

A preliminary trophic model of *Scomberomorus commerson* in the Persian Gulf

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Abstract

A preliminary Ecopath model was fitted to study the trophic interaction of *Scomberomorus commerson* in the Persian Gulf using the available data on most of the ecosystem compartments. Fifteen species were used in the present analysis. The values of Ecotrophic Efficiency (EE) in the model are high (>0.5) for most consumers of high trophic level except for *S. commerson* because of its high fishing mortality. The highest realized trophic level obtained was 4.04 for *S. commerson*. The maximum Omnivory Index (OI) was calculated as 0.88 for *Encrasicholina punctifer* by feeding on a wide variety of preys and the least, 0.08 for *S. commerson* with highly specialized feeding. Mixed trophic analysis indicates that benthos have a positive effect on most of the fish species. Most species have a negative impact on themselves, interpreted here as reflecting increased within-group competition for resources. This preliminary model can be helpful to determine the gaps in the present knowledge about pelagic system of the Persian Gulf.

Keywords: Ecopath, Omnivory Index, Trophic Level, Persian Gulf.

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Introduction:

The Persian Gulf is a shared body of water, between Iran, Kuwait, Saudi Arabia, Iraq, Bahrain, Qatar and U.A.E (Fig1). The Persian Gulf is very productive and supports valuable fisheries in all countries for penaeid shrimps and demersal fish, as well as for small and medium-sized pelagic species. Commercial fishing for demersal species became established in the second half of the 20th century, with the major fishery being the trawl fishery for penaeid shrimps. These trends suggest that trawling has had an impact on the ecosystem, in this regard bottom trawl fish fisheries were forbidden in the Persian Gulf by IFO.

The fisheries of the Persian Gulf are managed by RECOFI, although regulations exist. To date, some studies have been conducted on species interactions or on the ecosystem effects of trawling in the Persian Gulf.

The scombridae family is distributed in Indian and Pacific Ocean, as well as Red Sea, Arabian Sea, Oman Sea and Persian Gulf. This family includes 15 genus and 49 marine species (epipelagic and oceanic) (Collette & Nauen, 1983). The narrow-barred spanish mackerel, *Scomberomorus commerson* (Lacepede, 1800) is one of the important pelagic species of scombridae that is widely distributed in the tropical Indo- Pacific region, from the Red Sea and South Africa to southeast Asia, north to China and Japan and south to Australia (Randall, 1995), being an immigrant to the eastern Mediterranean Sea by the way of the Suez Canal (Ben-Tuvia, 1978). Annual catch of the narrow-barred Spanish mackerel has been reported 20137 mt in 2013 around 10% of the total production of large pelagic fishes (Iranian Fisheries Organization, 2015). Up to the 1980s, fisheries have to a large extent focused on obtaining information on the exploited resources in a 'single-species' management style. The concept of ecosystem-based management of fisheries emerged in the 1982 UN convention on the Law of the Sea (UNEP, 2001). In the last two decades, emphasis was put on ecosystem resources interaction, and the fact that these interactions are sometimes more important than the impact of the fisheries (Christensen and Pauly, 1997).

Fisheries data are not available for most non-target species, scientific surveys are expensive and time-consuming, and ongoing monitoring may be logistically impossible. The best option seems to be the development of models that represent the principal elements of the ecosystem and description of biomass flows between them, based on the best available information on who eats who (Gibbons-Fly, 2000).

Fisheries research of industrialized countries has lately focused on ecosystem modeling as a result of FAO, UNEP and EU incentives as well as Agenda 21 from Rio de Janeiro 1992 Earth Summit. This has led to the development of different modeling tools such as multispecific models: Multispecies Virtual Population Analysis (MSVPA) (Sparre, 1991) or ecosystem models: Ecopath with Ecosim. They have not as yet proved themselves as management tools, but are paving the way to future implementation of ecosystem-based management of fisheries.

Traditional and semi industrial fishing fleets carry out almost all fisheries in the Persian Gulf and the Oman Sea. Many demersal fish stocks have declined in the Persian Gulf & Oman Sea, in contrast, landings of large pelagic species have increased in southern fisheries of Iran from around 160432 tons in 2003 to 239593 tons in 2013 (Iranian fisheries organization, 2014). This increase in landings is mainly due to fishing effort increases (FAO, 2006).

As prey-predator relationships are a key factor in the ecosystem, Tunas and billfishes prey on fish, squid and crustaceans. The larger individuals (wahoo, bonitos, tunas and billfishes), which feed on pelagic fishes, are positioned at the top of the trophic web. The smaller individuals (juvenile tunas and billfishes, mackerels and seer fishes) prey on zooplankton (mainly crustaceans) and constitute part of the ration of large scombroids, sharks, cetaceans and seabirds (Roger, 1994); consequently understanding and modeling food webs are primordial in an ecosystem context (Link, 1999).

The purpose of the present study is to design and parameterize a preliminary Ecopath model of the *S. commerson* and the possible impact of fishing on food web of *S. commerson* including small pelagics and invertebrates, using the Ecopath with Ecosim software (Walters et al., 1997). It is made with currently available data from stomach content and collects population dynamic parameters of *S. commerson* to evaluate the impact of fishing.

Materials & Methods

Monthly collection samples were made using a range of methods in order to obtain fish from the widest possible size ranges from landing places of the Persian Gulf. The fish captured by commercial vessels using gillnets with 9 and 14 cm mesh size.

A total of 2093 *S. commerson* were randomly selected from 2011 to 2012 of six landing sites (Abadan, Genaveh, Bushehr, Tangestan, Dayer and Kangan) encompassing the entire coastline of the northern Persian Gulf (Fig1). Different food items were identified by Carpenter et al. (1997).

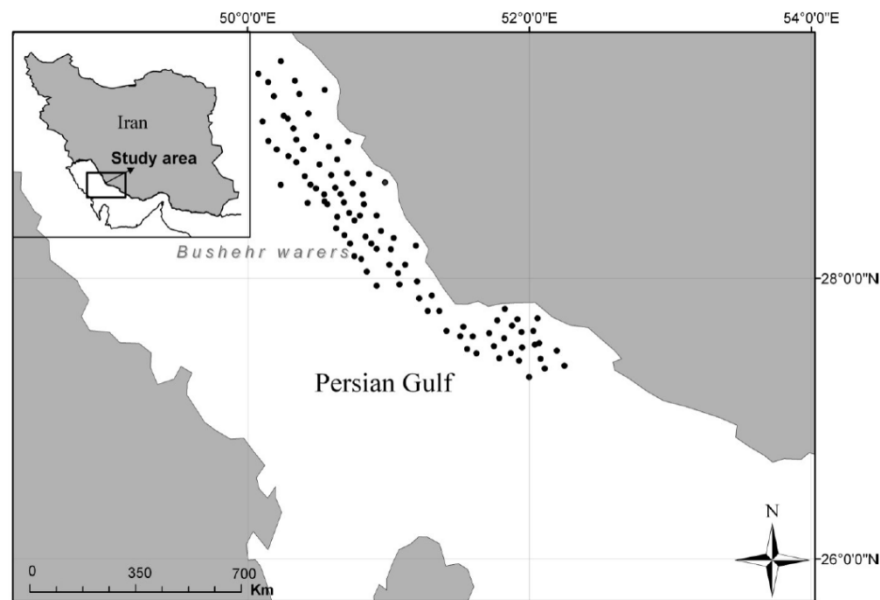


Fig 1. Map of Persian Gulf with showing sample sites

Ecosystem models

Ecopath was used for our study given the good representation of predator-prey interactions. The model's simplicity and its ability to accurately identify ecological relationships are also appropriate for our questions relating to the interaction between pelagic fishes and fisheries (Plaganyi and Butterworth, 2004).

Using this model, each trophic group in the model is represented by one balanced equation and requires five input parameters: biomass (B), production to biomass ratio (P/B), consumption to biomass ratio (Q/B), Ecotrophic Efficiency (EE) and diet composition (ΣDC). Systems included in the model also allow for the estimation of one missing parameter in each group (B, Q/B, P/B, or EE (Christensen and Pauly, 1992). *Ecopath* models are based on mass balance principles, assuming that production of a given prey group (*i*) is equal to the biomass lost to fishing or export, predation, and natural mortality other than predation (other mortality). This mass balance can be expressed as (Christensen and Pauly, 1992):

$$\text{Consumption} = \text{production} + \text{respiration} + \text{unassimilated food} \quad (1)$$

$$\text{Production} = \text{predation} + \text{fishing mortality} + \text{other mortality} \quad (2)$$

Model groups

Fifteen ecological groups were defined based on the most abundant species involved in diet composition of narrow-barred Spanish mackerel and other related species in the Persian Gulf.

The prey fish species or groups were *Atule mate* (yellowtail scad), *Leiognathus sp* (ponyfish), *Rastrelliger kanagurta* (Indian mackerel), *Encrasicholina punctifer* (*buccaneer anchovy*), and *Sardinella sp* (sardine). Invertebrate groups are included: mollusk, crustacean mainly *Penaeus semisulcatus*, polychaete, echinoderm, zooplankton, phytoplankton and detritus.

Biomass (B) estimates

According to the absence of reliable evidence relating to stock structure of narrow-barred spanish mackerel, a precautionary approach is assumed that there is a single stock throughout the Indian Ocean, until proven otherwise, three potential sub regions/stocks were considered as indicated below:

- East Africa,
- Persian Gulf & Oman Sea and East & West of India,
- Indonesia & Australia,

In this regard, average catches in the Indian Ocean over the period 2010–12, belonged to the second sub-stock (Persian Gulf & Oman Sea and East & West of India) were estimated around 58% of whole Indian Ocean, in accordance to this hypothesis, biomass of narrow-barred spanish mackerel for the second region was estimated around 132,820 mt (IOTC-WPNT02-2012 ; IOTC-SC17- 2014).

Biomass estimates of demersal fish, penaeids were obtained from trawl surveys conducted on the northern part of the Persian Gulf (Valinassab et al., 2012; Salarpour et al., 2008). The mean concentration of phytoplankton applied in the model for the Persian Gulf was estimated around 2.09 µg/l chlorophyll-a (Technical ROPME Report Series, 2012), and population density of zooplankton averaged as 14.1 x10³ organisms/m³ given by Technical ROPME Report Series (2010).

Estimates of macro benthic biomass are based Nourinejad et al. (2013) and an estimate of detritus biomass is from Vahabnezad et al. (2014).

Consumption to biomass ratio (Q/B) estimates

Consumption is the intake of food by a group over the time period considered. It is entered as the ratio of consumption over biomass (*Q/B*), is given by the equation:

$$\text{Log } (Q/B) = 7.964 - 0.204 \log W_{\infty} - 1.965 \cdot T' + 0.083 \cdot A + 0.532 \cdot h + 0.398$$

where, W_{∞} is the asymptotic weight (g), T' is an expression for the mean annual temperature of the water body, A is the aspect ratio, h is a dummy variable expressing food type (1 for herbivores, and 0 for detritivores and carnivores), and d is a dummy variable also expressing food type (1 for detritivores, and 0 for herbivores and carnivores). W_{∞} was calculated from the asymptotic length, L_{∞} of the von Bertalanffy growth curve transformed to weight by means of the length-weight relationship (Moreno and Castro, 1994).

Production to biomass ratio (P/B) estimates

In fish population whose individuals grow according to the von Bertalanffy Growth Function (VBGF) can use estimates of total mortality (Z) as input values for the production over biomass ratio (P/B) in Ecopath models. Available data from the literature and also estimated following the methods of Brey (1999) and Christensen et al. (2000) were used for benthic species and zooplanktons (table 1).

Ecotrophic efficiency (EE) estimates

The Ecotrophic Efficiency (EE) is the fraction of the production that is used in the system, i.e. either passed up the food web, used for biomass accumulation, migration or export. It varies between 0 and 1 and can be expected to approach 1 for groups with considerable predation pressure, is given by the equation:

$$EE = 1 - OM / (P/B)$$

Where, OM is other mortality and P/B is equal total mortality.

Diet composition

The diet matrix is constructed by designating the percent of each prey that occurs in each predator's diet. Ponyfish, halfbeak fish, Indian mackerel, carangid, and cephalopod comprised the majority of the diet of narrow-barred Spanish mackerel (Kaymaram et al., 2013). However, since these studies only listed proportions of Zoobenthos, ponyfish and *Encrasicholina punctifer* as prey in the diet, we also used a study by George (1964) to consider sardine as prey into diet in the Indian Ocean. Ponyfishes are mainly fed on zooplankton and benthic invertebrate (Smith, 2001). The diet of *E. punctifer* was mainly composed of plankton in the Persian Gulf which crustacean dominated the food with copepods and their eggs, which nauplius and semi digested copepods constituting 54% of the diet (Salarpour et al., 2008).

Invertebrate diet matrices were estimated using published literature and reports on the Persian Gulf and other area (Pourjomeh et al., 2014; Sandberg et al., 2000 and Castell, 1989) (Table 2).

The average diet was used as an input in our Ecopath model, while minimum and maximum values were used as ranges for calibration.

Table 1: Input parameters for the Persian Gulf model

Group name	Biomass (t/km ²)	Production / biomass (/year)	Consumption / biomass (/year)
1 <i>Scomberomorus commerson</i>	0.52	0.97	11.2
2 <i>Atule mate</i>	0.13	1.49	10.5
3 <i>Leiognathus sp.</i>	0.3	9.44	89
4 <i>Rastrelliger kanagurta</i>	0.001	5.85	29.9
5 <i>Encrasicholina punctifer</i>	0.23	6.44	59
6 <i>Sardinella sp.</i>	0.31	5.58	69
7 Bivalve	17.61	35.23	0.25
8 <i>Sepia Pharaonis</i>	0.061	4.63	36.5
9 <i>Penaeus semisulcatus</i>	0.24	3	0.24
10 Crustacean	17.61	35.23	0.25
11 Polychaete	17.61	37	0.25
12 Echinoderm	14.8	14.8	35
13 Zooplankton *	14.1x10 ³	35	0.25
14 Phytoplankton **	2.09	6.1	0
15 Detritus	1.30		

* Organisms /m³

** µg/l chlorophyll-a

Results

Most Ecopath models are built using a set of input parameters consisting of means for the given period. These preliminary inputs were chosen based on the best available information in the region, but the model is likely to be unbalanced at the first run, Values of the parameters have to be modified until a balanced model is achieved.

A preliminary model was successfully constructed for narrow-barred Spanish mackerel food web. In general, Ecotrophic Efficiency values are high for the fish groups, while they are low for phytoplankton and detritus (table 3). The low EE of phytoplankton indicates that only a small proportion of phytoplankton production is grazed in the water column, with the rest going toward detritus. Similarly, the low EE of detritus also indicates that a small fraction of detritus biomass is consumed, with the rest being buried in the sediment or exported out of the system.

Three species or species group (*A. mate*, *E. punctifer* and *Leiognathus sp.*) are unbalanced; their EE is greater than the others. This means that consumption (predation and fishing) is higher than production. Low EE calculated by the model for the top predators (less than 0.5) like for *S. commerson* seem unrealistic for this heavily fished species.

Ecopath also calculates the fractional trophic level (TL) for each group. Trophic levels estimated by model range from 1 (detritus and phytoplankton groups) while trophic levels of fish species are between 2.85 (*Sardinella* sp.) to 4.04 (*S. commerson*).

Table 2: diet composition matrix for the Persian Gulf

Prey \ predator	1	2	3	4	5	6	7	8	9	10	11	12	13
1 <i>S. commerson</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2 <i>Atule mate</i>	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00
3 <i>Leiognathus sp.</i>	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4 <i>Rastrelliger kanagurta</i>	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5 <i>Encrasicholina punctifer</i>	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6 <i>Sardinella sp.</i>	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7 Bivalve	0.00	0.23	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8 <i>Sepia Pharaonis</i>	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9 <i>Penaeus semisulcatus</i>	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.60	0.00	0.00	0.00	0.00	0.00
10 Crustacean	0.00	0.37	0.25	0.59	0.70	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.00
11 Polychaete	0.00	0.04	0.05	0.00	0.00	0.15	0.00	0.30	0.40	0.05	0.00	0.00	0.00
12 Echinoderm	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00
13 Zooplankton	0.00	0.20	0.20	0.00	0.00	0.70	0.20	0.00	0.00	0.30	0.00	0.00	0.00
14 Phytoplankton	0.00	0.00	0.50	0.10	0.30	0.15	0.80	0.00	0.00	0.00	0.10	0.10	0.00
15 Detritus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.60	0.90	0.90	1.00
16 Sum	1.00	1.00	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00

Predators in columns, preys in lines. Predators are called by their group number. The total diet of each predator is equal to 1.

Table 3: Outputs of the modified model.

	Group name	Trophic level	Habitat area (fraction)	Biomass in habitat area (t/km ²)	Biomass (t/km ²)	Production / biomass (/year)	Consumption / biomass (/year)	Ecotrophic efficiency
1	<i>Scomberomorus commerson</i>	4.045	1.000	0.520	0.520	0.970	11.20	0.450
2	<i>Atule mate</i>	3.304	1.000	0.130	0.130	1.490	10.50	0.990
3	<i>Leiognathus</i> sp.	2.600	1.000	0.300	0.300	9.440	89.00	0.990
4	<i>Rastrelliger kanagurta</i>	3.292	1.000	0.00100	0.00100	5.850	29.90	0.130
5	<i>Encrasicholina punctifer</i>	2.980	1.000	0.230	0.230	6.440	59.00	0.990
6	<i>Sardinella</i> sp.	2.850	1.000	0.310	0.310	5.580	69.00	0.754
7	<i>Bivalvia</i>	2.200	1.000	17.61	17.61	35.23	0.250	0.600
8	<i>Sepia Pharaonis</i>	3.790	1.000	0.0610	0.0610	4.630	36.50	0.800
9	<i>Penaeus semisulcatus</i>	3.100	1.000	0.240	0.240	3.000	0.240	0.980
10	crustacean	2.400	1.000	17.61	17.61	35.23	0.250	0.600
11	polychaete	2.000	1.000	17.61	17.61	37.00	0.250	0.600
12	Echinoderms	2.000	1.000	14.80	14.80	14.80	35.00	0.250
13	Zooplankton	2.000	1.000	14.80	14.80	35.00	0.250	0.700
14	phytoplankton	1.000	1.000	2.050	2.050	6.100		0.500
15	Detritus	1.000	1.000	1.303	1.303			0.395

Figure 2 shows the direct and indirect impact in system. The bars pointing upwards indicate positive impacts, while the bars pointing downwards show negative impacts. The bars should not be interpreted in an absolute sense; the impacts are relative, but comparable between groups (Christensen et al., 2002). In this example, the apex predators will have a negative impact on their preferred prey, for example, *A. mate* on any other group have a negative impact except on *S. commerson*. The impact of the *E. punctifer* on the other species is slightly positive, even though the former feeds on zooplankton directly. Most groups have a negative impact on themselves, interpreted here as reflecting increased within-group competition for resources.

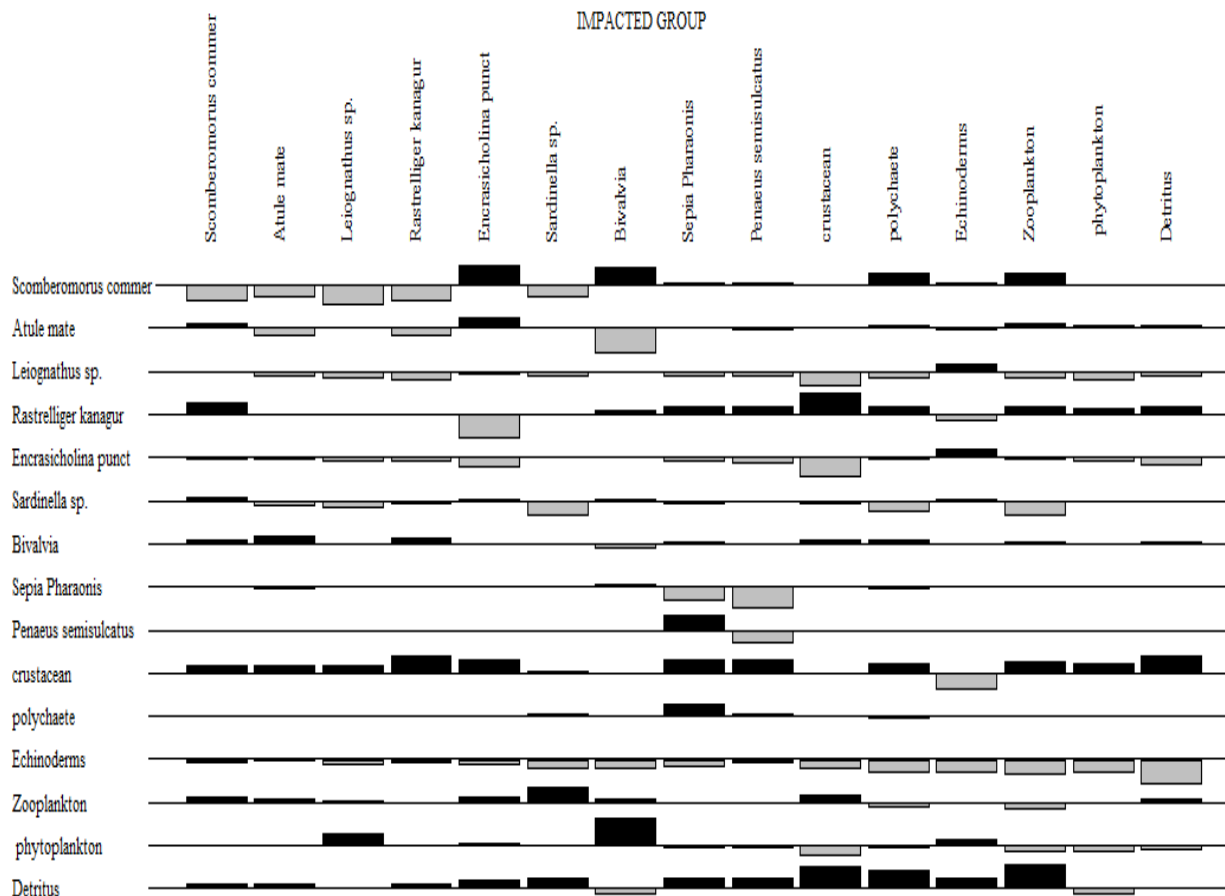


Figure 2: Mixed trophic impacts showing the combined direct and indirect trophic impacts that an infinitesimal increase of any of the groups on the left is predicted to have on the groups in the columns

EwE automatically builds a trophic flow diagram (Fig 3). The flows to detritus were maximum for phytoplankton, crustacean and polychaete. The least flows were observed for apex predators. The Omnivory Index (OI) was calculated as the variance of the trophic level of a consumer's prey groups. The maximum OI was observed for *E. punctifer* (OI=0.88), followed by *Leiognathus sp.* (OI=0.67) and *R. kanagurta* (OI=0.60) indicating feeding on a wide variety of preys. Highly specialized feeding (low OI) was observed for *S. commersoni* (OI=0.08)

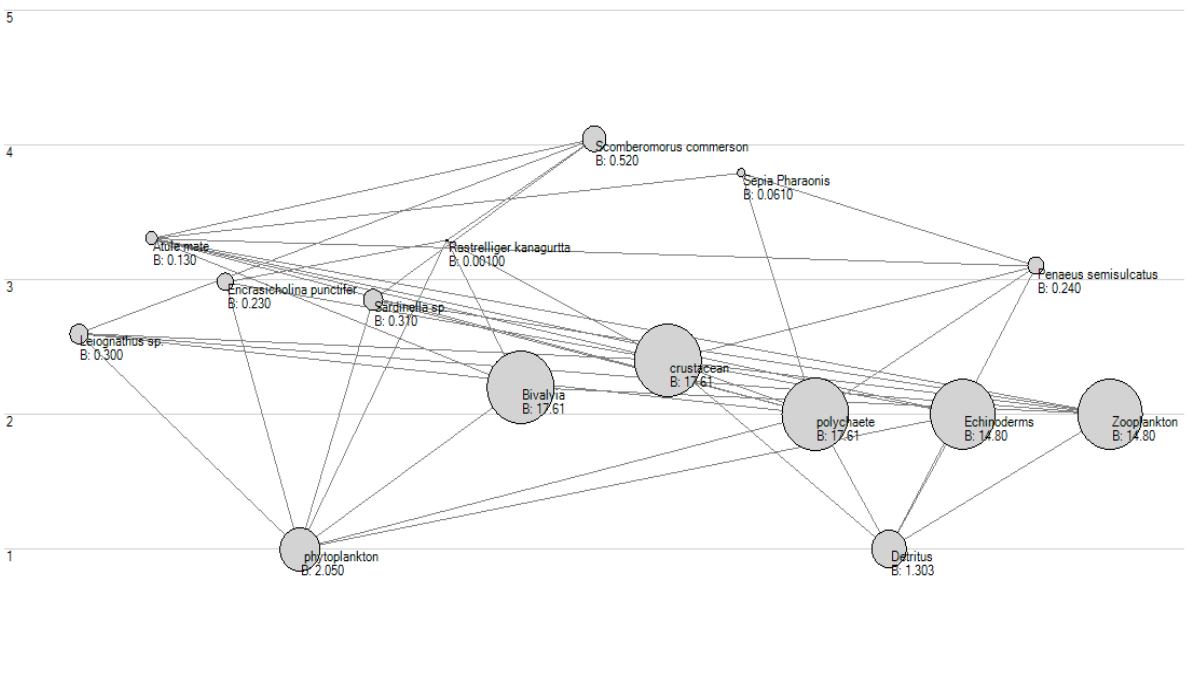


Fig 3: Flowchart of trophic interactions in the Persian Gulf in pelagic ecosystem of indicating trophic flows in t/km², Circle sizes represent biomass.

The prey and predator niche overlaps for the Persian Gulf ecosystem indicates that *S. commerson* and cephalopods have significant overlap in their diets with small pelagics. Maximum predatory overlap was observed in the case of cephalopods. The selection indices or electivity describe a predator's preference for prey and *S. commerson* had a marked preference for *R. kanagurta* in the Persian Gulf, while it avoided small benthic carnivores. *A. mate* was very selective feeders (on benthic omnivores and large zooplankton) and avoiding most prey groups.

Discussion

This study provides some useful insights into the trophic structure and functioning of the Persian Gulf. Results indicate that the ecosystem is in many aspects similar to other continental shelf and estuarine ecosystems.

Notable is the dominance of the detrital pathway over the grazing pathway. Grazing may not have a major effect in the Persian Gulf, considering the relatively shallow depth and high seasonal nutrient input into this ecosystem. In other estuarine environments grazing has been found to be highly variable and consumes from 2 to 45% of phytoplankton standing crop (Day et al., 1989). The inefficient grazing by herbivores has previously been shown for several other marine ecosystems, for example, the Gulf of Panama (Smayda, 1966), the northern Gulf of Mexico (Flint and Rabelais, 1981), the Gulf of Paria (Manickchand- Heileman et al., 2004).

The quality of the inputted data was assessed with the Ecopath pedigree index and the value obtained was 0.52 (scale 0-1). It appears that the marine food webs in which tuna exist are considerably short, with at least four trophic levels in many cases, and with tuna generally occupying the upper trophic positions because tunas and billfishes are opportunistic feeders (Roger, 1994). The findings of this study support the common view that tuna are top predators.

The Ecotrophic Efficiencies (EE) of most of the fish species were higher than 0.5. Accordance Dickie (1972) Minimum EE, which shows less fishing and predation pressure on species, but for *S. commerson* (less than 0.5) seems unrealistic because of this heavily fished species (Kaymaram et al., 2013; Grandcourt, 2013).

Tunas and billfishes prey on pelagic or epipelagic fishes (including juveniles of tunas), crustacean and cephalopods (squid). Yellowfin and bigeye tunas as well as swordfish feed on mesopelagic fishes (Menard et al., 2000, Allain, 2005). Coastal tunas feed on neritic and epipelagic prey (Olson and Boggs, 1986). Larger tunas feed on small pelagic fishes, mackerels, small tunas, carangids and flying fishes.

Analyses of stomach contents of *S. commerson* indicated that they feed heavily on small epipelagic and carangid fishes and large schools of prey-fish are associated with large schools of narrow-barred Spanish mackerel (Kaymaram et al., 2014). Since these preys of narrow-barred Spanish mackerel feed directly on zooplankton (mainly copepods), it seems that the tunas as a top of a short food web are very efficient from the point of view of energetics (Roger, 1994).

Mean trophic levels were calculated for each group using diet composition and prey trophic levels (Table 3). In our study, they assigned a trophic level of 1.0 to 4.04 Spanish mackerel and 3.3 *A. mate*. Published estimates of trophic levels with which these estimates could be compared are rare. Blaber et al. (1990) (TL=4.38) in the Solomon Islands and Goffredo and Dubinsky (2013) (TL=4.5) in Mediterranean Sea, considered trophic levels are higher than ours.

Mixed trophic impacts make it possible to assess the effect that changes in the biomass of a group will have on the biomass of the other groups in a system. Prey has a positive impact on its predator, while a predator has negative impact on its prey. MTI, developed by Ulanowicz and Puccia (1990), can also be regarded as a form of “ordinary” sensitivity analysis. In the Persian Gulf, since sardine and indian mackerel are major portion of the diet of many fish species; they have a positive impact on tunas, cephalopods and carangids. *S. commerson* has a negative impact on all the fish groups except on *E. punctifer* which could be because of prey and predator niche overlap. In addition, it confirmed that the two types of fisheries (gill nets and trawls) are impacting their own target population independently from each other (Mohamed et al., 2005).

Preparation of the predator-prey feeding matrix for the model was also a difficult task due to lack of previous studies on feeding ecology and some biomass estimations in this ecosystem. Most of

the qualitative data were provided by several studies on other ecosystems and were then converted into a quantitative form which might substantially influence the final results.

Thus, a decrease in the abundance of species at higher trophic levels through trawling could have resulted in this shift to a dominance of species of lower trophic levels in the Paria Gulf (Manickchand-Heileman et al., 2004). This is consistent with our observations in the Persian Gulf subjected to multispecies fisheries by gillnets, However, these results are only preliminary and further studies are required to verify the impacts of fishing in the Persian Gulf ecosystem.

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