Iranian Journal of Fisheries Sciences 19(6) 2804-2823 2020
DOI: 10.22092/ijfs.2020.122699

Research Article

Trophic dynamics analysis and ecosystem structure for some fish species of northern Oman Sea

Tajzadeh-Namin M.[1]; Valinassab T.[2*]; Ramezani Fard E.[1]; Ehteshami F.[2]

Received: May 2020 Accepted: July 2020

Abstract

In the present study, a trophic structure model for some fish species of the northern Oman Sea is developed through using mass balance modeling software, Ecopath with Ecosim (EwE). In this model, we simulated 16 functional groups spread across an area of 3998.20 km^2 from 2017 to 2018. Mean trophic level in the area of the present study was 3.49. Values calculated for system omnivory and connectance indices were 0.42 and 0.44, respectively. However, the values of ecotrophic efficiency in the model were high (>0.5) for most consumers of high trophic levels except for sharks and rays because of their high fishing mortality. Accordingly, mixed trophic impact showed that phytoplankton and detritus positively impacted almost all ecological groups. Also bentho-pelagics, the medium demersals, benthos, and crustaceans had a very negative impact on themselves due to cannibalism. Furthermore, the highest realized trophic level was 4.34 for sharks. The maximum omnivory index is calculated as 0.99 for medium demersals for feeding on a wide variety of preys. Also, the average catch per net primary production, i.e., the gross efficiency of the system was around 0.000198 (lower than the global average) indicating that the fishery is harvesting fishes high in the food chain. The primary production/respiration (PP/R) ratio is found to be 3.57 and the values of ascendancy (45.40%) and overhead (54.60%) showed stability of the ecosystem. Thus northern Oman Sea can be classified as an immature ecosystem (in the developmental stage), although it has some kind of system maturity. Accordingly, the food web of northern Oman Sea is consisted mostly of detritivorous, planktivorous, and carnivorous fish species. Besides, Ecopath with Ecosim (EwE) software can be an excellent option to examine interactions among ecological groups, and the impact of fishing in northern Oman Sea which is unquestionably helpful to develop concrete management strategies. The proper ecosystem-based fisheries management practice can improve the efficiency of this overexploited ecosystem.

Keywords: Connectance index, Ecopath, Ecotrophic efficiency, Fishery management, Omnivory index, Mixed trophic impact

1-Department of Marine Biology, Faculty of Natural Resources and Environment, Science and Research Branch, Islamic Azad University, Tehran, Iran.
2-Iranian Fisheries Science Research Institute (IFSRI), Agricultural Research, Education and Extension Organization (AREEO), Tehran, Iran.
*Corresponding author's Email: t_valinassab@yahoo.com

Introduction

Oman Sea is one of the most productive bodies of water in the world, located in subtropical zone, it has a total area of 94,000 km^2 that connects Persian Gulf to north-west Arabian Sea, and then to the Indian Ocean (Valinassab *et al.*, 2006). The Oman Sea is an ecologically and economically important ecosystem and also water of this sea is inherently exclusive and contains unusual faunal assemblages (Carpenter *et al.,* 1997; Behzadi *et al*., 2018; Nasrollahzadeh Saravi *et al*., 2019).

Fish species in Oman Sea are one of the most significant groups for both artisanal and industrial fisheries (Masrikat, 2012). An examination of fisheries statistics showed an increasing trend in fishing efforts in Oman Sea in recent years from 47,700 tons in 2000 to 328,279 tons in 2018 (Iran Fisheries Organization Statistical Yearbook, 2000-2010; 2013-2018). Therefore, with increasing fishing pressure, maintaining stability of this resource-rich area has become a serious concern, and ecological groups of fish species are classified as over-exploited in the region.

Over the past few years, there has been a growing awareness that traditional approaches to fisheries management were ineffective and somewhat unsuccessful (Mohamed, 2010). Therefore, the notion of ecosystem-based fisheries management has garnered attention to maintaining healthy ecosystems and sustainable fisheries (Gislason and Sinclair, 2000). This is often done by considering the impact of ecosystem on the fisheries resources as well as the impact of fishing on the ecosystem. Nowadays, biodynamic trophic modeling approach Ecopath with Ecosim (EwE) is widely applied to evaluate ecosystem structure and the effects of fishing (Christensen and Walters, 2004). And Ecopath models represent a mass-balanced budget of production, consumption, and fishing in a food web (Harvey *et al.,* 2003).

Thus, we proposed Ecopath model to help manage fisheries of fish resources in northern Oman Sea. It may be a suitable systemic model for studying this unparalleled ecosystem along with its intrinsic trophic structure and dynamics. However, the development of fishery management strategies needs to assess response of target species as well as the entire ecosystem to exploitation (Arreguin-Sanchez *et al.,* 2004). Although in recent years, ecosystem-based approach to fisheries management has become very popular, these natural resources are harvested accidentally by humans from the beginning (Dutta *et al.,* 2017). However, no previous study is conducted on trophic analysis using the Ecopath modeling approach in northern Oman Sea. Earlier, such research is conducted in Persian Gulf (Taghavi Motlagh *et al.*, 2014, Vahabnehzad, 2015, Hakimelahi, 2018) as well as in Persian Gulf and western Oman Sea (Behzadi, 2016).

Consequently, the present study may be a leading, innovative, and groundbreaking research study on coastal resource management using Ecopath approach. This paper attempts

[DOR: 20.1001.1.15622916.2020.19.6.39.1]

to estimate energy flow, trophic structure, and food web dynamics of some fish species of northern Oman Sea towards ecosystem-based fisheries management and sustainable fisheries of this specific ecosystem.

Materials and methods

Study area

To conduct the present study, we selected the northern part of Oman Sea with 3998. 20 km^2 (Fig. 1). The study was conducted from 2017 to 2018 and fish samples were collected seasonally from landing sites of northern part of Oman Sea. In this regard, the number of fish samples used in this study was 1032 that were randomly selected from ten landing sites (Meydani, Galak, Kalat, Tang, Pozm, Konarak, Chabahar, Ramin, Beris, and Pasabandar) encompassing the entire coastline of northern Oman Sea (Fig. 1). So in this study, to maintain the ability to select fish from a range of different sizes, the preference and emphasis was on bottom trawlers, such as Research Vessel Ferdows 1 (R/V Ferdows 1).

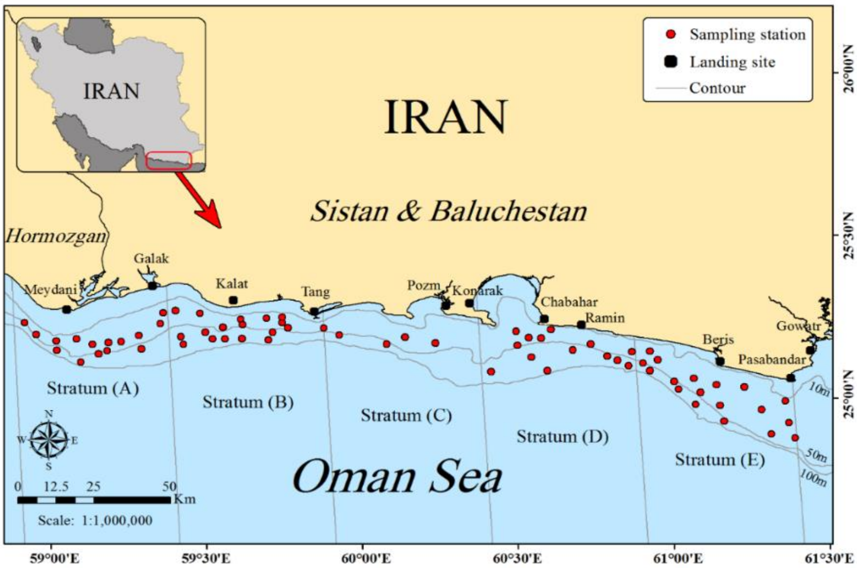

Figure 1: The study area for Ecopath model of some fish resources in northern Oman Sea.

An overview of the model

Accordingly, we have created a mass-balance food web model for management of fishery resources of northern Oman Sea, using Ecopath and Ecosim software version 6.6.16275.0. Ecopath model is widely used worldwide for ecosystem-based fisheries management. Ecopath is a dynamic trophic model capable of examining trophic interaction of all ecological groups and species in the ecosystem by combining energy flows between trophic levels as well as establishing interactions among components. There are two mass-balance limitations applied in the two master equations.

These are: Production = Catches + Predation Mortality+ Biomass Accumulation + Net Migration + Other Mortality, and Consumption =

Production + Respiration + Unassimilated Food.

Ecopath mass balance equation is the balance between productions with total losses and describes how much consumption by the predators, plus biomass caught (catch), plus biomass accumulation, plus net migration accounts for total biomass in the region:

$$B_i\ (P/B)_i\ EE_i = Y_i + \sum B_j\ (Q/B)_j + DC_{ij} + BA_i + NM_i$$

Where in B_i and B_j are biomass of group *i* and group *j*; *i* and *j* are prey and predator groups, Q is consumption, $(P/B)_i$ is production/biomass; EE_i is ecotrophic efficiency; $(Q/B)_j$ is food consumption per unit biomass of predator *j*; Y_i is yield; DC_{ij} is the fraction of *i* in diet of *j*; BA_i is the biomass accumulation and NM_i is the net migration of *i* group (Christensen and Pauly, 1998). Also biomass accumulation and net migration terms are not considered in the present study. The most common inputs for the model are *B*, *P/B*, *Q/B*, *Y*, and *DC*.

Model building

In the present study, the model consisted of 16 functional groups, i.e. 13 consumer groups, 2 producers (phytoplankton/ seaweeds) groups, and a detritus group of northern Oman Sea (Table 1). Accordingly, they are reflected based on data availability and different environmental factors, such as habitat, feeding habit, behavior, distribution pattern, and so forth, along with economically important fisheries of the present study area. The data on different aspects, such as diet composition and demographic parameters of them are obtained from the existing literature (Table 2), but preference and emphasis is placed on data from local and regional samples collected during the present study.

Basic parameterization

Biomass: Biomass of the groups is estimated in the habitat area (t/km^2) from the equation of biomass (*B*) = yield (*Y*)/fishing mortality (*F*); (Gulland, 1971). Biomass and CPUA data of all ecological groups except phytoplankton, zooplankton, and detritus were obtained from trawl surveys conducted on northern part of Oman Sea (Valinassab *et al.*, 2016, 2018). Phytoplankton, zooplankton, and detritus biomass are from Ebrahimi *et al.* (2014) (Table 1).

Production / Biomass

According to von Bertalanffy Growth Function (VBGF), in the fish population whose individuals grow, one can use estimates of total mortality (Z) as input values for the production over biomass ratio (P/B) in Ecopath models, (Z) can be expressed by (Beverton and Holt, 1957): $Z = P/B$

Available data from the literature (Table 1).

[DOR: 20.1001.1.15622916.2020.19.6.39.1]

Table 1: Basic input and output (in bold) parameters of mass-balance Ecopath model of northern Oman Sea.

Group name	Trophic level	Habitat area (fraction)	Biomass in habitat area (t/km^2)	CPUA kg/km^2	Production/ biomass (/year)	Consumption/ biomass (/year)	Ecotrophic efficiency	Production/ consumption
Sharks	4.34 [d]	1	0.08 [a]	0.0001 [a]	1.45 [e]	6.22 [e]	0.16 [d]	0.23
Rays	4.10 [d]	1	0.30 [a]	0.0030 [a]	0.75 [f]	5.96 [f]	0.44 [d]	0.13
Bentho-pelagics	4.08 [d]	1	2.60 [a]	0.6080 [a]	1.78 [q]	6.72 [z & m]	0.99 [d]	0.26
Mesopelagics	3.33 [d]	1	0.36 [a]	0.5016 [a]	1.75 [h]	12.72 [h]	0.96 [d]	0.14
Medium pelagics	3.64 [d]	1	2.67 [a]	0.1658 [a]	2.81 [g & f]	11.34 [g & f]	0.97 [d]	0.25
Small pelagics	3.18 [d]	1	1.66 [a]	0.0001 [a]	6.40 [k & f]	63.74 [k & f]	0.98 [d]	0.10
Medium demersals	2.86 [d]	1	2.99 [a]	0.2455 [a]	1.71 [n, r & v]	9.26 [n, r, v & z]	0.99 [d]	0.18
Small demersals	2.90 [d]	1	3.91 [a]	0.3214 [a]	4.56 [f, h & m]	24.70 [f, h, m & z]	0.99 [d]	0.18
Cephalopods	3.35 [d]	1	1.19 [a]	0.12540 [a]	8.17 [f & p]	26.58 [f & p]	0.99 [d]	0.31
Penaeid shrimps	3.19 [d]	1	0.68 [a]	0.0001 [a]	5.63 [m]	19.20 [m]	0.98 [d]	0.29
Crustaceans	2.83 [d]	1	2.20 [a]	0.0014 [a]	6.41 [f]	42.77 [f]	0.99 [d]	0.15
Benthos	2.64 [d]	1	2.27 [a]	0.0323 [a]	5.00 [b & f]	18.57 [b & f]	0.99 [d]	0.27
Zooplankton	2.33 [d]	1	34.40 [b & z]		52.00 [h]	178.00 [h]	0.99 [d]	0.29
Seaweeds	1.00 [d]	1	0.240 [c]	0.0001 [c]	11.90 [s]		0.96 [d]	
Phytoplankton	1.00 [d]	1	110.29 [b & z]		110.00 [h]		0.38 [d]	
Detritus	1.00 [d]	1	2.511 [b & z]				0.01 [d]	

[a] Valinassab *et al*. 2018 [e] Vivekanandan *et al*. 2003 [k] Salarpour *et al*. 2008a [q] Vahabnehzad 2015 [W] Kerdgari 2009

[b] Ebrahimi *et al*. 2014 [f] Mohamed *et al*. 2005 [m] (adayet Ullah *et al*. 2012 [r] Azhir *et al*. 2007 [z] Estimated in this study

[c] Valinassab *et al*. 2016 [g] Garces *et al*. 2003 [n] Norouzi 2010 [s] Nurhakim 2003

[d] Estimated in this study by Ecopath [h] Tesfamichael 2012 [p] Opitz 1996 [V] Karimi *et al*. 2015

Consumption / Biomass

Absolute consumption is computed by Ecopath and is expressed in terms of the unit "t/km^2/year", while the corresponding Q/B being a unitless ratio, Q/B is calculated from (Palomares and Pauly, 1998): $\log (Q/B) = 7.964 - 0.204 \log W_\infty - 1.965\ T' + 0.083A + 0.532h + 0.398d$, where W_∞ is asymptotic weight (g), T' is an expression for the mean annual temperature of the water body, expressed using $T' = 1000/\text{Kelvin}$ (Kelvin = C$^\circ$ + 273.15), 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, Table 1).

Diet composition

Diet matrix is constructed by designating the percent of each prey that occurred in each predator's diet (Table 3). So diet composition is used for estimation of trophic levels (Pauly *et al.,* 2000). In this study stomach content of five fish species in north Oman Sea, including *Trichiurus lepturus*, *Saurida tumbil*, *Pomadasys kaakan*, *Pomadasys stridens*, and *Nemipterus japonicus* is studied.

Table 2: Sources of diet for different groups.

Functional groups	Families/species	Sources	Locations
Sharks	Carcharhinidae	Raeisi *et al.* 2015	Persian Gulf
Rays	Dasyatidae	Rastgoo 2015	Oman Sea
Bentho-pelagics	*Trichiurus lepturus*	Estimated in this study	Oman Sea
Mesopelagics	*Benthosema pterotum*	Tesfamichael 2012	Red Sea
Medium pelagics	*Sphyraena jello*	Mohamed *et al*. 2005	Arabian Sea
	Atule mate	Garces *et al*. 2003	Sabah and Sarawak
	Sardinella sp.	Salarpour *et al*. 2008a	Persian Gulf
	Encrasicholina punctifer	Salarpour *et al*. 2008b	Persian Gulf
Medium demersals	*Saurida tumbil*	Estimated in this study	Oman Sea
	Pomadasys kaakan	Estimated in this study	Oman Sea
	Pomadasys stridens	Estimated in this study	Oman Sea
Small demersals	*Nemipterus japonicus*	Estimated in this study	Oman Sea
	Cynoglossus arel	Mohamed *et al*. 2005	Arabian Sea
	Photopectoralis bindus	Mohamed *et al*. 2005	Arabian Sea
	Cryptocentroides arabicus	Tesfamichael 2012	Red Sea
	Grammoplites suppositus	Mohamed *et al*. 2005	Arabian Sea
	Upeneus sulphureus	Ramteke *et al*. 2015	India waters
Cephalopods	*Sepia pharaonis*	Mohamed *et al*. 2005	Arabian Sea
	Uroteuthis duvaucelii	Mohamed *et al*. 2005	Arabian Sea
	Octopus sp.	Opitz 1996	Caribbean Sea
Crustaceans	Crabs	Mohamed *et al*. 2005	Arabian Sea
Penaeid shrimps	Penaeidae	Hadayet Ullah *et al*. 2012	The Bay of Bengal
Benthos	Echinodermata	Attaran-Fariman and Panahloo 2015	Oman Sea
	Worms	Guénette 2013	The Bay of Bengal
	Molluscs (others)	Tesfamichael 2012	Red Sea

Thus diets of praise of the five above mentioned species are collected from various kinds of literature and sources of the diets are presented in more detail in Table 2.

Ecotrophic efficiency

Ecotrophic efficiency (EE) indicates the proportion of an ecological group's production that is used in the system. There is no such visible method to directly estimate ecotrophic efficiency. The values of EE range between 0 and 1, they can be expected to approach 1 for groups with considerable predation pressure.

The equation for ecotrophic efficiency is: EE=1-OM/ (P/B).

Since OM is other mortality and P/B is equal to total mortality, in a few cases the EE value shows greater than one, which specifies that the total energy demand surpasses total production of the system.

Table 3: Diet composition matrix for northern Oman Sea.

	Prey \ predator	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Sharks									0.0006				
2	Rays									0.003				
3	Bentho-pelagics	0.01		0.02				0.12	0.020	0.03				
4	Medium pelagics			0.46	0.175			0.036	0.013	0.04				
5	Small pelagics	0.10		0.23	0.11			0.016		0.213			0.017	
6	Mesopelagics			0.04				0.003						
7	Medium demersals	0.03	0.03		0.01			0.043	0.022	0.063				
8	Small demersals	0.77	0.24	0.170	0.14			0.56	0.180	0.216	0.02	0.01	0.045	
9	Cephalopods	0.04		0.04				0.05	0.025	0.05	0.01			
10	Penaeid shrimps		0.12			0.05		0.01	0.148	0.10			0.022	
11	Crustaceans	0.05	0.40		0.03	0.24		0.106	0.123	0.14	0.65	0.322	0.042	
12	Benthos		0.14	0.04	0.09	0.005		0.046	0.146	0.056	0.10	0.550	0.477	
13	Zooplankton				0.35	0.275	1.00		0.05		0.01		0.067	0.10
14	Seaweeds				0.095			0.0066	0.003				0.017	
15	Phytoplankton					0.25			0.015		0.01		0.047	0.90
16	Detritus		0.07			0.18		0.003	0.255	0.083	0.20	0.118	0.266	
Import			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sum			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
(1 - Sum)			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Hence this parameter is used for balancing the model; changes in EE values are monitored iteratively as adjustments made to input parameters (Blanchard *et al.*, 2002). In the present study, EE was estimated by the software.

Model validation

In this paper, we only used Ecopath part of the model. Most Ecopath models are built using a set of input parameters consisting means for the given period in the region. Once Ecopath parameters are entered into the software and the underlying assumptions are tested with PREBAL approach, the model requires balancing to maintain laws of thermodynamics. During balancing thermodynamic and ecological rules must be followed. Darwall *et al.* (2010) describe ecological and thermodynamic rules in an easy to read box (Box 1). So once the model is balanced, the process of rechecking PREBAL estimations as well as checking for incompatible vital rates (*P/B*, *Q/B*, etc) was performed. However, ecotrophic efficiency is calculated by Ecopath software. And the value of EE helps for model validation. In general, ecotrophic efficiency values are high for the fish groups, while they are low for phytoplankton and detritus. Low EE for phytoplankton indicates that only a small proportion of phytoplankton production is grazed in the water column, while the rest is going toward detritus. Similarly, low EE for detritus indicates that a small fraction of detritus biomass is consumed, with the rest being buried in the sediment or exported out of the system (Dutta *et al.*, 2017).

Results

In the present study, the EE values for all groups varied between 0.01 and 0.99 (Table 1). Besides, in this study EE value was high in all fish groups except sharks and rays. Detritus (0.01) had the lowest EE values. Phytoplankton had an EE value of 0.38, indicating that only a small proportion of the production is used in the system. Based on the results of this study, all fish groups are exposed to exploitation except sharks and rays. Predators in columns and preys in lines. Predators are called by their group number. The total diet of each predator is equal to 1.

Energy flow

The energy flow is taken from trophic level (TL) estimation varying between 1.00 for phytoplankton, seaweeds, and detritus and 4.34 for top predators, which are sharks. Also, trophic levels of fish species have ranged between 2.86 (medium demersals) to 4.34 (sharks) (Fig. 2).

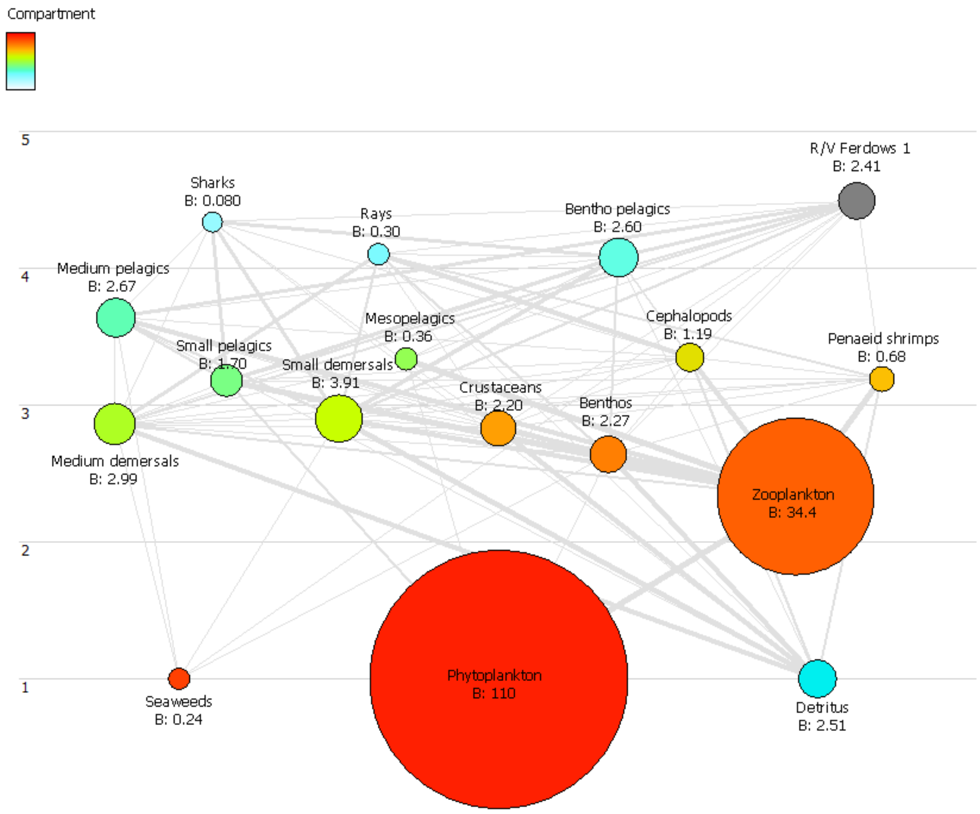

Figure 2: Flowchart of trophic interactions in northern Oman Sea indicating trophic flows in t/km^2, circle sizes represent biomass.

Omnivory index

The maximum OI was observed for medium demersals (OI=0.99), followed by small demersals (OI=0.67), cephalopods (OI=0.58), and benthos (OI=0.51) indicating feeding on a wide variety of preys. Also, highly specialized feeding (low OI) was observed for mesopelagics (OI=0.0002).

Mixed trophic impact

Figure 3 shows the groups′ direct and indirect impact on the system. According to the results of this study, fishery with trawl net had a negative impact on sharks, rays, bentho-pelagics, medium pelagics, medium demersals, and small demersals, though it had a positive impact on benthos, cephalopods, and crustaceans because most of them use benthos, cephalopods, and crustaceans as a food source. Bentho-pelagics, medium demersals, benthos, and crustaceans impacted themselves very negatively due to cannibalism, which is called zero-order cycle. Zooplankton use phytoplankton as a food source, so zooplankton had a negative impact on phytoplankton. Phytoplankton had a positive impact on zooplankton. Phytoplankton and detritus positively impacted almost all groups.

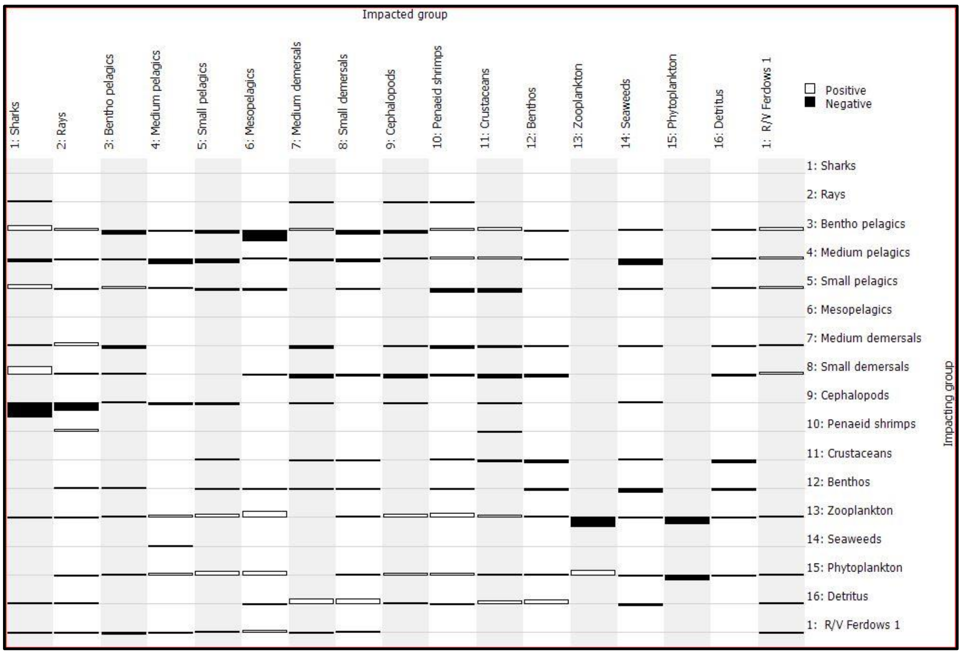

Figure 3: Mixed trophic impact of northern Oman Sea, which shows positive (above baseline) and negative (below baseline) impact of the groups and fishing. Although, the impacts are relative, they are comparable between groups.

Respiration and assimilation

Table 4 represents respiration and assimilation of functional groups of northern Oman Sea. Respiration (R) and assimilation (A) were very high for zooplankton. Among other groups, R and A were high for small pelagics, crustaceans, and small demersals. Both R and A were always low at higher trophic levels. In this study P/R ratio

[DOR: 20.1001.1.15622916.2020.19.6.39.1]

was highest for cephalopods (0.62) and lowest for small pelagics (0.14).

Respiration/ Biomass as the R/B ratio can be seen as an expression of activity of the group. Unmistakably, there is a two-way relationship between them, that is, the higher the level of activity in a given group, the higher the ratio. Zooplankton and small pelagics had the highest R/B ratios (Table 4).

Table 4: Respiration and assimilation of functional groups of northern Oman Sea.

Group name	Respiration (t/km^2/year)	Assimilation (t/km^2/year)	Respiration/ assimilation	Production/ respiration	Respiration / biomass (/year)
Sharks	0.28	0.40	0.71	0.41	3.53
Rays	1.21	1.43	0.84	0.19	4.02
Bentho-pelagics	9.35	14.00	0.67	0.49	3.60
Medium pelagics	16.70	24.20	0.69	0.45	6.26
Small pelagics	75.80	86.70	0.87	0.14	44.60
Mesopelagics	3.03	3.66	0.83	0.21	8.43
Medium demersals	17.00	22.10	0.77	0.30	5.70
Small demersals	59.40	77.30	0.77	0.30	15.20
Cephalopods	15.60	25.30	0.62	0.62	13.10
Penaeid shrimps	6.62	10.40	0.63	0.58	9.73
Crustaceans	61.20	75.30	0.81	0.23	27.80
Benthos	22.40	33.70	0.66	0.51	9.86
Zooplankton	3110.00	4898.00	0.63	0.58	90.40
Seaweeds					
Phytoplankton					
Detritus					

Transfer efficiency

Results of the present study showed the total transfer efficiency in northern Oman Sea was 10.60%, the energy transferred from the primary producers was 10.40% and from detritus was 15.00% (Table 5).

Table 5: Transfer efficiencies from different trophic levels.

Source/trophic level	II	III	IV	V	VI	VII	VIII	IX	X
Producers	5.39	14.40	14.40	14.60	14.30	14.40	14.40		
Detritus	16.60	13.90	14.70	14.40	14.30	14.50			
All flows	5.68	14.30	14.50	14.50	14.30	14.40	14.30	11.90	3.82

Proportion of total flow originating from detritus: 0.35
Transfer efficiencies (calculated as geometric mean for TL II–IV)
From primary producers: 10.40%
From detritus: 15.00%
Total: 10.60%

[DOR: 20.1001.1.15622916.2020.19.6.39.1]

Total System Statistics and Model Comparison

The total system statistics of northern Oman Sea ecosystem is an output of Ecopath with Ecosim suite, which is shown in Table 6.

Table 6: Total system statistics of Ecopath model of northern Oman Sea (some parameters are dimensionless)

Parameter	Value	Units
Sum of all consumption	6591.37	t km^{-2}year^{-1}
Sum of all exports	8736.78	t km^{-2}year^{-1}
Sum of all respiratory flows	3398.37	t km^{-2}year^{-1}
Sum of all flows into detritus	8855.18	t km^{-2}year^{-1}
Total system throughput	27581.70	t km^{-2}year^{-1}
Sum of all production	14009.47	t km^{-2}year^{-1}
Mean trophic level of the catch	3.49	
Gross efficiency (catch/net p.p.)	0.000198	
Calculated total net primary production	12134.75	t km^{-2}year^{-1}
Total primary production/total respiration	3.57	
Net system production	8736.38	t km^{-2}year^{-1}
Total primary production/total biomass	73.15	
Total biomass/total throughput	0.01	t km^{-2}year^{-1}
Total biomass (excluding detritus)	165.88	t km^{-2}
Total catch	2.41	t km-^{2}year-1
Finn's cycling index	5.70	% of total throughput
Finn's mean path length	2.27	
Ascendency	45.40	
Overhead	54.60	
Connectance index	0.44	
System omnivory index	0.42	
Ecopath pedigree index	0.78	

Discussion

Trophic level (TL) is a significant quantitative metric for ecosystem analysis, as it appears to present a descriptive variable for many parameters in both ecological and fishery contexts (Gascuel *et al.*, 2005). Accordingly, mean TL of fisheries landings is used as an index of sustainability in exploited marine ecosystems. So fisheries first tend to remove large slower-growing fishes and thus reduce mean TL of the remaining fish in an ecosystem (Pauly *et al.*, 2002). Nevertheless, under the sequential collapse/replacement mode a decline in mean trophic level should be accompanied by reduced catch of high-trophic level species, as these species become economically depleted (Essington *et al.*, 2006). In this regard, the mean trophic level of northern Oman Sea is estimated to be 3.49 (Table 6). Table 7 shows results of comparing Ecopath models between the studied ecosystem and other ecosystems. The mean trophic level of the present study was close to those of coastal ecosystems of southwest India (Vivekanandan, 2013) and Persian Gulf (Vahabnehzad, 2015), but was lower than that reported from Persian Gulf and Oman Sea (Behzadi, 2016). Low mean trophic level indicates relative absence of top predators in the system (Dutta *et al.*, 2017). Transfer efficiency (TE) is the fraction of total flows at each trophic level to another trophic level through consumption.

Table 7: Ecopath model comparisons with different ecosystems.

Different study area References	Total throughput (t km^{-2} year^{-1})	Gross efficiency (catch/net pp)	Omnivore index	Mean trophic level	Net primary production (t km^{-2} year^{-1})	Total transfer efficiency (%)
Bay of Bengal, Bangladesh (Hadayet Ullah *et al*. 2012)	2628.00	0.001500	0.224	2.450	1017.36	5.60
Southern Plateau, New Zealand (Bradford-Grieve *et al*. 2003)	1136.00	0.010000	-	4.480	2650.00	-
Southwestern Gulf of Mexico (Arreguin-Sanchez *et al*. 2004)	11293.00	0.001600	0.170	2.820	4668.70	12.50
Southwest Indian Coast (Vivekanandan *et al*. 2003)	14083.44	0.600000	0.100	3.610	2323.15	-
Northern Hangzhou Bay (Xu *et al*. 2011)	19323.00	0.026000	0.350	-	6785.80	9.60
Arabian Sea off Karnataka (Mohamed *et al*. 2005)	5421.00	0.001000	0.299	3.040	4095.00	13.40
Bay of Bengal, Sundarban’s Estuary (Dutta *et al*. 2017)	5220.57	0.001000	0.352	2.716	1745.51	9.70
Persian Gulf (Vahabnehzad 2015)	-	0.000013	0.270	3.600	12.505	-
Persian Gulf and Oman Sea (Behzadi 2016)	48724.28	-	0.240	4.090	4325.12	-
Present Study Northern Oman Sea	27581.70	0.000198	0.42	3.49	12134.75	10.60

The TE from one TL to another TL is a vital estimation to figure out the condition of a particular ecosystem and it influences the food web structure and the fish yield (Gaedke and Straile, 1994). Ecosystem components are grouped into discrete levels and transfer efficiencies are estimated (Lindeman, 1942). In coastal ecosystems, the range of TE varies between 10.00 and 20.00% (Odum, 1971). In this study the TE was 10.60. The TE is estimated as the geometric mean of trophic levels 2–4. Hence, it portrays that the detrital food pathway was dominant in this particular efficient ecosystem. The total flow proportion originating from detritus in this study was 0.35. Hadayet Ullah *et al.* (2012) estimated the total transfer efficiency of 5.90% in Sundarban’s ecosystem of Bangladesh. However, Ryther (1969) estimated the efficiency of coastal ecosystem to be 15.00%. Bradford-Grieve *et al.* (2003) projected total efficiency of Southern Plateau of New Zealand to be 23.00%. Furthermore, according to the present study the total system throughput was similar to the results of the study conducted by Xu *et al.* (2011).

However, the gross efficiency of the fishery is computed as the ratio between total catch (landings plus discards) and total primary production in the system. As a result, this ratio varies widely between different systems. So systems with a fishery harvesting fishes which are low in the food chain (e.g., an upwelling fishery) are more valuable than systems in which fisheries concentrate on apex predators (e.g., oceanic tuna fisheries). Accordingly, for northern Oman Sea model the value obtained was 0.000198 (lower than the global average) indicating a fishery harvesting fishes which are high in the food chain (the weighted global average is about 0.0002). The system omnivory index is the average omnivory index of all consumers weighted by the logarithm of each consumer's food intake (Christensen and Walters, 2004). So it is a measure for the variance of the trophic level estimate for each group. A higher value of omnivory index indicates that the consumer feeds on many trophic levels. It is dimensionless. In this study, the system omnivory index was 0.42 and the connectance index, which is the ratio of the number of actual links to the number of possible links for a given food web, was 0.44. The input parameters used for the fitting model were ecological group-wise estimates of production biomass (P/B) ratio, consumption biomass (Q/B) ratio, biomass, diet composition, and fleet-wise and group-wise fishery catches. The quality of inputted data was assessed with Ecopath pedigree index and the value obtained was 0.78 (scale 0-1) which reflects high quality of the model (Table 6).

Also net primary production of the present system was higher than that of other ecosystems (Table 7). Low net primary production value is due to high levels of productivity, large catch at lower trophic levels, and overfishing (Pauly and Christensen, 1995). On the other hand, consumers of the present system and Bay of Bengal ecosystem off Karnataka coast and northern Hangzhou Bay showed a wider feeding variety than other ecosystems, as their omnivory index was high. The result of mixed trophic impact in this study showed that the trawl net had a negative impact on sharks, rays, bentho-pelagics, medium pelagics, medium demersals, and small demersals. Assimilation was lowest in top predators such as sharks and rays, and very high in zooplankton (4898.00 t/km^2/year). Therefore, the ratio of respiration to assimilation can never exceed 1 because respiration cannot exceed assimilation. For top predators, whose production is relatively low, the respiration/assimilation ratio can be expected to be close to 1, while it tends to be lower but still positive for organisms at lower trophic levels.

As Odum (1969) stated, based on the 24 attributes of ecosystem maturity, all ecosystems tend to move toward maturity without any human intervention. According to Christensen and Pauly (1992) the system of linear equations in Ecopath identifies several attributes of Odum.

Odum (1969) argued that mature ecosystems have web-like connections and are less susceptible to perturbations also as mature ecosystems they should become more dependent on detrital flows and less on flows from primary producers. Hence, system's primary production/respiration ratio (PP/R) could describe the maturity of an ecosystem (Odum, 1969).

However, during early stages of ecosystem development, the PP/R ratio is higher than one, but with maturity when fixed energy is balanced by maintenance, it decreases and approaches 1. And in systems that suffer from exploitation or pollution, the ratio is expected to be less than 1 (Hadayet Ullah *et al.*, 2012). However, as Buchary (1999) asserted, in developing systems the relation between total system productivity and total system biomass (P/B) is high, whereas in mature systems it is low. According to Odum's classification, northern Oman Sea ecosystem is in a developing stage, since the PP/R ratio of 3.57 was greater than 1, which represents an immature ecosystem (Table 6). The ascendancy was the measurement scale for the system’s growth and development of network links, whereas fraction of a system’s capacity is not considered as ascendancy, rather considered as the system's overhead which was the energy reserve of an ecosystem (Ulanowicz and Norden, 1990). Based on the results of the present study and previous works conducted using Ecopath, the results of relative values of species, including ascendancy (45.40) and large overhead (54.60) indicated stability in northern Oman Sea ecosystem and some sorts of maturity. Therefore, it demonstrated that northern Oman Sea ecosystem had significant strength in reserve and can either be resistant or resilient to perturbations and could return to its original level quickly (Table 6). In this regard, northern Oman Sea ecosystem is developed based on the combination of characteristics of a mature system (high total system throughput, ascendency, and overhead) as well as an immature ecosystem (high PP/B and PP/R, low Finn's cycling index, and mean path length). As a result, it can be classified as an immature ecosystem (in the developmental stage), although it has some kind of system maturity (Table 6).

The results of reports published by Daryanabard *et al.* (2002) and Vallinassab *et al.* (2018) show that total landings are decreased along the coastline in northern Oman Sea due to fishing pressure. This is especially happening for bottom trawling process. Therefore, most of the fish are classified as over-exploited in the region. Overexploitation of carnivorous fish populations may lead to top-down effects in the trophic levels of grazing and detritus food chains of Oman Sea. While overfishing and the frequent collapse of traditional fish stocks are due to increased trend in fish catch,

[DOR: 20.1001.1.15622916.2020.19.6.39.1]

together with the impact of fishing on ecosystems and fishery management (Pauly *et al.,* 2005). Also, Bottom-Up increases the effect in phytoplankton, detritus, and zooplankton at the base of the food web and the effect of fishery's Top-bottom food cascading that was low. And as were observed, these effects may be related to removing some predators or competitors.

As a result, Ecopath model gives a clear snapshot of this particular ecosystem, as the system is more productive and efficient than many other coastal marine ecosystems (Table 7). Besides, the food web of northern Oman Sea mainly includes detritivorous, planktivorous, and carnivorous. But, Ecotrophy efficiency of numerous fish was very high and close to 1, it could be because of overfishing associated with harvesting these species; also low ecotrophy efficiency in detritus (0.01) indicates that a large amount of energy input to the food web buried within the sediments is not transferred to higher levels. However, the amounts of ecotrophy efficiency of 0.38 and 0.99 for phytoplankton and zooplankton communities affected by higher levels are predation phenomenon. Therefore, according to this study, overfishing was the most significant threatening factor for future health of all groups of fish in northern Oman Sea. Consequently, based on the results of the present study, it is recommended to manage the fish catch. And environmental management of the reef ecosystem should also be considered. Besides, it is suggested to estimate biomass, feeding ecology, and population dynamics of all components of the food web for ecosystem-based fisheries management and sustainable fisheries. To achieve this aim, the Ecopath with Ecosim (EwE) software is an excellent option to examine interactions among ecological groups, and impact of fishing in northern Oman Sea which is unquestionably helpful to develop concrete management strategies. Proper ecosystem-based fisheries management practices can improve efficiency of this particular and overexploited ecosystem.

Acknowledgements

The authors gratefully acknowledge Dr. Siamak Behzadi and Dr. Ronaldo Angelini for their encouragement and unconditional help. The authors also are grateful to the fishermen from northern Oman Sea and the crew of R/V Ferdows 1 for their help in data and sample collection.

References

Arreguin-Sanchez F., Zetina-Rejón M., Manickchand-Heileman S., Ramírez-Rodríguez M. and Vidal L., 2004. Simulated response to harvesting strategies in an exploited ecosystem in the southwestern Gulf of Mexico. *Ecological Modelling*, 172(**2-4**), 421-432.

Attaran-Fariman, G. and Panahloo, N., 2015. Diet of three Sea star (Echinodermata: Asteroidea) from Chabahar coastal area. *Journal of Marine Biology, Islamic Azad University, Ahvaz Branch*, 7(**3**), 33-44 in Persian.

Azhir, M.A., Hosseiny, S.A. and Daryanabard, G.H., 2007. An investigation of some biological aspects of three species: Tiger toothed Croaker, *Otolithes ruber*, Javelin grunter, *Pomadasys kaakan* and Black pomfret, *Parastromateus niger* in the Oman Sea for optimizing fishing season. Final report, Iranian Fisheries Science Research Institute, PROJECT 85.463, I.R.I. 122P., in Persian.

Behzadi, S., 2016. Using of trophodynamic indicators of demersal and benthic commercial fishes to determination of the Persian Gulf and Oman Sea fisheries ecosystem health (Hormuzgun Province). PhD thesis. Department of Marine and Atmospheric Sciences, Hormuzgan University, Hormuzgan, Iran, 334P., in Persian.

Behzadi, S., Kamrani, E., Kaymaram, F., Ranjbar, M., 2018. Trophic level, food preference and feeding ecology of *Rachycentron canadum* (Linnaeus, 1766), in Hormuzgan Province waters (northern Persian Gulf and Oman Sea). *Iranian Journal of Fisheries Sciences*. 17 (1),179-193. DOI: 10.22092/IJFS.2018.115608

Beverton, R.J.H. and Holt, S.J., 1957. On the dynamics of exploited fish populations. Chapman and Hall, UK, 533P.

Blanchard, J.L., Pinnegar, J.K. and Mackinson, S., 2002. Exploring marine mammal-fishery interactions using 'Ecopath with Ecosim': Modelling the Barents Sea ecosystem. Sci. Ser. Tech Rep., CEFAS Lowestoft, 117, 52P.

Bradford-Grieve, J.M., Probert, P.K., Nodder, S.D., Thompson, D., Hall, J., Hanchet, S., Boyd, P., Zeldis, J., Baker, A.N., Best, H.A., Broekhuizen, N., Childerhouse, S., Clark, M., Hadfield, M., Safi, K. and Wilkinson, S., 2003. Pilot trophic model for subantarctic water over the Southern Plateau, New Zealand: a low biomass, high transfer efficiency system. *Journal of Experimental Marine Biology and Ecology*, 289(**2**), 223–262.

Buchary, E.A., 1999. Evaluating the effect of the 1980 trawl ban in the Java Sea, Indonesia: An Ecosystem-based Approach. M.Sc, University of British Columbia, Resource Management and Environmental Studies, Vancouver, Canada. 143P.

Carpenter, K.E., Krupp, F., Jones, D.A. and Zajonz, U., 1997. FAO species identification guide for fishery purposes. The living marine resources of Kuwait, Eastern Saudi Arabia, Bahrain, Qatar, and the United Arab Emirates. Food and Agriculture Organization of the United Nations (FAO), Rome, 293P.

Christensen, V. and Pauly, D., 1992. The ECOPATH II- a software for balancing steady state ecosystem models and calculating network characteristics. *Ecological Modeling*, 61(**3-4**), 169-185.

Christensen, V. and Pauly, D., 1998. Changes in models of aquatic ecosystems approaching carrying capacity. *Ecological Applications*, 8(**1**) Supplements: S104-S109.

Christensen, V. and Walters, C.J., 2004. Ecopath with Ecosim: methods, capabilities and limitations. *Ecological Modelling*, 172(**2-4**), 109–139.

Darwall, W.R.T., Allison, E.H., Turner, G.F. and Irvine, K., 2010. Lake of flies, or lake of fish? A trophic model of Lake Malawi. *Ecological Modelling*, 221(**4**), 713-727.

Daryanabard, R., Hosseini, A. and Valinassab, T., 2002. Monitoring of demersal resources by swept area method in the Oman Sea (Sistan and Baluchestan Province). Final Report, Iranian Fisheries Research Organization, Tehran, Iran, 146P., in Persian.

Dutta, S., Chakraborty, K. and Hazra, S., 2017. Ecosystem structure and trophic dynamics of an exploited ecosystem of Bay of Bengal, Sundarban Estuary, India. *Fisheries Science*, 83(**2**), 145-159.

Ebrahimi, M., Owfi, F., Dehghan, S. and Sanjani, S., 2014. Hydrology and hydrobiological study of the Iranian waters in the Oman Sea. Final report, Iranian Fisheries Research Institute, Persian Gulf and Oman Sea Ecology Research Center, PROJECT 1/100/200000/04/8502, I.R.I. 146P., in Persian.

Essington, T.E., Beaudreau, A.H. and Wiedenmann, J., 2006. Fishing through marine food webs. Proceedings of the National Academy of Sciences, 103(**9**), 3171-3175.

Gaedke, U. and Straile, D., 1994. Seasonal changes of trophic transfer efficiencies in a plankton food web derived from biomass size distribution and network analysis. *Applications of Ecological Models,* 75–76, 435–445.

Garces, L.R., Alias, M., Abu Talib, A., Mohamad-Norizam, M. and Silvestre, G.T., 2003. A trophic model of the coastal fisheries ecosystem off the west coast of Sabha and Sarawak, Malaysia, 333-352. In: Silverstre G.T., Garces L.R., Stobutzki I., Ahmed M., Valmonte-Santos R.A., Luna C. Lachica-Aliňo L., Nunro P., Christensen V. and Pauly D. (eds), Assessment, Management and Future Directions for Coastal Fisheries in Asian Countries. WorldFish Centre Conference Proceedings. 67, 120.

Gascuel, D., Bozec, Y.M., Chassot, E., Colomb, A. and Laurans, M., 2005. The trophic spectrum: theory and application as an ecosystem indicator. *ICES Journal of Marine Science*, 62(**3**), 443–452.

Gislason, H. and Sinclair, M.M., 2000. Ecosystem Effects of Fishing. *ICES Journal of Marine Science*, 57, 466–467.

Guénette, S., 2013. An exploratory ecosystem model of the Bay of Bengal large marine ecosystem. Phuket, Thailand, Bay of Bengal Large Marine Ecosystem Project (BOBLME), 69P.

Gulland, J.A., 1971. The Fish Resources of the Ocean. Food and Agriculture Organization of the United Nations, Fishing News Books, Surrey, England.

Hadayet Ullah, M.D., Rashed-Un-Nabi, M.D. and Al-Mamun, M.D.A., 2012. Trophic model of the coastal ecosystem of the Bay of Bengal using mass balance Ecopath model. *Ecological Modelling,* 225, 82–94.

Hakimelahi, M., 2018. Modelling trophic structure and energy flows in the coastal ecosystem of the Persian Gulf (Qeshm Island) using Ecopath with Ecosim. PhD thesis.

[DOR: 20.1001.1.15622916.2020.19.6.39.1]

Khorramshahr University of Marine Science and Technology, Khuzestan, Iran, 161P., in Persian.

Harvey, C.J., Cox, S.P., Essington, T.E., Hansson, S. and Kitchell, J.F., 2003. An ecosystem model of food web and fisheries interactions in the Baltic Sea. *ICES Journal of Marine Science*, 60(**5**), 939–950.

Iran Fisheries Organization Statistical Yearbook, 2000-2010. Iran Fisheries Organization. Planning and Programming Department, Tehran, Iran, 42P., in Persian.

Iran Fisheries Organization Statistical Yearbook, 2013-2018. Iran Fisheries Organization. Planning and Programming Department, Tehran, Iran, 33P., in Persian.

Karimi, S., Katiraei, E., Soofiani, N. and Paykanheirati, F., 2015. Investigating the length-weight relationship and growth parameters of Stripped Piggy *Pomadasys stridens* (Forsskâl, 1775) in northern part of Persian Gulf (Bushehr). *Journal of Applied Ichthyological Research*, 3(**2**), 97-106.

Kerdgari, M., 2009. Biological characteristics and determination of population dynamics parameters of *Nemipterus japonicus* in the coastal waters of Bushehr Province - Persian Gulf. PhD thesis, Department of Marine Ecology, Science and Research Branch, Islamic Azad University, Tehran, Iran, 122P., in Persian.

Lindeman, R.L., 1942. The trophic-dynamic aspects of ecology. *Ecology*, 23(**4**), 399– 417.

Masrikat, J.A.N., 2012. Standing stock of demersal fish assessment in southern part of South China Sea. *Journal of Coastal Development,* 15(**3**), 276-281.

Mohamed, K.S., 2010. Trophic modelling of marine ecosystems and ecosystem-based fisheries management. *Fishing Chimes*, 30(**9**), 35-39.

Mohamed, K.S., Zacharia, P.U., Muthiah, C., Abdurahiman, K.P. and Nayak, T.H., 2005. Atrophic model of the Arabian Sea ecosystem off Kamataka and simulation of fishery yields for its multigear marine fisheries. *Indian Journal of Marine Sciences*, 38, 69-76.

Nasrollahzadeh Saravi, H., Pourang, N., Foog, S., Makhlough, A., 2019. Eutrophication and trophic status using different indices: A study in the Iranian coastal waters of the Caspian Sea. *Iranian Journal of Fisheries Sciences***.** 18 (3), 531-546. DOI: 10.22092/ijfs.2018.117717

Norouzi, H., 2010. Evaluation of some biological indices and population dynamic of "*Saurida tumbil*" in the northern Persian Gulf and Oman Sea. PhD thesis, Department of Marine Ecology, Science and Research Branch, Islamic Azad University, Tehran, Iran, 90P., in Persian.

Nurhakim, S., 2003. Marine fisheries resources of the north coast of central Java: An ecosystem analysis, 299-312. In: Silverstre G.T., Garces L.R., Stobutzki I., Ahmed M., Valmonte-Santos R.A., Luna C. Lachica-Aliňo L., Nunro P., Christensen V. and Pauly D. (eds), Assessment, Management and Future Directions for Coastal Fisheries in Asian Countries.

WorldFish Centre Conference Proceedings 67, 120P.

Odum, E.P., 1969. The strategy of ecosystem development. *Science*, 164(**3877**), 262-270.

Odum, E.P., 1971. Fundamentals of ecology, 3rd Edition. W.B. Saunders, Philadelphia, USA, 574P.

Opitz, S., 1996. Trophic interactions in Caribbean coral reefs. ICLARM Tech. Rep. 43, 341P., Manila, Philippines.

Palomares, M.L.D. and Pauly, D., 1998. Predicting food consumption of fish populations as functions of mortality, food type, morphometrics, temperature and salinity. *Marine and Freshwater Research*, 49(**5**), 447-453.

Pauly, D. and Christensen, V., 1995. Primary production required to sustain global fisheries. *Nature*, 374: 255–257.

Pauly D., Christensen V. and Walters C., 2000. Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES Journal of Marine Science*, 57(**3**), 697-706.

Pauly D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R. and Zeller, D., 2002. Towards sustainability in world fisheries. *Nature*, 418, 689–695.

Pauly, D., Watson, R. and Alder, J., 2005. Global trends in world fisheries: impacts on marine ecosystems and food security. *Philosophical Transactions of the Royal Society B*, 360(**1453**), 5–12.

Raeisi, H., Kamrani, E., Patimar, R. and Sourinejad, I., 2015. Determination of white cheek shark *Carcharhinus dussumieri* (Müller and Henle, 1839) feeding habitat in Hormozgan waters, Persian Gulf. *Journal of Applied Ichthyological Research*, 3(**3**), 19-34, in Persian.

Ramteke, K.K., Landge, A.T., Chakraborty, S.K., Borah, S., Surya, S., Lianthuamluaia, A. and Joshi, H.D., 2015. Food and feeding habits of *Upeneus sulphureus* (Cuvier, 1829) from Mumbai waters of India. *Ecology, Environment and Conservation*, 21(**3**), 1235-1239.

Rastgoo, A.R., 2015. Feeding habits and trophic level estimation of dominant batoid fishes in the Oman Sea. PhD thesis, Department of Marine Ecology, Science and Research Branch, Islamic Azad University, Tehran, Iran, 145P., In Persian.

Ryther, J.H., 1969. Photosynthesis and fish production in the sea. *Science*, 166(**3901**), 72–76.

Salarpour, A., Darvishi, M. and Behzadi, S., 2008a. Reproduction and feeding biology of Sind Sardinella (*Sardinella sindensis*) from coastal waters of Qeshm Island, Persian Gulf. *Iranian Scientific Fisheries Journal*, 17(**2**), 59-70, in Persian.

Salarpour, A., Darvishi, M., Behzadi, S. and Seraji, F., 2008b. Reproduction and feeding of buccaneer anchovy (*Encrasicholina punctifer*) from coastal waters of Qeshm Island, the Persian Gulf. *Iranian Scientific Fisheries Journal*, 17, 45-54, in Persian.

Taghavi Motlagh, S.A., Hakim Elahi, M. and Ghodrati Shojaei, M., 2014. Ecological relationships of some aquatic species in the Persian Gulf coastal ecosystem (Hormozgan Province): An Ecopath preliminary

[DOR: 20.1001.1.15622916.2020.19.6.39.1]

approach. *Journal of Oceanography*, 4(**16**), 1-13, in Persian.

Tesfamichael, D., 2012. Assessment of the Red Sea ecosystem with emphasis on fisheries. PhD thesis, Department of Resource Management and Environmental Studies, University of British Columbia, Vancouver, Canada, 241P.

Ulanowicz, R.E. and Norden, J.S., 1990. Symmetrical overhead in flow and networks. *International Journal* of *Systems Science*, 21(**2**), 429–437.

Vahabnehzad, A., 2015. Ecological interaction between some demersal fishes in the Persian Gulf. PhD thesis. Department of Marine Ecology, Science and Research Branch, Islamic Azad University, Tehran, Iran, 171P., in Persian.

Valinassab, T., Daryanabard, R., Dehghani, R. and Pierce, G.J., 2006. Abundance of demersal fish resources in the Persian Gulf and Oman Sea. *Journal of the Marine Biological Association of the United Kingdom*, 86(**6**), 1455-1462.

Valinassab, T., Daryanabard, G., Kaymaram, F., Talebzadeh, S., Vahabnejad, A., Khorshidian, K., Shabani, M.J., Moradi, G., Esmaeili, A., Kaviani, A., Kamali, E., Darvishi, M., Behzadi, S., Salarpouri, A., Haji Rezaei, A., Mousavi, S.A., Kadkhodaei, A., Mehdinejad, A., Azhir, M., Rezvani, A. and Niamaymandi, N., 2016. Biomass estimation of demersal resources in the Persian Gulf and Oman Sea by Swept area method. Final report, Iranian Fisheries Science Research Institute, PROJECT 50819, I.R.I. 264P., in Persian.

Valinassab, T., Daryanabard, G., Salarpori, A., Dehghani, R., Behzadi, S., Shabani, M., 2018. Biomass estimation of demersal resources in the Persian Gulf and Oman Sea by Swept area method. Final report, Iranian Fisheries Science Research Institute, PROJECT 0/12/12/024/940054, I.R.I. 191P., in Persian.

Vivekanandan, E., 2013. The trawl fisheries of the western Bay of Bengal. Presented at the APFIC Regional Expert Workshop of Food and Agriculture Organization of the United Nations on tropical trawl fishery management, 30th September- 4th October, Phuket, Thailand, www.fao.org, Rome, Italy.

Vivekanandan, E., Srinath, M., Pillai, V.N., Immanuel, S. and Kurup, K.N., 2003. Trophic model of the coastal fisheries ecosystem of the southwest coast of India. In: Assessment, management and future directions for coastal fisheries in Asian Countries. WorldFish Center conference proceedings, 67, 281-298.

Xu, S., Chen, Z., Li, S. and He, P., 2011. Modeling trophic structure and energy flows in a coastal artificial ecosystem using mass-balance Ecopath model. *Estuaries and Coasts*, 34(**2**), 351-363.