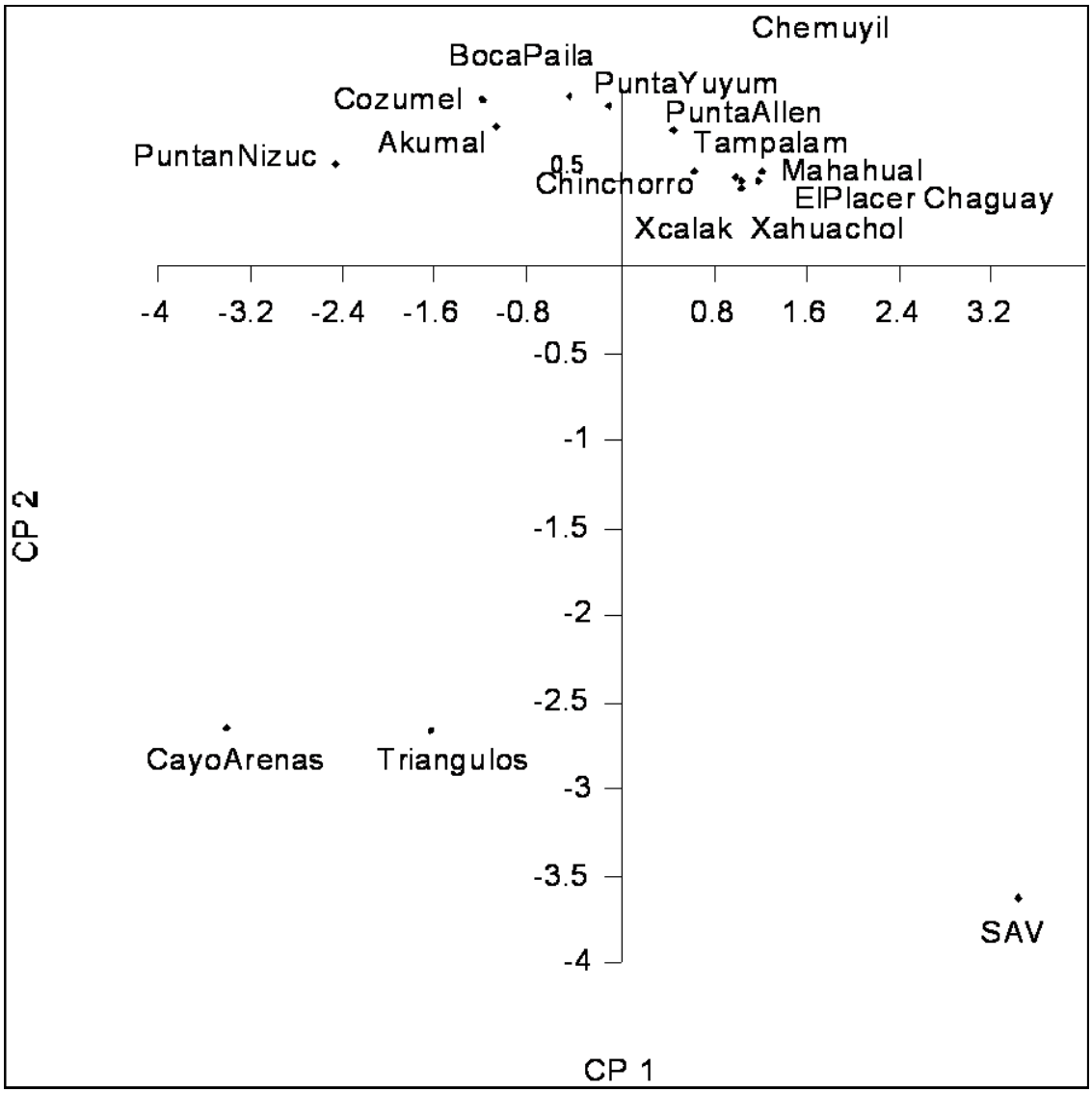

Figure 3. Principal Component analysis using components 1 and 2 as gradients of environmental variability (78.6% of total variance explained.)

The Mantel test was used to test the correlation of coral reef similarity with geographical distance,with the distance in days of transport as an effect of currents, and with the environmental similarity. Prior to the partial Mantel test, the simple correlations between the matrices of the independent variables were obtained and all combinations between them were positive, and higher than 0.75 (highly significant).

Partial Mantel, controlling the geographical distance and the distance in days of transport, was negative and significant in both cases (Table 2). The other possible combinations were spurious.

Correlations between biological similarity with geographical distance, with the distance in days of transport and with the environmental variables, identified a significant decrease in biological similarity when the distances increase and when the climate changes, confirming in our case the paradigm that the similarity should decrease with geographical distance (Nekola and White 1999) and to make the environment more different.

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.

Table 1. Coral reef localities and source of data included in this study. A = abundance data. Source: 1. Marks, 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).

Data	Locality	Source
A	Akumal	1,3
A	Boca paila	1
A	Cavo Arenas	4,7
A	Chaguav	1
A	Chemuvil	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	Puunta Yuyum	1
A	Veracruz System	5,6,7
A	Tampalan	1
A	Triangulos	4,7
A	Xahuayxol	1
A	Xcalak	1

Table 2. 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. (*e*) spurious correlations; (*) statistical significance p < 0.05

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*

Cluster analysis showed an unexpected similarity between 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 in the Yucatan shelf, which are closer. One of the obvious reasons for this similarity is the number of sharing 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.

Interpreting like a greater connectivity the similarity between those reefs that were more similar to each other by their composition, abundance and richness, draw attention specifically the high similarity found among the corals reefs in the central region of the Mexican Caribbean with those in the VRS; this is a contradictory result because a great distance separates them and different environmental conditions prevailing in each region. Then, considering the 1,269 miles between Punta Allen who is located in the central region of the Mexican Caribbean, to those reefs in the VRS at the south of the Gulf of Mexico, and the days of transport to cover that distance would be around 88 days, follow the pattern of annual flows average, the ability of coral larval survival to be transported at one time is unlikely because the duration of them in the water column is at most twelve days (Lugo-Fernández *et al.*,2001).

The extension of larval dispersal and their recruitment to the adult population is different for each specie. The chances of dispersal largely depend on the speed of the currents. It has been reported that larvae of some types of corals can last from eight hours to twelve days in the water column (Lugo-Fernández *et al*. 2001). From drifting buoys and simulating flows as a mechanism of transport has been made to infer the possible routes of dispersal of larvae produced in the Flower Garden Banks Coral during spawning events, and the effect of hurricane on its dispersion.

Among the natural factors that cause drastic changes in the structure of coral communities are hurricanes, which

are also extraordinary phenomena as potential dispersal of larvae in a considerable time by reducing the movement or transport them to more remote sites where they were originated, although it should also consider the possible physical damage caused by the strong turbulence caused by the phenomenon. For the Flower Garden Banks reef north of the Gulf of Mexico off Texas-Louisiana in the U.S., found that the path followed by the dispersal of larvae produced in the reef is modified by the effects of hurricanes (Lugo-Fernández *et al.* 2001). They also mentioned that under these conditions a hurricane can cause a large shift in a short period of time causing a strong dispersion of larvae, as well as horizontal and vertical mixing of the water column (Lugo-Fernández *et al.* 2001, Jordan and Dahlgren,2002).

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, an 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 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, values of similarity between localities are not quite clear, finding that the similarity decreases with geographical distance, which is generally accepted by the current theory. In this case, despite that the correlation coefficients found were low, however they were significant.

Finally, 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 unveiled.

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