Response of Fish Assemblages to Protection Areas Designation: Yucatan Coast

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ABSTRACT

Yucatan coast is characterized for its biodiversity and habitat heterogeneity. Four Biospheres Reserves designation indicates its value in terms of species richness. In this study we evaluate the influence of Reserves to the protection of fish species. We address two questions: How and why fish assemblages vary among protected areas with not and what local habitat features best explain the variation? We sampled in 40 localities located in coastal systems protected (Celestun, Bocas de Dzilam and Rio Lagartos) and a system subject to anthropogenic uses (Chelem Lagoon). A total of 4355 individuals, comprising 56 fish species (28 families), were collected using a beach seine. In terms of species number per family, Syngnathidae (5 species) was the most diverse, followed by Sciaenidae and Gerreidae (four species). Even though, high species richness was recorded in Chelem lagoon (29), the highest density and biomass values were significantly greater in protected areas. Cluster and ordination analysis demonstrated that fish assemblage structures were markedly different between protected and not protected systems. The results stand out the importance of connectivity between natural Reserves for the protection and maintaining of biodiversity of not protected ecosystems.

KEY WORDS: Biosphere Reserves, connectivity, coastal lagoons, fish species assemblages, anthropogenic use.

Respuesta de los Ensamblajes de Peces a la Designación de las Áreas Protegidas: Costa de Yucatán

La costa de Yucatán se caracteriza por su biodiversidad y heterogeneidad de hábitat. La designación de cuatro Reservas de la Biosfera, indica su valor en términos de riqueza de especies. En este estudio se evalúa la influencia de las Reservas para la protección de las especies de peces. Consideramos dos preguntas. ¿Cómo y por qué los ensamblajes de peces varían entre las áreas protegidas con las que no lo están y cuales son las características ambientales que explican esta variación? Se muestrearon 40 localidades localizadas en sistemas costeros protegidos (Celestún, Bocas de Dzilam y Río Lagartos) y un sistema sujeto a uso antropogénico (laguna Chelem). Se colectaron un total de 4355 individuos que comprenden a 56 especies (28 familias) utilizando un chinchorro playero. La familia Syngnathidae fue la más diversa en términos del número de especies (5 especies). Le siguió en importancia Sciaenidae y Gerreidae (cuatro especies). No obstante una alta riqueza de especies se registró en la laguna de Chelem (27), la densidad y biomasa fueron significativamente mayores en las áreas protegidas. Análisis de Ordenación demuestran que las estructuras de los ensamblajes de peces son diferentes entre las reservas al obtenido en el sistema no protegido. Los resultados resaltan la importancia de la conectividad entre Reservas naturales para la protección y mantenimiento de la biodiversidad de los ecosistemas no protegidos.

PALABRAS CLAVES: Reservas de la Biosfera, conectividad, lagunas costeras, ensamblajes de especies de peces, uso antropogénico.

INTRODUCTION

Due to the abundance of its fishery resources, tourism heritage and its value for biodiversity, Yucatan Peninsula is recognized for its great ecological and coastal potential (Capurro 2003). Its karstic nature and location in the Gulf of Mexico and Caribbean Sea are the principal factors that cause this biological richness. Its unique ecological and physiographic conditions, favor the presence of a characteristic flora and fauna, some of them endemic (*Gambusia yucatana yucatana*, *Poecilia velifera*) that uses coastal wetlands as critical habitats. Two Biosphere Reserves have been established in Yucatan coast: Celestun and Rio Lagartos; both of them notables by the presence of not perturbed ecosystems. Also the Ecological Reserves of El Palmar and Bocas de Dzilam were stipulated to preserve the conservation of the ecosystems (mangrove, forest) and the integral utilization of the natural resources. These areas are interconnected by a wide Biological coastal corridor, where economical activities like fishery, aquaculture, ecotourism, port commerce are realized. Because of this interaction between protected ecosystems with not, and considering the important function of these environments as critical habitats for fish resources, we try to evaluate fish species composition and diversity in a spatial scale, contrasting protected ecosystems with not. This information is basic to establish the coastal management plan.

The integration of the abiotic and biotic characteristic, indicate the environmental condition of the ecosystem. In healthy environments, the species richness and diversity show the highest values compared with systems subject to anthropogenic pressure (Blaber 2000). Also the energy fluxes are more complex and the level of recycled production more elevated (Belgrano *et al*. 2005). These kinds of biological considerations are included for conducting environmental assessments on ecosystems subject to different impacts. Given that two estuaries are not

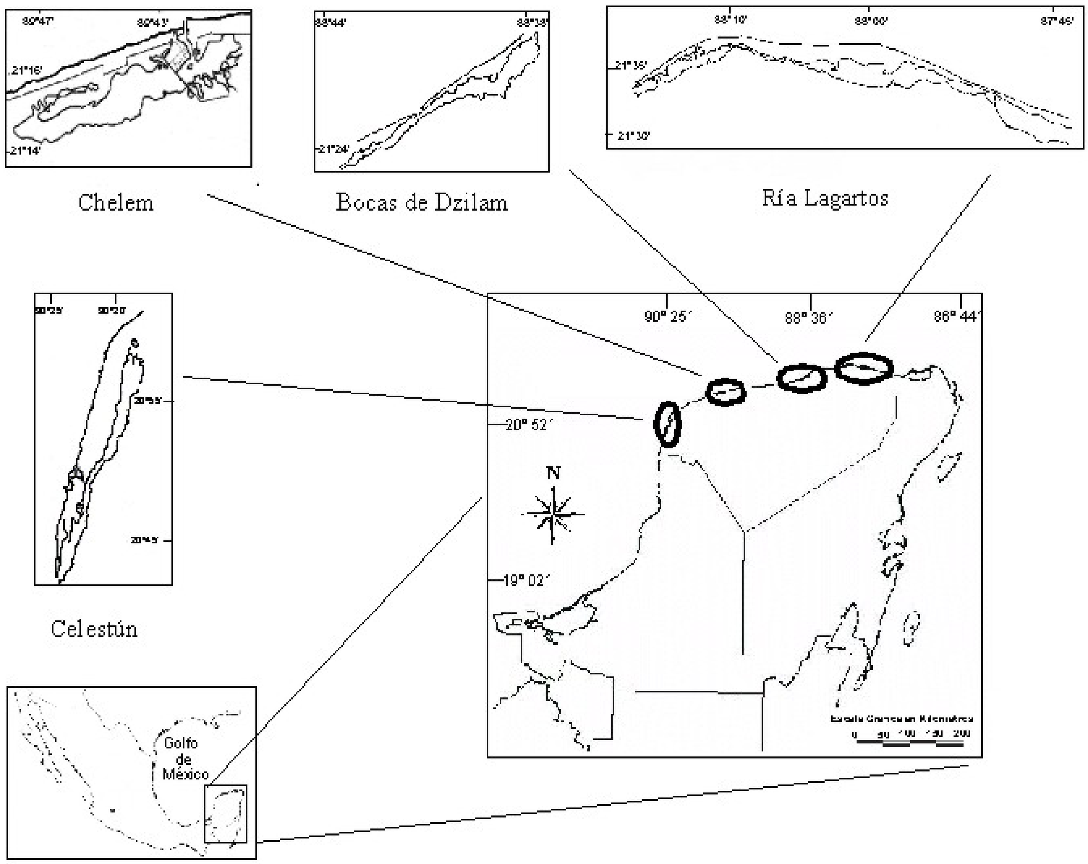

Figure 1. Locations of the coastal lagoons from Yucatan estate, Mexico.

identical in terms of either biotic or abiotic characteristics, it could be postulated that the structure of the fish assemblages for each estuary will also be different. However if the fishes respond to the environment in a consistent manner, then the communities occupying similar types of estuaries in a particular region would reflect this similarity (Whitfield 1999). A number of studies have been realized in diverse coastal ecosystems from the Yucatan Peninsula, with particular emphasis on fish assemblages (Vega-Cendejas *et al*. 1994, Vargas 2004, Vega-Cendejas and Hernández 2004, García 2004, Arceo 2005, Peralta 2006). However, no studies have considered the entire Yucatan coast. This research aims to describe and compare the structure of fish communities from a spatial scale along the coast of Yucatan and the evaluation of biological connectivity between protected areas for biodiversity conservation.

MATERIALS AND METHODS

The spatial variability of fish assemblages composition was investigated at the same period of time (May - June, 2005) in a basic network of 40 sampling stations at the coast of Yucatan (350 km littoral), including Celestun, Chelem, bocas de Dzilam and Río Lagartos lagoons (Figure 1). Chelem is near Progreso Port with an antrophogenic use, while the other ecosystems are Natural Protected Areas (NPA). bEach site was geopositioned (Garmin's 12 XLS) and hydrological parameters were recorded (temperature, salinity, pH, turbidez, conductivity y nutrients) with a multi-analyzer (Horiba) and depth with a digital equipment.

Sampling was realized with a beach seine (15 x 2m, 2.5 mesh size). All fishes were identified considering the specific references and deposited in the Institutional fish collection (CINV-NEC). The community ecological descriptors as richness, diversity and dominance of species, were obtained for each ecosystem. Non-parametric multidimensional scaling (MDS) was employed for ordination of sampling sites. SIMPER routine was used to find main discriminating species in groups of samples obtained with quantitative data. After the standardization of ecological parameters recorded at each site, an integral biodiversity index (IBI), that related species richness, abundance, biomass and diversity was designed to compare ecological parameters between ecosystems. Values higher than 0.6 indicate a high biodiversity, while values lower than 0.2, showed warning situations. All analyses were made using PRIMER 5 (Clarke and Gorley 2001) and STATISTICA 6.0 software.

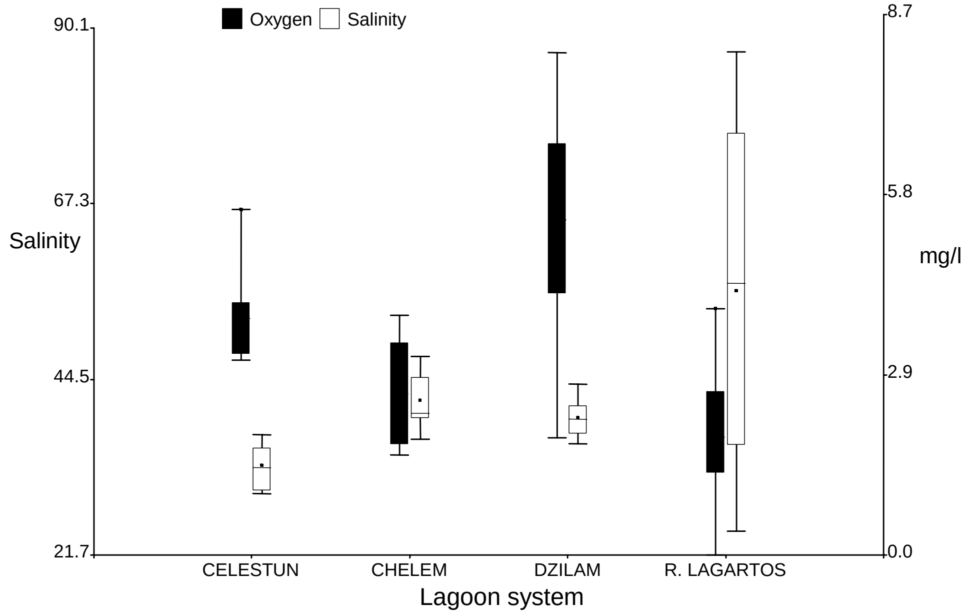

Figure 2. Average salinity and dissolved oxygen registered in the coastal lagoons from Yucatan, Mexico.

RESULTS

The variables that showed the strongest variation between the four coastal ecosystems were salinity and dissolved oxygen. Euclidean distance separates Chelem and Rio Lagartos (highest salinity - lowest oxygen values) from Celestún and Bocas de Dzilam (lower salinity – high oxygen). These differences were statistically significant (salinity $H = 10.5$, $p = 0.0145$; oxygen $H = 16.88$, $p = 0.0007$). Rio Lagartos showed the greatest variation in salinity between localities (56 ± 22.8), while Dzilam was more stable (39.5 ± 2.8) (Figure 2).

In the four coastal lagoons, the fish communities was represented by juveniles and adult stages with a total of 56 species included in 29 families and 45 genera, from which 7 species represented >78% (Table 1). The highest species richness was recorded in Chelem and Dzilam (29), and the lowest in R. Lagartos (24). The test for differences between density was significant ($R = 0.225$, $p = 0.006$) with the highest average value obtained in Dzilam. The dominant species ìn Celestún, Chelem and Dzilam considering its density and biomass were *Lagodon rhomboides* and *Sphoeroides testudineus*, respectively. Rio Lagartos and Chelem were the more contrasted ecosystems in relation to species composition and community structure, with representatives of the Cyprinodontidae family as dominant species. Considering the ecological parameters and IBI obtained for each lagunar system, Dzilam showed the highest values. By contrast, in Celestún and Chelem the lowest densities and biomass were recorded (Tabla 2).

The classification analysis considering fish species composition and abundance, yielded two main groups of stations corresponding one of them to inner stations from Rio Lagartos lagoon (hipersaline conditions), and the other group includes almost all of the sites. The MDS ordination of the samples showed a stress value for two dimensions (0.16), which can be considered acceptable (Figure 3). Several locations from Celestun Reserve are differentiating because of the presence of typical species, like *Mugil cephalus* (CE07) and *Cihlasoma urophthalmus* (CE08), and most of the other sites are grouped because of the dominance of *Lagodon rhomboides* and *Sphoeroides testudineus*. SIMPER analysis allowed finding the pattern of individual species variation between the four costal systems (Figure 4). A set of species (Cyprinodontidae) is representative of Rio Lagartos and Dzilam ecosystems. *Cyprinodon artifrons* and *Floridichthys polyommus* contribute with more than 60% in Rio Lagartos, 23% in Dzilam, 16% in Chelem and 0% in Celestun.

DISCUSSION

The results of this research support the idea that habitat, as well as the hydrology, is the main factors in determining the structure of fish assemblages. We also contribute to the importance of connectivity for maintaining the stability and biodiversity of not protected ecosystems. Currently one of the best mechanisms for the conservation and stability of ecosystems is via NPA (Halpern and Warner 2002, Da Silva *et al*. 2005). The NPA are designed to maintain and restore populations; however there is still little understanding about the ecology and larval dispersal. In this research, the presence of two mayor reserves between the not protected zone (Chelem

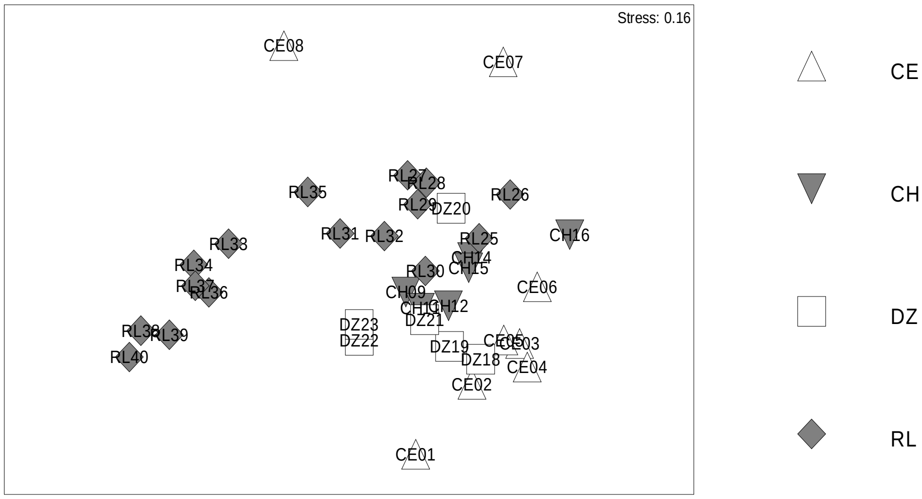

Figure 3. MDS ordination of the stations located at Celestun (Ce), Chelem (Che), Bocas Dizlam (DZ) and Rio Lagartos lagoons from the coast of Yucatan, Mexico.

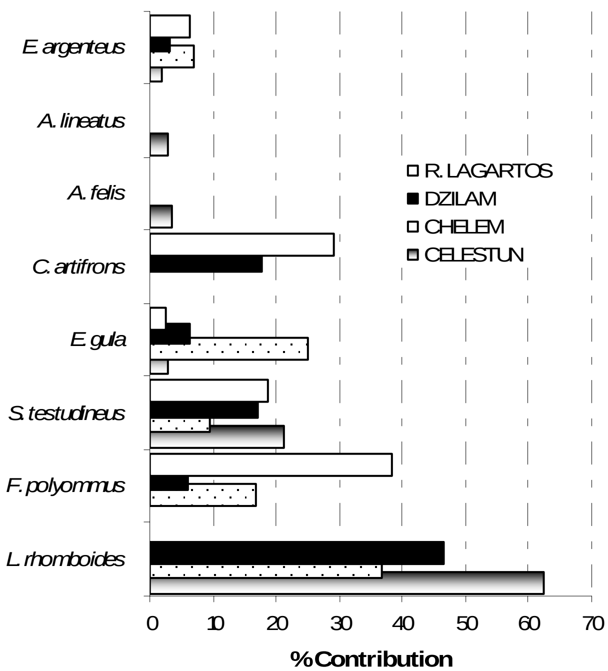

Figure 4. Species contributions to total similarity for each coastal system (SIMPER analysis). Only higher contributing species adding to 50 % of total dissimilarity are specified.

lagoon), allows the flow and biological exchange for the maintaining of diversity. Even though this area is impacted, we found that species richness and diversity is preserved (29 species). In this case, NPA is synonymous with conservation for the adjoining areas. By contrast, Rio Lagartos that is a protected ecosystem, it is natural impacted by hyper saline conditions with a positive gradient from the inlet to the inner zone, where salinity can exceed 100 (Vega-Cendejas y Hernandez, 2004). In the inlet of this system, where marine condition prevails, we found a similar fish species composition to the other coastal ecosystems of Yucatan.

The observed trend of cyprinodontidae species to increase their abundance in natural and anthropogenic impacted systems (Chelem, Rio Lagartos, respectively), will explain the turnover of quantitative species composition along the cost. These species are very tolerant to low dissolved oxygen and high salinity levels (Vega-Cendejas and Hernández, 2004). These results indicate that habitat degradation, affect an important group of species while others, perhaps more resistant, can take advantage of this, increasing their abundance and extending their ecological niche (Colburn, 1988). Multivariate numerical analyses allowed defining the environmental parameters as the main factors inducing spatial variability of fish community composition, while the level of human impact appears to play the main role in fish assemblage composition changes along the coast. According to the results of the MDS, we can distinguish two main groups. One of the groups includes the inner stations from Rio Lagartos, where *Cyprinodon artifrons* and *Floridichthys polyommus* are dominant. The other group denotes the biological connectivity between NPA, with *Lagodon rhomboides* and *Sphoroides testudineus* as the representative fish species.

These results highlight the importance of the Reserves and are key information for the establishment of the management plan for the coast of Yucatan, Mexico.

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Table 1. Fish species recorded in natural Reserves (Celestun, Bocas de Dzilam and Rio Lagartos lagoons) and a coastal system not protected (Chelem), Yucatan coast, Mexico.

ORDEN	FAMILIA	ESPECIE	Celestun	Chelem	Bocas de Dzilam	Rio La-gartos
Myliobatiformes	Dasyatidae	*Dasyatis americana* Hildebrand & Schroeder, 1928			X	
	Gymnuridae	*Gymnura micrura* (Bloch & Schneider, 1801)	X	X		
Elopiformes	Elopidae	*Elops saurus* Linnaeus, 1766	X			X
Clupeiformes	Engraulidae	*Anchoa lamprotaenia* Hildebrand, 1943	X			
		Anchoa mitchilli (Valenciennes, 1848)	X			X
	Clupeidae	*Harengula jaguana* Poey, 1865		X	X	
		Opisthonema oglinum (Lesueur, 1818)		X		
Siluriformes	Ariidae	*Ariopsis felis* (Linnaeus, 1766)	X		X	X
Aulopiformes	Synodontidae	*Synodus foetens* (Linnaeus, 1766)	X	X	X	X
Batrachoidiformes	Batrachoididae	*Opsanus beta* (Goode & Bean, 1880)	X	X		X
Mugiliformes	Mugilidae	*Mugil curema* Valenciennes, 1836	X	X		
		Mugil cephalus Linnaeus, 1758	X			
		Mugil trichodon Poey, 1875	X	X	X	
Atheriniformes	Atherinopsidae	*Menidia colei* Hubbs, 1936	X	X		X
		Menidia peninsulae (Goode & Bean, 1879)				X
Beloniformes	Belonidae	*Strongylura notata* (Poey, 1860)		X	X	X
	Hemiramphidae	*Chriodorus atherinoides* Goode & Bean, 1882	X			
		Hyporhamphus unifasciatus (Ranzani, 1842)				X
Cyprinodontiformes	Fundulidae	*Lucania parva* (Baird & Girard, 1855)		X	X	
		Fundulus persimilis Miller, 1955		X		
		Fundulus grandissimus Hubbs, 1936		X		
	Poeciliidae	*Poecilia velifera* (Regan, 1914)			X	
		Gambusia yucatana Regan, 1914			X	
	Cyprinodontidae	*Cyprinodon artifrons* Hubbs, 1936			X	X
		Floridichthys polyommus Hubbs, 1936		X	X	X
		Garmanella pulcra Hubbs, 1936			X	X
Gasterosteifomes	Syngnathidae	*Hippocampus erectus* Perry, 1810		X		
		Syngnathus floridae (Jordan & Gilbert, 1882)		X		
		Syngnathus scovelli (Evermann & Kendall, 1896)		X		
		Sygnathus makaxi Herald & Dawson, 1972		X	X	X
Scorpaeniformes	Triglidae	*Prionotus scitulus* Jordan & Gilbert, 1882		X		
Perciformes	Centropomidae	*Centropomus undecimalis* (Bloch, 1792)			X	
	Carangidae	*Hemicaranx amblyrhynchus* (Cuvier, 1833)				X
		Selene vomer (Linnaeus, 1758)		X		
	Lutjanidae	*Lutjanus griseus* (Linnaeus, 1758)	X	X	X	
	Gerreidae	*Eucinostomus argenteus* Baird & Girard, 1855	X	X	X	X
		Eucinostomus gula (Quoy & Gaimard, 1824)	X	X	X	X
		Eugerres plumieri Cuvier, 1830	X			
		Gerres cinereus (Walbaum, 1792)	X		X	

Table 1. Continued.

		Gerres cinereus (Walbaum, 1792)	X		X	
	Haemulidae	*Haemulon plumierii* (Lacepède, 1801)				X
		Orthopristis chrysoptera (Linnaeus, 1766)	X		X	
	Sparidae	*Archosargus probatocephalus* (Walbaum, 1792	X		X	X
		Archosarbus rhomboidalis (Linnaeus, 1758)	X	X		
		Lagodon rhomboides (Linnaeus, 1766)	X	X	X	X
	Sciaenidae	*Bairdiella chrysoura (Lacepède, 1802)*			X	
		Cynoscion nebulosus (Cuvier, 1830)			X	X
		Micropogonias furnieri (Desmarest, 1823)	X			
		Micropogonias undulatus (Linnaeus, 1766)	X			
	Cichlidae	*"Cichlasoma" urophthalmus* (Günther, 1862)	X		X	
	Gobiidae	*Gobionellus oceanicus* (Pallas, 1770)	X			
	Sphyraenidae	*Sphyraena barracuda* (Edwards, 1771)			X	X
Pleuronectiformes	Paralichthyidae	*Paralichthys albigutta* Jordan & Gilbert, 1882		X	X	X
	Achiridae	*Achirus lineatus* (Linnaeus, 1758)	X	X	X	X
Tetraodontiformes	Tetraodontidae	*Sphoeroides nephelus* (Goode & Bean, 1882)		X		
		Sphoeroides testudineus (Linnaeus, 1758)	X	X	X	X
	Diodontidae	*Diodon holocanthus* Linnaeus, 1758		X		

Table 2. Ecological parameters of the fish communities registered in the coastal lagoons of the Yucatan Peninsula. The integral biodiversity index (IBI, %) with the relative density and (biomass) of the most representative species are specified. Total and average density and biomass are in 100 m^2.

	Celestun	**Chelem**	**Dzilam**	**R. Lagartos**
Species richness	27	29	29	24
Total density	1.9 ± 3.1	2.4 ± 4.8	4.8 ± 15.3	4.2 ± 56.1
Total Biomass	56.3 ± 99.2	35.9 ± 84.6	37.9 ± 82.2	56.1 ± 160.8
Average density	1.9 ± 3.1	2.4 ± 4.8	4. 8 ± 37.9	4.2 ± 7.2
Average biomass	56.3 ± 99.2	35.9 ± 84.6	37.9 ± 82.1	56.1 ± 160.8
Diversity	2.03	2.08	1.52	1.83
IBI	38.0	34.0	**47.0**	29.0
Rep. species	*L. rhomboides* 62.1 (40.9) *S. testudineus* 21.5 (48.7) *A. felis* 3.4 (1.8) *A. lineatus* 3.0 (0.5)	*L. rhomboides* 36.3 (19.4) *E. gula* 25.0 (19.4) *F. polyommus* 18.9 (8.4) *S. testudineus* 9.6 (54.2)	*L. rhomboides* 45.5 (16.8) *S. testudineus* 18.3 (73.2) *C. artifrons* 16.0 (0.8) *E. gula* 7.9 (2.5)	*F. polyommus* 38.6 (18.5) *C. artifrons* 29.3 (8.3) *S. testudineus* 18.5 (68.9) *E. argenteus* 6.3 (0.9)