Spatial and temporal distribution pattern and biomass trend of flathead slipper lobster, *Thenus orientalis* (Lund, 1793) from Gulf of Oman

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Abstract
The aim of the present study was to investigate the amount of biomass and Catch Per Unit Area (CPUA) as well as to determine the distribution pattern of flathead slipper lobster, *Thenus orientalis* as one of the most important and commercial aquatic species in the north coast of the Gulf of Oman. There was an annual monitoring survey during 2009-2019 by using R/V 'Ferdows-1'covering the depths10-100 m which equipped with bottom trawl net. The highest CPUA was recorded in eastern and western region of the study area (45.54 kg/nm^2 and 25.40 kg/nm^2), although density of species was lower in the central area (Stratum B, C, D). The highest biomass (22.7 tons) and CPUA (52.13 kg/nm^2) was found in 10-20 m and 20–30 m depth layer, respectively. The comparison of mean CPUA and biomass in different depth-layers and stratum revealed that the mean CPUA and biomass have a descending trend with increasing of depth. Results of this study showed that the abundance of this species dramatically decreased over past decade to about 13.3 kg/nm^2 in 2019. Therefore, it is necessary to implement a regulatory mechanism to manage the stocks of this commercially valuable species, such as closed fishing season during the breeding and reproduction period, only permitted to use traps for harvesting of lobster, prohibited to take egg-bearing females or juvenile lobsters.

Keywords: Slipper lobster, Catch per unit area, Biomass, Distribution, *Thenus orientalis*

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Introduction

The Gulf of Oman is the northwestern part of the Arabian Sea and connects with the Persian Gulf through the Strait of Hormuz (Pous *et al*., 2004). It is around 560 km long and at its widest point is 320 km wide (Hafezieh *et al*., 2014). This sea has a lot of economic valuable aquatic resources and one of the important fishing areas that unfortunately its stock has been overfishing in the last two decades. Spiny lobsters are among the most valuable and highly-priced crustaceans in the Gulf of Oman and an important export product. Due to destructive fishing methods and overfishing, spiny lobster catches in Gulf of Oman have declined during the last decade (Marzouqi *et al*., 2008; Mehanna *et al*., 2012; Ajdari and Mirzaei, 2022). The flathead slipper lobster, *Thenus orientalis* ranks next to spiny lobsters in export value. In recent years, the amount of fishing has not been enough to cover the high demand. Therefore, this species placed among the most exploited resources.

T. orientalis widespread in the indo-western Pacific region and found from the east coast of Africa to the Gulf of Oman and the Persian Gulf (Mahapatro *et al*., 2018). This species is caught throughout its geographical distribution area and is often caught as bycatch in trawlers (Spanier and Lavalli, 2007).

In order to management of valuable aquatic resources, it is recommended that frequency monitor abundance, catch statistics, fishery indices and catch per unit of area (CPUA), then sustainable exploitation or conservation of threatened and endangered species is recommended for better management. A number of studies have begun to examine spatial distributions of flathead slipper lobsters. Jones (1993) investigated mean catch per hour and mean catch per hectare of *Thenus indicus* and *T. orientalis* using standard trawl fishery gear. He reported mean catch per hectare of *T. orientalis* was 2.01. Kagwade *et al*. (1991) reported a catch rate of 1.7 kg per unit effort (trawler) of *T. orientalis* in certain areas of India.

Valinassab *et al*. (2006) estimated biomass values for commercial and noncommercial groups in bottom trawl catches in the Persian Gulf and Oman Sea. They calculated percentage contribution of *T. orientalis* to total estimated biomass and reported it was 0.02 and 0.01 percent for Persian Gulf and Oman Sea, respectively. Although some investigations have documented the CPUA or biomass of many different demersal resource in the Gulf of Oman (Valinassab *et al*., 2006; Shojaei and Taghavimotlagh 2011; Ghotbeddin *et al*., 2015; Eisapoor *et al*., 2020), not enough research have been conducted on the catch composition and CPUA of *T. orientalis* species in the Oman Sea.

The main objectives of this research are: to prepare the distribution pattern and determine the main fishing area of flathead lobster and to estimate the amount of catch per unit area (CPUA) and biomass of *T. orientalis* in different strata and depth layers of the Oman Sea and check it trend of the index during 2009 to 2019.

Material and methods

The study area was restricted to the Iranian waters of the northern Gulf of Oman (Sistan and Balochistan provinces waters), between the latitudes of 24˚ 50′ to 25˚ 15′ N, and longitudes 58˚ 55′E to 61˚ 25′ E. The total area was stratified into 5 strata A, B, C, D and E and each stratum was classified into four depth layers of 10-20, 20-30, 30-50 and 50- 100m (Table 1 and Fig.1). The total area and area of each stratum or depth layer was calculated with a plannimeter (Tables 2 and 3).

Table 1: Coordinates of sampling area.

Stratum	Sampling area	Longitude	Area (nm^2)
A	Biahi, Meidani, Rabech, Galak	55°58E- 59°25E	115.99
B	Darak, Makisar, Tang	59°25E- 59°55E	180.93
C	Gordim, Rashedi, Pozm	59°55E- 60°25E	235
D	Konarak, Chabahar, Ramin, Lipar	60°25E- 60°55E	268.5
E	Beris, Pasabandar, Gowatr	60°55E- 61°25E	363.8

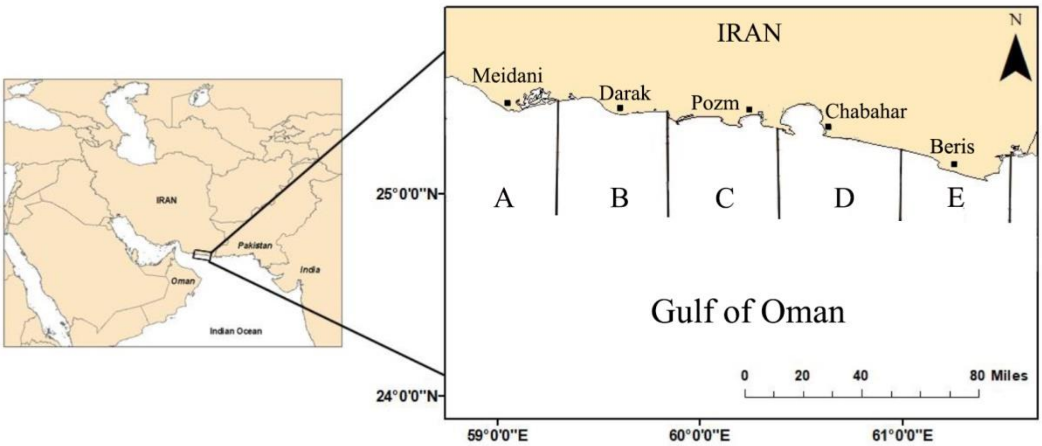

Figure 1: Map of sampling area along the Gulf of Oman.

Table 2: Area of each stratum in north coast of Gulf of Oman.

Stratum	A	B	C	D	E	Total
Area (nm^2)	116	180.9	235	268.5	363.8	1164.2

Table 3: Area of each depth layer in north coast of Gulf of Oman.

Stratum	10-20	20-30	30-50	50-100	Total
Area (nm^2)	358.3.	178.2	174.08	453.6	1164.2

The study was conducted during the years 2009 to 2019 using research vessel (Ferdows-1) equipped with a bottom trawl net. Each trawl duration was 1 hour, and mean towing speed was about 3 knots. Furthermore, the date, time, towing speed and distance, depth, and geographic location were recorded at each sampling station.

The amounts of biomass and CPUA index were estimated based on Sparre (1998) using following formula:

CPUE = Cw/a

Where: Cw=catch amount of *Thenus orientalis*; a: swept area (nm)

The swept area (a) was estimated as:

a = D.h.X

Where, D: towing distance (nm) registered by Simrad Plotter; h: headline (m), X: wingspread coefficient = 0.65 (derived from Mirzaei et al., 2021)

The total biomass (B) is estimated as:

B = CPUA * A / 0.5

Where, A: total area (nm^2); 0.5: catch coefficient

Statistical analysis was performed using SPSS software (version 20). One-way ANOVA and Tukey's post hoc tests were used to determine the presence of statistically significant differences between calculated values for different strata or depth layers. Arc-GIS software (Version 10.2) was used to create distribution pattern map of *T. orientalis* using the Inverse Distance Weighting (IDW) method.

Results

In the current study, by covering the deep layers of 10 to 100 meters of the Gulf of Oman and catching data at different sampling stations during 11 years of study period, the estimated results were made based on the amount of catch per unit area and biomass.

A comparison among different strata, revealed that the highest mean CPUA and biomass of *T. orientalis* were in stratum E (Beris, Pasabandar, Gowatr) with 45.54 kg/nm^2 and 33.14 tones, respectively. In contrast, the lowest mean CPUA of *T. orientalis* was found in stratum B (Darak, Makisar, Tang) with 14.85 kg/nm^2 and follows with 18.01 kg/nm^2 in stratum C (Konarak, Chabahar, Ramin, Lipar) (Figs. 2, 3) and the Lowest biomass were in stratum B with value of 5.37 tons and almost the same value was estimated for strata A (5.89 tones). In general, the amount of catch per unit area in the western and eastern regions of study area had the highest rate.

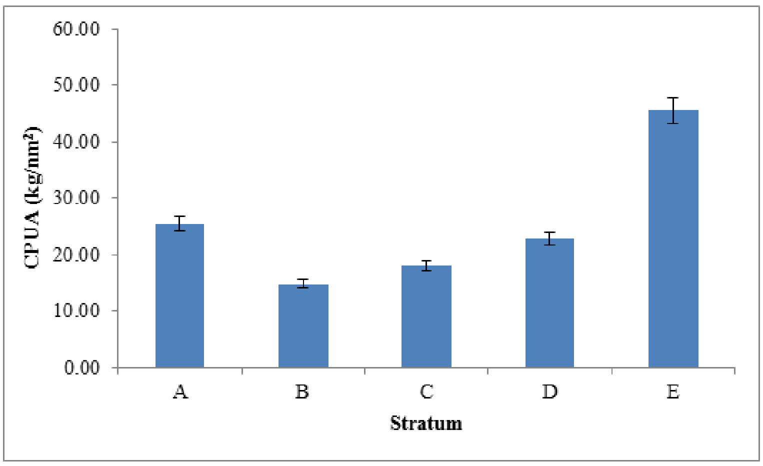

Figure 2: Mean CPUA (kg/nm^2) of *T. orientalis* in separate stratum from 2009 to 2019 in Gulf of Oman (Sistan and Baluchestan Province).

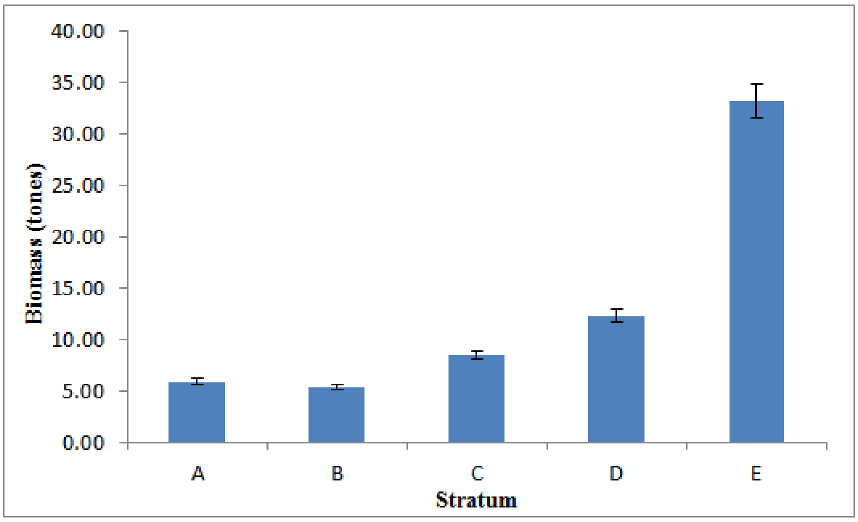

Figure 3: Mean Biomass (tones) of *T. orientalis* in separate stratum from 2009 to 2019 in Gulf of Oman (Sistan and Baluchestan Province).

The highest and lowest mean CPUA values were 52.13 kg/ nm^2 and 15.81 kg/ nm^2 in 20-30 and 50-100 m depth layers, respectively (Figs. 4 and 5). The mean biomass was relatively high (22.77 tones and 18.59 tones) in both 20-30 and 10-20 m depth zones and was markedly lower (9.42 tones) in 30-50 m depth layer.

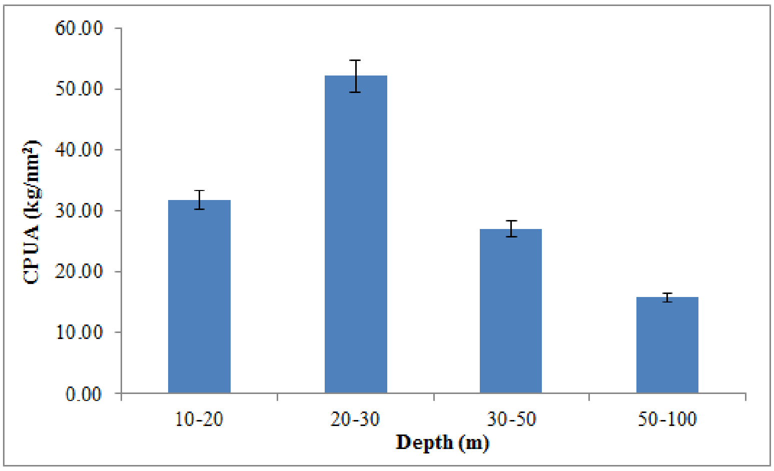

Figure 4: Mean CPUA (kg/nm^2) of *T. orientalis* in different depth layers from 2009 to 2019 in Gulf of Oman (Sistan and Baluchestan Province).

Figure 6 and 7 shows a detailed comparison of annual CPUA and biomass changes over 11-year period. The highest values of mean biomass (146 tones) and mean CPUA (63 kg/nm^2) were observed in 2012, while the lowest values (9.8 tones and 4.2 kg/nm^2) were observed in 2018. The graph shows a clear sharply upward trend from 2009 to 2012, then a slight downward trend in the last seven years. A comparison of the 11-year trend of changes per catch per unit area shows that after a sharp 418.9% increase in catch per unit area by 2012, this species has had the largest downward trend since 2012 (78.8%).

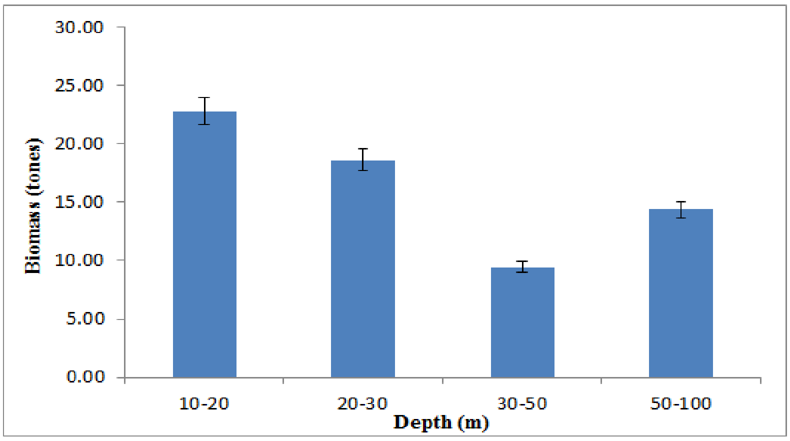

Figure 5: Mean Biomass (tones) of *T. orientalis* in different depth layers from 2009 to 2019 in Gulf of Oman (Sistan and Baluchestan Province).

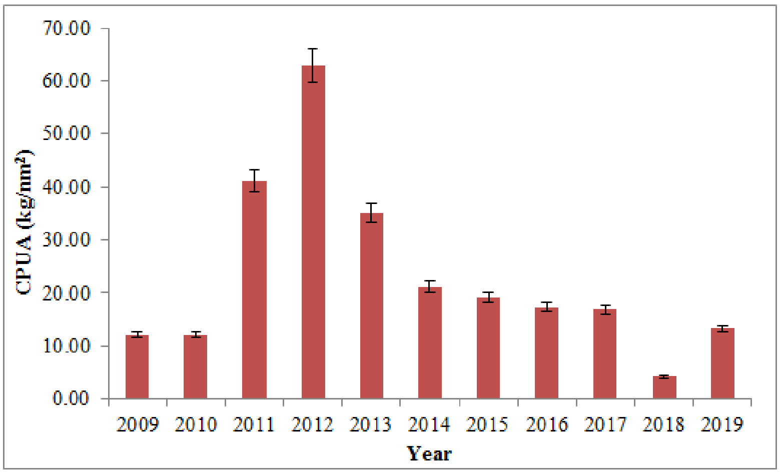

Figure 6: The trend of changes in *T. orientalis* CPUA from 2009 to 2019 in Gulf of Oman (Sistan and Baluchestan Province).

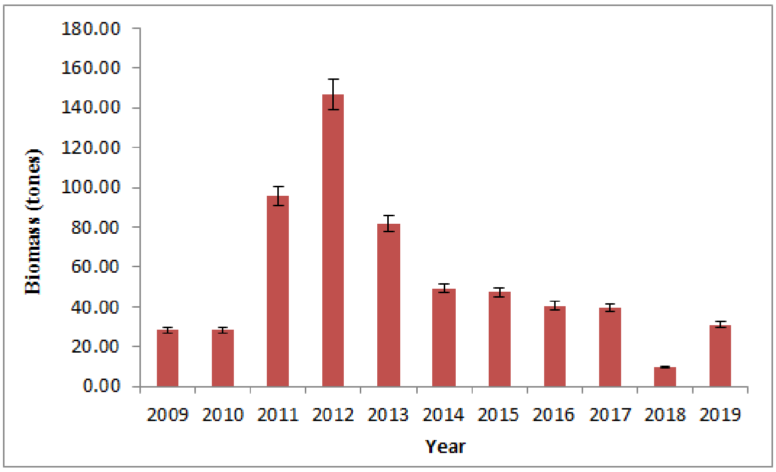

Figure 7: The trend of changes in *T. orientalis* Biomass from 2009 to 2019 in Gulf of Oman (Sistan and Baluchestan Province).

Figure 8 showed the *T. orientalis* distributed pattern throughout northern part the Gulf of Oman in different stratum and depth layers. The highest abundance and distribution of *T. orientalis* was observed in the eastern and western parts of the study area (Stratum E and A) and most of the *T. orientalis* abundance was found in the shallow areas with a descending trend with increasing the depth.

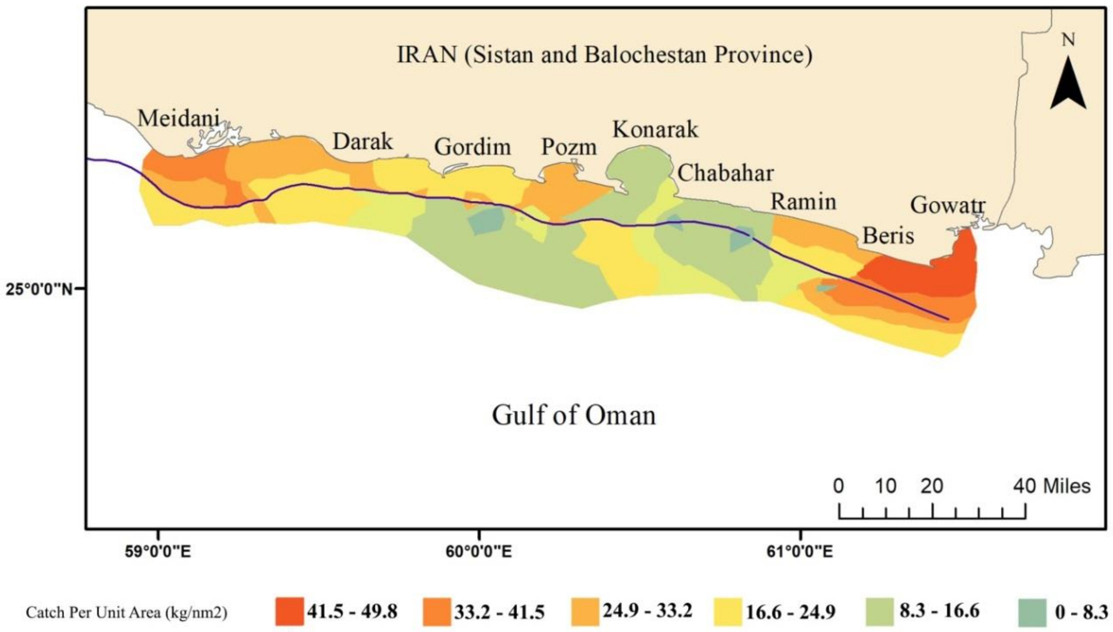

Figure 8: The distribution pattern of *T. orientalis* species in the North coast of Gulf of Oman (Sistan and Baluchestan Province).

Discussion

Harvested at a sustainable rate is recognized as an essential feature of the exploitation of marine living stocks. To achieve sustainable exploitation, stock status monitoring, including the estimation of biological indices such as biomass and CPUA are essential for the management of demersal stocks.

The current study found that the maximum total mean CPUA of flathead slipper lobster was 45.54 kn/nm^2 and 25.40 kg/nm^2 for stratum E and A, respectively. In fact, the highest distribution and abundance of this species was in eastern and western regions of Gulf of Oman. Although, the status of the flathead lobsters was in very good condition from 2009 to 2012, total mean CPUA of flathead lobster has decreased 4.7 times from 2012 to 2019. This results showed importance of these resources was located in the second, but fisheries shift to *T. orientalis* species due to overexploitation of other commercial lobsters such as spiny lobsters (*Panulirus homarus, Panulirus polyphagus, Panulirus versicolor*) .

One of the main reasons of the low density and abundance of flathead slipper lobster in stratum B, C, D located in central part of study area (close to fishing ports) can be due to high activity of illegal fisheries, higher fishing effort and using non-standard fishing gears in which have damaged to lobster resources. There are, however, other possible explanations. King (1995) believes that the overexploitation cause lack of having a safe and suitable ecosystem and consequently cause the obligatory migration of aquatic resources to other areas and shifting to a new fishing grounds. Although flathead lobster is caught as by-catch of fisheries of other species including that of spiny lobsters, shrimp, but trawl nets are also used for fishing of soft-bottom species. Therefore, another possible explanation for the declining trend in CPUA and biomass of lobster over the past decade is the increase in efforts to expand trawling to maximize the use of deep-sea resources.

In accordance with the present results, previous studies in the waters off Mumbai have demonstrated that fishery for *T. orientalis* lasted only up to 1994. Extensive exploitation of spawning females, which formed 60% of the total catch, was detrimental to recruitment and led to a rapid decline and collapse of the lobster fishery (Radhakrishnan *et al*., 2005).

The comparison between different depth layers clear showed the maximum biomass is in shallow muddy area at a depth of 10-20 m, with a descending trend with increasing the depth. Furthermore, the highest mean CPUA was observed in 10 to 30 meters deep layers. These results are in accord with recent studies indicating that flathead Lobsters live on soft bottom of mud or sand, sometimes mixed with shells or gravel, at depths between 10 m and 60 m (Johnston, 1995; Chakraborty and Radhakrishnan, 2015).

This study explored the status of flathead lobsters population over time in the Gulf of Oman. Results indicate strong declines in abundance due to increasing demand for this commercially important species and subsequently increase in fishing effort and use of non-standard fishing gears for further exploitation. To maintain lobster stocks and sustainable exploitation need to take all lobster species (spiny lobsters and flathead lobster) into consideration in any management strategy in Gulf of Oman. According to the existing conditions, returning back the undersized and egg-bearing female lobsters to the sea are the only options that should be considered first to protect stocks. Fishing season limitation and ban fishing of lobsters are last-ditch management tool to avoid reducing lobster population.

Due to the achievement flathead lobster culture technique and its faster and easier growth than spiny lobsters in different methods, such as land based, tank method and open sea cage system, knowledge on larval and juvenile distribution and stocking, breeding and produce larvae in hatcheries, fattening (harvest lobsters when they reach to marketing size), feeding and post-harvest practice should be educated and extended among coastal and local communities.

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