

A Preliminary Trophic Model of Bahía de la Ascensión, Quintana Roo, Mexico [*Modelo trófico preliminar de Bahía Ascensión, Quintana Roo, México*]

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ABSTRACT

Bahía de la Ascension is a bay with an area of 260 km², located along the coast of the state of Quintana Roo, Yucatan Peninsula, Mexico. This paper provides a preliminary description of the marine ecosystem and its mass balance fluxes using the Ecopath with Ecosim software. Bahía de la Ascension is heavily influenced by mangrove and coral reef areas, and functions as a nursery area for important fishery resources (lobster, sharks, other fishes). A flow diagram, summary statistics and mixed trophic impacts of the groups in the ecosystem is provided. Results suggest that 22% of the total system throughput consists of flows to detritus. The key resource in the ecosystem, due to the value of its catch, is lobster (*Panulirus argus*). The most abundant consumer group is benthic invertebrates. Better data for primary production, detritus biomass and detailed benthic invertebrate groups, as well as explicit consideration of seasonality would help to improve the model.

RESUMEN

Este trabajo presenta una descripción preliminar del balance de flujos de biomasa de la comunidad de Bahía Ascensión. Esta Bahía tiene un área de 260 km² y está localizada en el estado de Quintana Roo, en la Península de Yucatán. Esta fuertemente influenciada por áreas de manglar y arrecifes de coral, y ha sido considerada como un área de crianza de importantes recursos pesqueros (langosta, tiburones y otros peces). Se

presenta el diagrama de flujo, un resumen de estadísticas del ecosistema y los impactos tróficos entre grupos de especies. Los resultados indican que el 22% del flujo total del ecosistema es expresado como flujo a detritus. El recurso pesquero de mayor importancia económica es la langosta. El grupo consumidor de mayor abundancia son los invertebrados bentónicos. Se considera, para futuros trabajos, involucrar en mayor medida las variaciones estacionales, debido a los períodos climáticos claramente definidos en la región. Asimismo, dada la carencia de datos más específicos para la Bahía, se considera de suma importancia obtener mayor detalle en los datos de entrada, particularmente los relativos a producción primaria, biomasa de detritus, y mayor detalle en el grupo de invertebrados bentónicos. Esto mejoraría sustancialmente la calidad del presente modelo.

INTRODUCTION

Bahía de la Ascensión represents an important area for artisanal fishing activities in Quintana Roo, on the Yucatan Peninsula of Mexico (Figure 1). It also functions as a nursery area for some of the most important commercially exploited resources along the Mexican Caribbean coast, such as lobster (*Panulirus argus*), sharks and a large number of other fish species (Vásquez-Yeomans, 1990; Lozano-Alvarez and Briones-Fourzan, 1991; Zárate, 1996).

Bahía de la Ascensión is a shallow bay, covering approximately 260 km², with an average depth of 2.5 m, and which is located in the northeast of the Yucatan Peninsula, Mexico between 19° 45' N and 87° 30' W in the tropical western Atlantic (López-Ornat, 1983). It is connected to the Caribbean Sea through a coral reef of 12 km width (Espejel, 1983) and is surrounded by well-developed mangroves (Olmsted *et al.*, 1983). Salinity varies between 22 to 31. Water exchange with the sea is low and driven by tides, which have a maximum amplitude of 25 cm (Lankford, 1976). The substratum shows a well-marked zonation: the inner part is covered by calcareous sand interspersed with green and red algae (*Dasycladus* spp. and *Laurencia* spp.) and scattered seagrass (*Thalassia testudinum*). The outer part, which is influenced by the open sea, has mainly hard bottom with coral-reef, coral limestone, calcareous algae and rocks with some patches

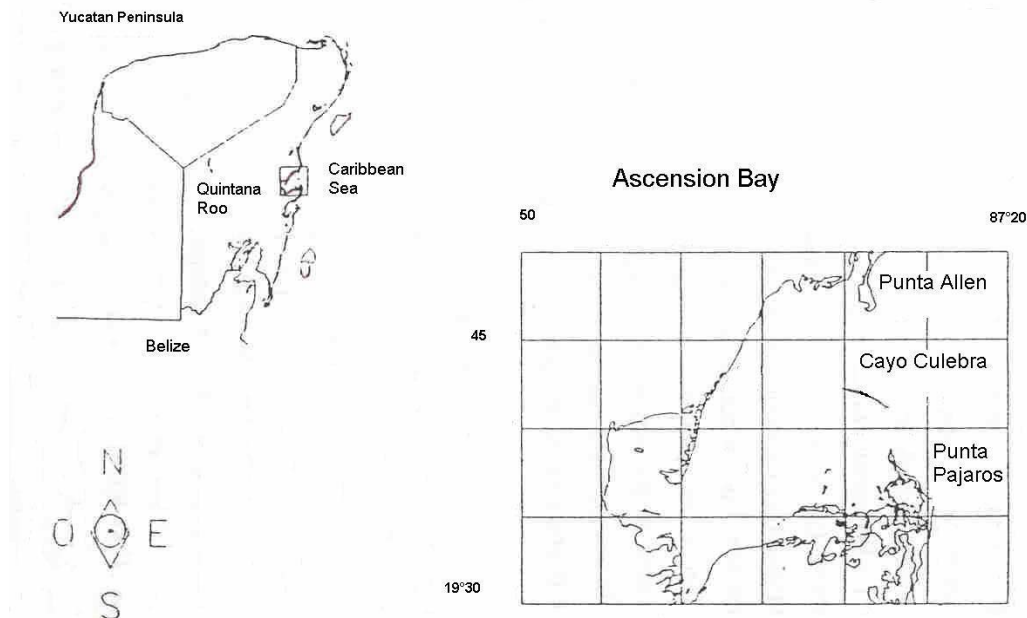


Figure 1: Location of Bahía de la Ascención Bay, on the Yucatan peninsula, Mexico. Shadow region indicates study area. [Localización de Bahía Ascención en la Península de Yucatán, México. Región sombreada representa el área de estudio.]

of seagrass (Espejel, 1983; Eggleston *et al.*, 1990; Lozano-Alvarez, 1992). In this area, algae richness is high with Rhodophyta being the dominant group (Quijano-Fernández, 1988). The bay is characterized by a high concentration of nutrients, some of which is exported to adjacent areas. Mangroves around the bay contribute detritus, which is associated with high densities of meiofauna. Spiny lobsters attain a high biomass within the bay, and jointly with small sharks, mojarras, juvenile macabi (*Elops saurus*) and jacks (Carangidae), are the most important exploited resources.

Given the ecological and economic importance of Bahía de la Ascención, it is useful to understand the ecosystem dynamics and its responses to exploitation. This would contribute to and improve the management strategies applied in the area (Beddington, 1984). This document provides a preliminary description of the marine community in Bahía de la Ascención and its mass balance fluxes using the Ecopath approach (Christensen and Pauly, 1992; Pauly *et al.*, 2000).

MATERIAL AND METHODS

The general model details and the required parameters are described in Polovina and Ow (1983), Polovina (1984), Christensen and Pauly (1992) and Pauly *et al.* (2000).

The trophic relationship between each functional group and the other ecosystem components is represented as follows

$$B_i * PB_i * EE - \sum_{j=1}^n B_j * QB_j * DC_{ji} - EX_i = 0$$

where B_i = biomass of group (i); P/B = production/biomass ratio of group (i); EE_i = ecotrophic efficiency of group (i); Q_j/B_j = consumption/biomass ratio of group (j); DC_{ji} = fraction of the prey (i) in the average diet of predator (j); EX_i = exports out of the system (including fisheries catches) of group (i); the summation corresponds to total biomass of species (i) consumed by predators (j).

The present model was constructed with 18 functional groups as follows:

Benthic producers: This group consists of seagrass *Thalassia testudinum*, benthic algae, represented (because of their relative abundance) by *Penicillus capitatus*, *Bathofora oerstedii*, *Halimeda incressata* and *Laurencia intricata* (Aguilar-Rosas *et al.*, 1989), and microalgae.

Phytoplankton: Information on phytoplankton was based on Steidinger (1973) for estuarine waters of the Gulf of Mexico. Steidinger reported numerical abundance of microflagellates and nanoplankton, with diatoms, dinoflagellates and Cyanophyceae being the principal

components along the Gulf coast. The most common diatom group was the genus *Chaetoceros*.

Two zooplankton groups: To maintain appropriate trophic differentiation, zooplankton were grouped into herbivorous and carnivorous groups. The dominant groups of zooplankton are copepods, particularly *Acartia* spp. and *Labidocera* spp. (Campos-Hernandez and Suarez-Morales, 1993).

Benthic invertebrates: These include polychaete annelids of the families Cirratulidae, Capitellidae and Nereidae, with *Ceratonereis singularis* being very abundant (Jiménez-Perez, 1992). Amphipoda is also an abundant group, represented by the families Aoridae, Melitidae, Leucothoidae and Lysianassidae; with species such as *Amphilocheus neapolitanis*, *Colomastrix pusilla*, *Cymadusa filosa* and *Stenothoe gallensi* being most abundant (Jiménez-Perez, 1992).

Lobster: The lobster, *Panulirus argus*, is important because of its abundance and commercial value. Bahía de la Ascensión is a recruitment area for postlarvae, which remain and grow within the bay for two years, after which the juveniles emigrate to deeper waters, and tend to settle on coral reefs (Lozano-Alvarez, 1992).

Stone crab: *Mennipe mercenaria* is the key species, but other crabs are also included in this group.

Bonefish (macabi): *Albula vulpes* is an important species for sportfishing, but large specimens are not found in the study area, as this species lives in the open sea during the adult part of its life cycle (Basurto and Villanueva, 1996).

Jacks: These are here represented by *Caranx hippos*, *C. latus* and *C. chrysos*. Jacks are abundant along the coast, but infrequently found in the bay.

Snappers: Here, snappers are represented by *Lutjanus griseus*, *L. analis*, *L. synagris* and *Ocyurus chrysurus*.

Mojarra: Represented by *Eugerres plumieri*, *Gerres cinereus*, *Calamus bajonado* and *Archosargus rhomboidalis*.

Barracuda: Represented within the bay mainly by juveniles of *Sphryraena barracuda* (Basurto and Villanueva, 1996).

Permit: *Trachinotus falcatus*, an important species for commercial and sport fishing.

Cazones (small sharks): Represented by *Rizoprionodon terraenovae*, and juveniles (less than 110 cm) of *Carcharhinus limbatus* and *Negaprion brevirostris*.

Two shark groups: Adults of *Carcharhinus limbatus*, *C. leucas* and *Negaprion brevirostris* were treated as 'sharks', while the nurse shark *Ginglymostoma cirratum* was retained as a separate group (Zárate, 1996). Separation was based on dietary differences.

Dolphins: Represented by *Tursiops truncatus* (Zacarias, 1992).

Birds: The region presents a high diversity of aquatic birds, the most important species being: *Phalacrocorax auritus*, *Ajaia ajaja*, *Egretta* spp. and *Casmerodius albus* (Rangel-Salazar *et al.*, 1993).

The inputs units are t·km⁻²·year⁻¹. The biomass for benthic producers was estimated by Ecopath, assuming an Ecotrophic Efficiency (EE) of 0.95, and EE values for the rest of the groups were estimated by Ecopath. The biomass for exploited groups was estimated either from surplus yield models using catch and effort data for the period 1989 to 1995, or from the annual average catch. For phytoplankton and zooplankton groups, biomass and other parameters were taken from other estuarine Gulf of Mexico Models (Abarca-Arenas and Valero-Pacheco, 1993; De la Cruz-Aguero, 1993; Rosado-Solórzano and Guzmán del Prío, 1998). The inputs biomass, P/B and Q/B ratios, catches and EE values are shown in Table 1, and the diet matrix in Table 2.

Arreguín-Sánchez *et al.* (1993) provided data on P/B and Q/B ratios for benthic producers, mojarras, plankton, benthic invertebrates and sharks; and Opitz (1993) for marine birds. Values for the other groups were modified from models of Monterey Bay (Olivieri *et al.*, 1993) and of the Yucatan continental shelf ecosystem (Arreguín-Sánchez *et al.*, 1993).

The original stomach contents data for the diet matrix of benthic invertebrates were taken from Olivieri *et al.* (1993); bonefish from Fisher (1978) and García (1992); for lobster from Peacock (1974), Kanciruck (1980) and Colinas-Sanchez and Briones-Fourzan (1990); for crabs from Chávez and Fernández (1976); for jacks from Fisher (1978), De la Cruz and Franco (1981), Sierra and Popova (1982), Popova and Sierra (1985), Barba-Torres and Gaspar-Dillones (1987), Chávez *et al.* (1987) and García (1992); for snappers from Moe (1969), Fisher (1978), Claro (1981, 1983), Munro (1983), Yañez-Arancibia and Sánchez-Gil (1986) and Polovina and Ralston (1987); for mojarra

Table 1: Parametrization of the mass balance model for Bahía Ascención, Mexican Caribbean. P/B: production/biomass; Q/B: consumption/biomass; EE: ecotrophic efficiency; TL: trophic level; Omn.: omnivory index; Resp.: respiration; and Assim.: assimilation. [*Parametrización del modelo balanceado para el ecosistema de Bahía Ascención, Caribe Mexicano. P/B=Producción/Biomasa, Q/B=Consumo/Biomasa, EE=Eficiencia Ecotrófica, ww = peso húmedo.*]

Group No.	Group Name	Biomass (t·km ⁻²)	P/B (year ⁻¹)	Q/B (year ⁻¹)	EE	Catch (t·km ⁻²)	TL	Net Efficiency	Omn.	Resp.	Assim.
1	Phytoplankton	26.97	112.98	-	(0.391)	-	(1.00)	-	-	-	-
2	Herbivorous zooplankton	13.70	13.82	94.67	(0.982)	-	(2.00)	0.182	-	848.249	1037.583
3	Carnivorous zooplankton	2.00	15.00	90.00	(0.724)	-	(3.00)	0.208	0.06	114	144
4	Benthic primary producers	26.40	14.00	-	(0.455)	-	(1.00)	-	-	-	-
5	Benthic invertebrates	19.21	2.50	8.20	(0.687)	-	(2.30)	(0.381)	(0.41)	(77.993)	(126.018)
6	Bonefish	0.40	1.13	9.80	(0.819)	0.003	(2.78)	(0.144)	(0.405)	(2.684)	(3.136)
7	Lobster	2.40	0.62	8.20	(0.818)	0.006	(2.98)	(0.095)	(0.325)	(14.256)	(15.744)
8	Crabs	0.05	3.00	12.50	(0.918)	0.002	(2.96)	(0.300)	(0.454)	(0.385)	(0.550)
9	Jacks	(0.96)	0.40	4.50	0.900	0.001	(3.12)	(0.111)	(0.440)	(3.087)	(3.473)
10	Snappers	0.63	0.49	5.60	(0.960)	0.003	(3.31)	(0.109)	(0.203)	(2.514)	(2.822)
11	Mojarras	0.76	1.09	15.30	(0.950)	0.001	(2.81)	(0.119)	(0.392)	(6.148)	(6.977)
12	Barracuda	0.15	0.57	5.90	(0.869)	0.001	(3.28)	(0.121)	(0.552)	(0.623)	(0.708)
13	Permit	(0.58)	0.45	7.60	0.900	0.001	(2.93)	(0.074)	(0.450)	(3.283)	(3.545)
14	Cazones	0.25	0.40	4.50	(0.948)	0.003	(3.44)	(0.111)	(0.433)	(0.800)	(0.900)
15	Sharks	0.03	0.32	9.70	(0.313)	0.003	(3.68)	(0.041)	(0.649)	(0.223)	(0.223)
16	Nurse shark	0.03	0.32	3.60	(0.815)	0.002	(3.86)	(0.111)	(0.134)	(0.077)	(0.086)
17	Dolphin	0.04	0.10	25.00	(0.708)	-	(3.78)	(0.005)	(0.098)	(0.796)	(0.800)
18	Marine birds	0.01	5.40	70.00	(0.955)	-	(3.51)	(0.096)	(0.337)	(0.506)	(0.560)
19	Detritus	13.00	-	-	-	-	(1.00)	-	(0.583)	-	-

Table 2: Diet matrix showing proportional diet composition for the functional groups in the trophic model for Bahía Ascención, Mexican Caribbean.

Group No.	Prey	Predator															
		2	3	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Phytoplankton	0.900	0.030	0.100	-	-	-	0.133	0.043	0.051	0.066	0.065	-	-	-	-	-
2	Herbivorous zooplankton	-	0.940	0.100	-	-	0.030	-	0.034	0.050	-	0.060	-	-	-	-	-
3	Carnivorous zooplankton	-	0.030	0.100	-	-	0.030	0.012	0.035	0.002	0.025	0.023	0.103	-	-	0.123	-
4	Benthic primary producers	0.100	-	0.200	-	0.250	0.300	0.054	0.005	0.131	-	0.005	0.108	0.148	-	-	0.015
5	Benthic invertebrates	-	-	-	0.601	0.740	0.603	0.590	0.733	0.576	0.386	0.535	0.420	0.104	0.281	0.258	0.452
6	Macabí	-	-	-	-	-	-	0.015	-	-	0.042	0.007	0.048	0.074	-	0.150	0.012
7	Lobster	-	-	-	-	0.003	-	0.106	0.075	-	0.048	0.010	0.028	0.012	0.282	0.121	0.220
8	Crabs	-	-	-	-	-	0.010	0.005	0.004	-	0.005	0.005	0.017	0.055	0.135	0.020	0.015
9	Jacks	-	-	-	-	0.001	-	-	0.001	-	0.060	0.030	0.038	0.106	0.152	0.040	0.010
10	Snappers	-	-	-	-	0.001	-	0.006	0.009	0.003	0.038	-	0.028	0.121	0.150	0.033	0.045
11	Mojarras	-	-	-	-	0.005	-	0.021	0.027	-	0.130	-	0.114	0.100	-	0.150	0.112
12	Barracuda	-	-	-	-	-	-	0.003	-	-	0.010	-	0.015	0.050	-	0.020	-
13	Permit	-	-	-	-	-	-	0.007	0.006	-	0.009	0.010	0.028	0.052	-	0.070	0.021
14	Cazones	-	-	-	-	-	-	0.003	0.004	-	0.012	-	0.008	0.048	-	0.015	0.023
15	Sharks	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	Nurse shark	-	-	-	-	-	-	-	-	-	-	-	-	0.020	-	-	-
17	Dolphin	-	-	-	-	-	-	-	-	-	-	-	0.002	0.002	-	-	-
18	Marine Birds	-	-	-	-	-	0.027	-	-	-	-	-	0.019	0.028	-	-	0.005
19	Detritus	-	-	0.500	0.399	-	-	0.045	0.024	0.187	0.149	0.250	0.022	-	-	-	0.070
	Import	-	-	-	-	-	-	-	-	-	0.020	-	0.002	0.080	-	-	-

from Randall (1967), Yañez-Arancibia (1978), Abarca-Arenas *et al.* (1982), González and Rodríguez (1983), Salas (1984, 1986) and Abarca-Arenas (1987); for barracuda from Mendoza (1993); for permit from Fisher (1978) and Munro (1983); for cazones (small sharks) from Russo (1975), Gómez and Bashirulah (1984) and Cortés and Gruber (1990); for sharks from Castro (1983), Compagno (1984), Alvarez (1988), Dudley and Cliff (1993) and Olivieri *et al.* (1993); for nurse shark from Compagno (1984), for dolphins from Barros and Odell (1990) and Zacarias (1992); for marine birds from Dumas and Witman (1993) and Olivieri *et al.* (1993). Some of the original input parameters were subsequently modified in order to balance the model.

Following model balancing, the Ecoranger routine (Christensen and Pauly, 1996) was used to obtain a better fit of the model. Ecoranger consists of a semi-Bayesian approach in which the distribution of the parameters from the first balanced model provided the prior distributions. Triangular prior distributions were selected, together with minimization of residuals, as criterion for constraint. It was decided that at least 3000 positive solutions were required to obtain posterior parameter distributions.

RESULTS AND DISCUSSION

The most problematic groups in terms of balancing the model were snappers, crabs, cazones (small sharks) and mojarra, for which original input biomass had to be reduced. The highest biomass among consumer levels was that of lobsters, followed by mojarras. This is consistent with the knowledge of the area as the most important nursery area for lobster in the Mexican Caribbean region (Lozano-Alvarez and Briones-Fourzan, 1991) and some fish larvae of several oceanic and coastal species (Vasquez-Yeomans, 1990). Benthic invertebrates constitute a very important link between primary producers and the higher trophic levels (TL). The average TL in the ecosystem is approximately 2.7. TL for lobster was 2.98 and 3.86 for top predators such as nurse shark. These values are similar to those reported by Opitz (1993) for a Caribbean coral reef ecosystem.

Table 3 shows that of a total system throughput of 4,815 t·km⁻²·year⁻¹, 35% (1,686 t·km⁻²·year⁻¹) corresponds to flows to

consumption, while flows to detritus were 22% of the total. This is consistent with previous reports that the bay exports detritus to adjacent areas.

Table 3: Summary statistics for the ecosystem of Bahía de la Ascención, Mexican Caribbean.

Attribute	Magnitude	units
Sum of all consumption	1,686,826	t·km ⁻² ·year ⁻¹
Sum of all exports	984,122	t·km ⁻² ·year ⁻¹
Sum of all respiratory flows	1,075,623	t·km ⁻² ·year ⁻¹
Sum of all flows into detritus	1,068,189	t·km ⁻² ·year ⁻¹
Total system throughput	4,815,000	t·km ⁻² ·year ⁻¹
Sum of all production	3,686,000	t·km ⁻² ·year ⁻¹
Mean trophic level of catches	3.2	
Gross efficiency (catch/net pp)	0.000008	
Calculated total net primary production	3,416,671	t·km ⁻² ·year ⁻¹
Total primary production/total respiration	3,176	
Net system production	2,341,047	t·km ⁻² ·year ⁻¹
Total primary production/total biomass	36,124	
Total biomass/total throughput	0.020	
Total biomass (excl. detritus)	94,583	t·km ⁻²
Total catches	0.026	t·km ⁻² ·year ⁻¹
Connectance Index	0.426	
System Omnivory Index	0.283	

The direct and indirect impacts of predation and competition were explored using the Leontif matrix of Ecopath (Figure 2). For economically important species some impacts are relevant, lobsters show positive impact on nurse sharks and birds, and negative impacts on benthic invertebrates, snappers and mojarras. Snappers show positive impacts on sharks, dolphins and marine birds, and negative impacts on lobsters, crabs and cazones (small sharks). On the other hand, lobsters are impacted negatively when the biomass of jacks and snapper increase; macabi are impacted negatively when jackas and dolphins biomass increase; biomass of permits affect jacks biomass and, snapper are impacted negative when mojarras biomass increases.

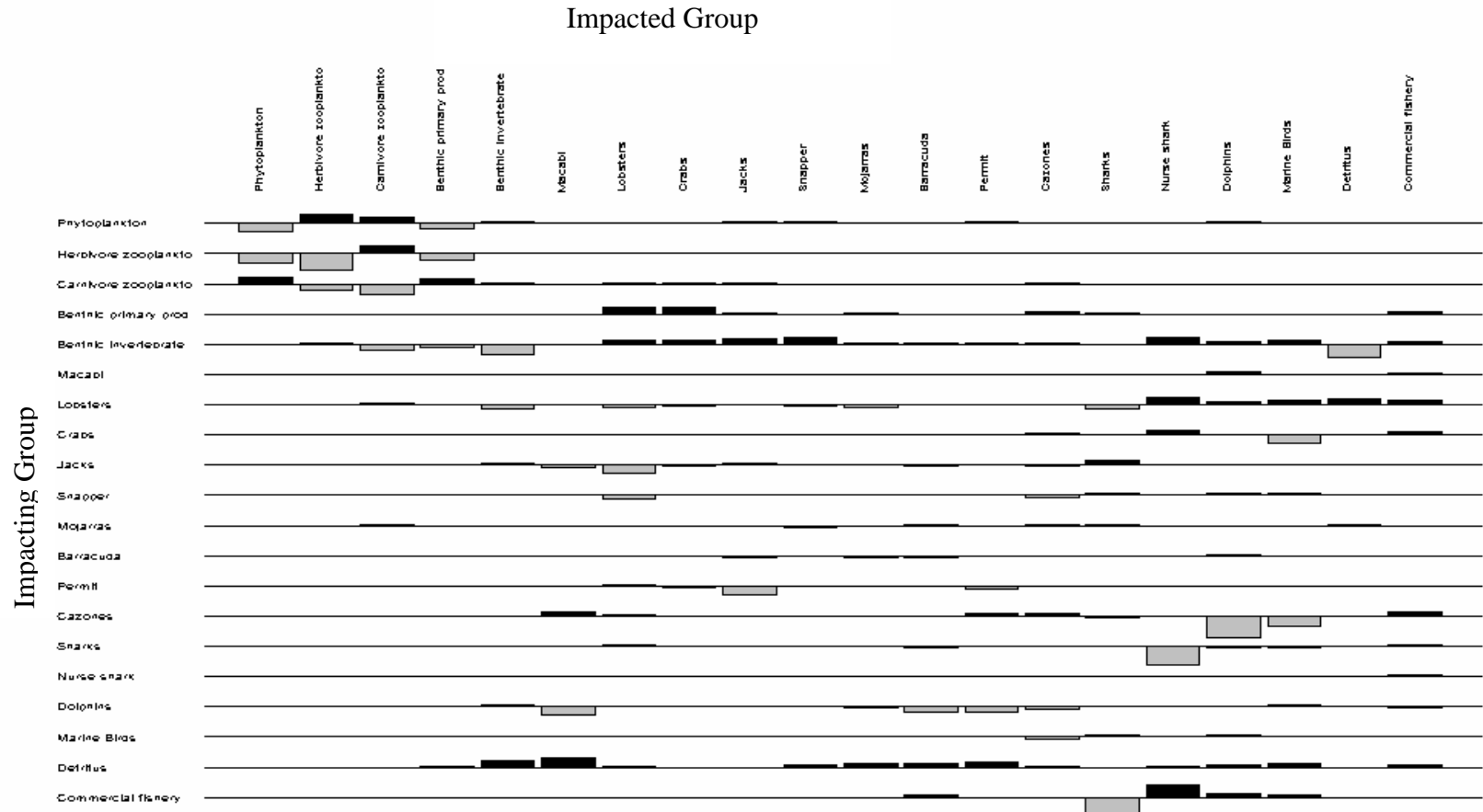


Figure 2: Mixed trophic impacts in Bahía de la Ascención, Yucatan Peninsula, as analyzed by the Leontief matrix. Positive impacts are shown above the line and negative below each group line. [*Impactos tróficos mezclados en Bahía de la Ascención, Península de Yucatán, analizados por la matriz de Leontief. Impactos positivos se muestran arriba de la línea y los negativos hacia abajo.*]

To balance the model, it was required to assume food imports from adjacent areas, such as reefs, and mangrove. Groups that required these inputs in their diet were barracudas, cazones and sharks, species that are known to move within the coastal region. To improve this model, some considerations should be given to splitting several groups, e.g., benthic invertebrates could be split into several groups, such as molluscs, microcrustaceans and annelids. Given the high complexity of invertebrate groups in this area, such separate treatment should improve any comparison of results with other similar systems.

With lobster being the most abundant group, and a secondary consumer in the system, it is important to note that the population is not homogeneously distributed by size. Small lobsters usually occur in the inner part of the bay, and larger animals occupy zones closer to the reef (Lozano-Alvarez and Briones-Fourzan, 1991). Thus, diet composition could vary significantly from one area to another. Another important factor related to lobsters could be the strong seasonal variation in catches, mainly due to a closed season. We assume that changes in biomass of lobsters due to fishing could introduce important seasonal differences in the trophic dynamics of the ecosystem, given that lobster are the most abundant group.

Furthermore, three very distinct seasonal periods can be distinguished in Bahía de la Ascensión: dry, rainy and winter storms (Merino and Otero, 1991). As a consequence, general species composition, distribution and abundance of the community present seasonal variations. Because the input values used in this Ecopath model were on an annual basis, it is recommended to explore a model involving seasonal variations.

The present study presents a preliminary model, providing basic insights into the structure and dynamics of this ecosystem. Some aspects could not be addressed in this study, and should be considered in future work. For example, information related to migration should be evaluated, particularly since Bahía de la Ascensión is a nursery area for lobsters and commercial fish species, where individuals gain biomass, and then emigrate as adults to adjacent ecosystems.

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