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Trophic modeling of the continental shelf ecosystem outside of Tabasco, Mexico: A network and modularity analysis

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ABSTRACT

The continental shelf of the southern Gulf of Mexico is influenced by a critical riverine basin that serves as a productive area for economic activities, notably fishing and oil extraction activities. The area is thus subjected to multiple uses, and this can alter the structure and functioning of the ecosystem. Hence, the assessment and sustainable use of natural resources requires the consideration of complex trophic interactions in the ecosystem. This study characterizes the structure and function of the continental shelf ecosystem food web outside of Tabasco, Mexico. Meaningful compartments with strong trophic interrelationships that may be of relevance to the sustainability of the ecosystem were also identified using a modularity maximization algorithm. The Ecopath approach is employed to construct a trophic model with 33 functional living groups and a detritus pool. Barracudas and sharks are found to be the main predators. Detritus also plays an important role in the food web, as this group supplies half of the system's primary energy supply and has significant positive mixed trophic impacts on several functional groups. A constant supply of organic matter via continental discharge reinforces the important role of detritus while limiting matter recycling in the ecosystem. A high degree of omnivory in the food web also forms intricate trophic relationships. According to ecosystem indices, the ecosystem is well organized, and this is also evident given the presence of three meaningful compartments in the food web. Flows within compartments were higher than between them. These compartments include heterogeneous functional groups and may prove central to the resilience of the ecosystem. Two compartments include groups from the base of the food web, one included primary and secondary producers from the sea bottom and the other comprised groups from the water column.

1. Introduction

Coastal zone ecosystems are especially vulnerable to persistent anthropogenic pressures resulting from urban development, pollution, habitat modification, freshwater use, living resource extraction and climate change, among other factors. This is the case along the Continental Shelf off of Tabasco, which is influenced by the most critical river basins in Mexico and by the most extensive wetlands in Mesoamerica. The ecosystem includes nearly one-third of the nation's fluvial drainage flow through the Mezcalapa and Grijalva–Usumacinta deltaic complex, generating highly productive waters in the area as a result of nutrient-rich freshwater discharge. These effluents create environmental conditions that support major marine fisheries that produce fishing resources such as oysters, jacks, mackerel, snapper, shrimp, and blue crab. The area also supports activities related to the oil industry, including oil extraction, oil ship transit, and submarine petroleum pipeline operation. Additionally, the cattle, aquaculture, and agriculture industries have expanded in recent decades, and wetland areas are being converted to support these activities. The area is thus subjected to multiple uses, potentially causing changes in the structure and functioning of the continental shelf ecosystem. Given the variety of anthropogenic endeavors supported in this region, there is a constant demand for scientific knowledge on the effective management and conservation of this critical area (Pérez-Sánchez and Muir, 2003).

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In this context, it is a prevailing scientific challenge to maintain healthy and productive ecosystems in coastal zones. For this reason, ecosystem modeling has been recommended as a useful system status reporting and resource management tool (Levin et al., 2009). One modeling approach involves quantifying biomass flows in food webs to reveal trophic structures and functioning. Trophic models may be used to study ecosystem resilience (Ulanowicz et al., 2009; Arreguín-Sánchez, 2014), as ecosystem responses to threats are mediated by interactions between species in food webs (Pascual and Dunne, 2006). It is common to quantify resilience dynamically using indexes that summarize the response of the food web to perturbations. However, it is often necessary to identify the strongest interrelationships between biotic components of ecosystems, since they play a key role in the food web energy transference. Furthermore, it has been demonstrated the presence of compartments or modules in food webs formed by groups of species with strong trophic interactions (Krause et al., 2003; Stouffer and Bascompte, 2011). As members of these compartments are more intensively interconnected to one another than they are with other food web members, they can isolate the perturbations throughout the entire food web (Melián and Bascompte, 2004). In this sense, modularity of food web is important for resilience and stability of ecosystems. Given the complexity of marine coastal ecosystems and the difficulty to elaborate management plans, it is relevant to identify the presence of compartments in food web and their composition in order to characterize the structure of food webs and the relevance of functional groups.

The present study characterizes food web structures and functions by considering trophic relationships and by quantifying energy flows in the continental shelf ecosystem outside of Tabasco, Mexico. Additionally, we test the hypothesis of the presence of compartments with strong trophic interactions in the food web.

2. Materials and methods

2.1. Study area

The continental shelf outside of Tabasco spans 13,000 km^2, covering approximately 200 km of coastline (Fig. 1).

This continental shelf includes clastic layers of primarily muddy clays and sediments that foster the establishment of various communities of marine organisms. The main geomorphologic characteristics of this zone are related to the development of the alluvial plains of the Mezcalapa and Grijalva–Usumacinta deltaic complex. Water in the region is characterized by a high degree of turbidity due to considerable organic matter, residual substances, and sediment contributions from fluvial systems (Callejas-Jimenez et al., 2012; Villalobos-Zapata, 1989). However, large nutrient deposits favor primary production and the subsequent development of numerous marine species, several of which present commercial value. Tides are predominantly diurnal, and differences in sea levels between ebb and neap tides do not exceed 40 cm. Fluvial patterns render tide effects in this area insignificant, although their effect during the dry season is more pronounced.

The local climate is warm and sub-humid with abundant rainfall in the summer accumulating to between 2000 and 4500 mm (Yáñez-Arancibia et al., 2013).

Fishery facilities established in the continental shelf ecosystem include a shrimp trawling fleet and several artisanal fisheries. The former is an offshore trawl fleet that operates in waters of between 9 and 64 m depth using four trawl nets. The main shrimp target species are *Farfantepenaus aztecus* and *Litopenaues setiferus*. Artisanal boats use fishing tools such as short longlines, hook lines, gillnets, and beach seines to catch several species of finfish and invertebrates.

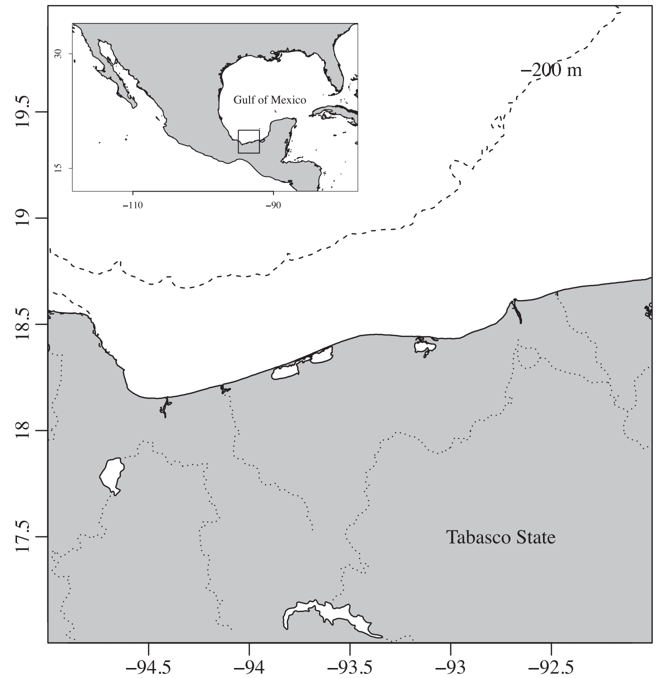

Fig. 1. Study area, the continental shelf outside of Tabasco in the Gulf of Mexico showing the main rivers (dotted lines) and the 200 m isobath (dashed line).

2.2. Model construction

The trophic model of the continental shelf outside of Tabasco was constructed using the Ecopath with Ecosim (EwE) approach (Christensen and Walters, 2004). EwE is defined by a linear equation for each species or functional group (i). Each equation represents an energy balance between production and energy costs or ecosystem losses. Thus, the production of each group (i) can be expressed by the following linear equation:

$$B_i \cdot \left(\frac{P}{B}\right)_i \cdot EE_i = \sum_{j=1}^{n} B_i \cdot \left(\frac{Q}{B}\right)_j \cdot DC_{ji} + Y_i + E_i + BA_i$$

where for an i group, B_i is biomass, $(P/B)_i$ is the production/biomass ratio, EE_i is ecotrophic efficiency, B_j is the biomass of predator j, $(Q/B)_j$ is the consumption/biomass ratio of predator j, DC_{ji} is the proportion of prey i in the diet of predator j, and Y_i is the export value, which in this study includes fishery catch when a group is exploited. E_i is the net migration rate, and BA_i is the biomass accumulation rate. The last two terms of the equation were not used in the present study due to the lack of data assuming that both of them do not represent significant flows of the system. Based on the equation, input parameters for each model group include B, P/B, Q/B, and EE. Because this equation is balanced, if one parameter is unknown, it can be estimated from the model. Nevertheless, the diet composition (DC_{ij}) of all consumers is required to depict all trophic relationships. Additionally, EE_i values must be less than or equal to 1, and these values are used to balance the model.

2.3. Input data and information sources

We defined 33 functional groups based on their relative abundance and ecological trophic relationships (see supplementary material, S1). A functional group refers to a species or several species (often taxonomically related) that perform similar trophic roles. While certain groups included several species, others included a class of species or only one species. We considered two groups of primary producers, one group of zooplankton, four groups