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Investigation of the relative abundance of cephalopods in the neritic zone of Northeast Gulf of Oman using field data

Reza Badali[1], Seyyed Yousef Paighambari[2*], Parviz Zare[3], Reza Abbaspour Naderi[4]

[1]Ph.D. candidate, Fishing and Exploitation Department, Faculty of Fisheries and Environment, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

[2]Associate Professor, Fishing and Exploitation Department, Faculty of Fisheries and Environment, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

[3]Assistant Professor, Fishing and Exploitation Department, Faculty of Fisheries and Environment, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

[4]Expert, Capture and Fishery Office, Iranian Fisheries Organization, Tehran, Iran

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Corresponding author:
sypaighambari@gau.ac.ir

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Abstract

Previous studies on the relative abundance of cephalopods in the Gulf of Oman have been limited, primarily focusing on the commercial species *Sepia pharaonis*. Therefore, the relative abundance of some cephalopods in the Northeast Gulf of Oman (neritic zone) was studied based using the Catch Per Unit Effort (CPUE) index. Commercial fisheries data were collected using field sampling by a stern trawler with a bottom trawl gear (cod-end mesh size: 85 mm) from the Ferdows fishing fleet. The possible effects of five variables including depth, distance from the shoreline, fishing time of day, the velocity of the vessel, and type of haul on CPUE were measured using Generalized Linear Models, Zero-Inflated Models, and Redundancy Analysis (regression and ordination analyses). *Sepia pharaonis* and *Uroteuthis (Photololigo) duvaucelii* had the highest relative abundance based on weight and number, respectively. Weight-based relative abundance of *Sepia pharaonis* was 5251.126 gr/hour (S.E. ± 1156.672), while the number-based relative abundance of *Uroteuthis (Photololigo) duvaucelii* was 56.201 individual/hour (S.E. ± 8.560). Overall, *Sepia pharaonis*, *Uroteuthis (Photololigo) duvaucelii*, and *Sepia stellifera* had the highest relative abundance values based on weight. Also, *Uroteuthis (Photololigo) duvaucelii*, *Sepia stellifera*, and *Sepia omani* had the highest relative abundance values based on their numbers. According to the uneven topography of the study area, both in regression and ordination analyses, the depth variable had the greatest effect on the relative abundance of cephalopods. The effect of depth was more noticeable in ordination analyses ($p < 0.001$).

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Introduction

Biology science covers studies from the protoplasm to the ecosphere. Ecology encloses biology (Ardakani, 2013), and discusses the living organisms, populations, biological communities, ecosystem, and ecosphere to understand the mutual impact of living organisms on themselves and the environment (Ardakani, 2013). Ecological studies play an important role in sciences including fisheries. Researchers in fisheries may study the ecology of humans, animals, and plants, including occurrence or non-occurrence of overfishing, estimation of absolute and relative abundance of aquatic animals and algae bloom.

Commercial fisheries and scientific survey data are the two primary data sources to determine species abundance (Rufener et al., 2021) and field sampling can be applied to both. Researchers believe that information from commercial data (logbooks) could augment survey data and improve estimates of the distribution and relative abundance of commercial species (Fox & Starr, 1996). Field sampling, especially from the commercial fishing fleet, is one of the tools to conduct a more accurate investigation of aquatic biology and ecology. In this connection, commercially data-limited stocks, such as cephalopods, are candidates.

Since the 1970s, following the over-exploitation of demersal fisheries resources, species with short life cycles have continued to increase their share of global captures (Chen, 1996; Chen et al., 2008; Rodhouse, 2001). The largest share of cephalopod catch in the world is squids, and oceanic squids make the most contribution (Chen et al., 2008). As such, the global diversity of coastal cephalopods should not be ignored (Pissara, 2017), and their presence in the catch composition should not be neglected (Jereb & Roper, 2005; Jereb & Roper, 2010; Jereb et al., 2016).

Pissara (2017) researched the pattern of the worldwide diversity of coastal cephalopods and showed that The Persian Gulf and Gulf of Oman ecoregions have a relatively large number of species. Many species of squids, cuttlefishes, and octopuses live in coastal areas of these regions (Jereb & Roper, 2005; Jereb & Roper, 2010; Jereb et al., 2016; Pissara, 2017). Even though some of these species are not commercial, they participate in the marine food webs - especially at higher trophic levels (Piatkowski et al., 2001). Cephalopods are active predators that hunt most aquatic groups except elasmobranchs (Budelmann, 1996), they are prey for fishes, crustaceans, marine mammals, and seabirds (Piatkowski et al., 2001). Even cephalopods, like *Sthenoteuthis oualaniensis* (Moazzam, 2019), have been observed to have an impact on fisheries activities by eating fish caught in fishing gear in an unnatural manner (Piatkowski et al., 2001).

Studies on the relative abundance of cephalopods in the Gulf of Oman is limited and focused on the commercial and well-known species *Sepia pharaonis* (Abbaspour Naderi et al., 2018; Salahi-gezaz et al., 2016). A few studies have examined the relative abundance of other species, including *Sepia omani* (Paighambari et al., 2022) and *Sthenoteuthis oualaniensis* (Paighambari et al., 2012). However, there is no specific information about the relative abundance of octopuses in the region.

Therefore, the CPUE index was used to assess relative abundance (Quinn II & Deriso, 1999), similar to earlier researchers who utilized CPUE (Catch Per Unit Effort) and CPUA (Catch Per Unit of Area) as comparative abundance indices (Hilborn & Walters, 1992; King, 2007). Thus, the relative abundance of some cephalopods of the Northeast Gulf of Oman was studied in this research.

Martial and methods

Data Collection

Field sampling was used to collect data from commercial fisheries to investigate the relative abundance of cephalopods in the region. Field sampling increases the accuracy of the obtained information and gives us information about the relative abundance of discarded cephalopods. In order to conduct field operations, a stern trawler with a bottom trawl gear (cod-end mesh size: 85 mm) from the Ferdows fishing fleet was chosen (Figure 1). The fishing season for this fleet is from April to September every year.

Figure 1. Upper deck of the commercial fishing vessel (stern trawler)

August and September 2020 were the period of data collection. The fishing ground and the study area were in the east of the Gulf of Oman, in the waters of the Islamic Republic of Iran (Figure 2). The census method was considered to record the total number (sometimes sub-samples). The actual weight method was used to record the total weight (NOAA, 2015).

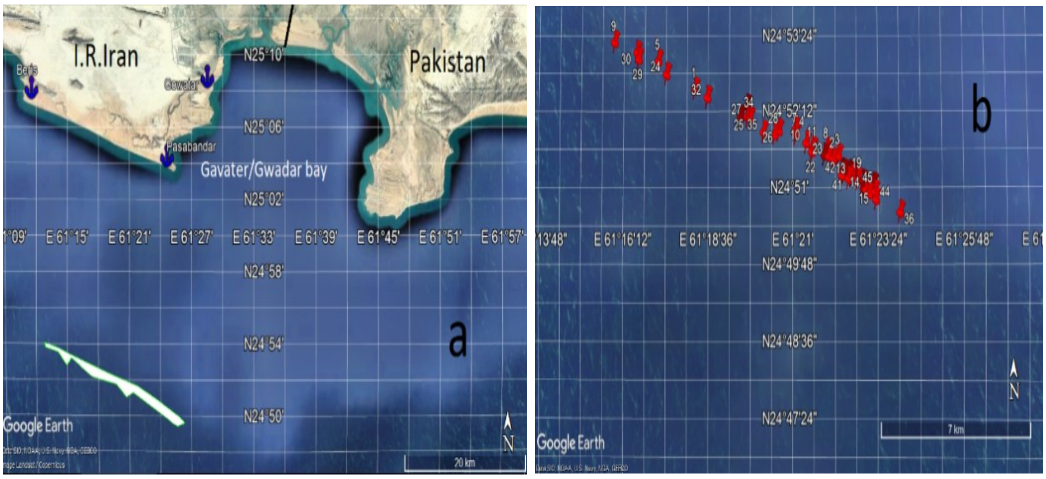

Figure 2. The study area in the Gulf of Oman. a) Fishing ground (deeper areas are darker in color in the gulf). b) Mean coordinates of each haul.

Data Analysis

A total of 45 hauls were implemented in the northeast of the Gulf of Oman with new move-on rules. The vessels of this fishing fleet should be 12 nautical miles away from the shoreline. Only 42 out of 45 samples (hauls) were used to calculate the relative catch abundance and analyze the factors affecting it. So, the data of the three hauls was not fully recorded. CPUE was calculated using Formula 1 (King, 2007; Spare & Venema, 1998):

$$CPUE = \frac{C_w}{t} \quad (1)$$

CPUE: Catch Per Unit Effort (gr/hour or individual/hour)

C_w: total weight (gr) or individual (#)

t: haul period (hour)

Trawl fishing is an active method, so the variables that change during the fishing operation may have a significant effect on the calculated relative abundance. Therefore, five independent variables were selected including depth (127.68-176-69 meters), distance from the shoreline (12.90-14.24 nautical miles), fishing time of day, the velocity of the vessel (2.51-3.13 knots), and type of haul. Due to limitations, geographic coordinate variables (latitude & longitude) were omitted. The actual range of depth, distance from the shoreline, and vessel velocity variables were 74-212 meters, 12.76-15.94 nautical miles, and 4-8 knots, respectively.

VMS (Vessel Monitoring System) data helped to record the information of independent variables. Due to the number of cephalopods caught and the occasional U-shaped movements of the vessel, recording the movement path with independent variables was very difficult. However, the start and end times of each haul were recorded. After checking the VMS data, the points of the vessel's path in the time range of each haul were entered (3-7 points) into the Google Earth Pro software 7.3.0 version. Sometimes the selected point was outside the time range of the haul, and sometimes close to it. Connecting these points determined the path of each haul.

In Google Earth Pro, the mean depth of 11-31 points at each haul's path was calculated for the average depth. The average distance of 3-7 main points to the shoreline was the distance from the coast of each haul. The average velocity of the vessel, only from the points located in the time range of each haul, was obtained (very high or low values, which indicated the stopping or rotation of the vessel, were not considered). The fishing time of day was recorded based on the proximity of the fishing operation to one of the three times of sunrise, noon, and sunset, while the trawling was recorded based on the direct or rotation movement of the vessel.

Descriptive statistics of the relative abundance of cephalopods are calculated and presented based on the above formula (i.e., continuous data). However, the suitable response variable for Generalized Linear Models (GLM) with Poisson, Negative Binomial (NB), Quasi-Poisson, and Bernoulli distributions, Zero-Inflated Models with Poisson (ZIP) and Negative Binomial (ZINB) distribution, and some others are count data (Zuur et al., 2009). Therefore, only for modeling and statistical analysis, the number-based CPUE values were multiplied by the smallest haul time (2.33 hours) to turn them into integers or counts (instead of continuous data). With this, after rounding, the value zero for non-zero values are removed. The same was done for the weight-based CPUE. Bernoulli GLM was implemented only for number-based CPUE - containing values of zero and one - of two species with three different links logit, probit, and cloglog. In addition to the aforementioned statistical models, performing a generalized linear model with Gaussian distribution was also included in the modeling (i.e., simple regression). The sequence of variables at any type of implemented statistical models (regression) was as shown in Formula 2:

$$CPUE_{ij\ (one\ species\ of\ Cephalopoda)} \sim d + ds + ft_i + v + th_j \quad (2)$$

$CPUE_{ij}$ is the response variable (CPUE) of one species that is affected by existing independent variables; d is the effect of depth; ds is the effect of distance from the shoreline; ft_i is the effect of fishing time of day from time i, v is the effect of the velocity of the vessel; and th_j is the effect of type of haul from type j.

Akaike Information Criterion (AIC) was considered for model selection when the difference between the best and the second models was ≥2 (Sakamoto et al., 1999). Due to the lack of AIC in Quasi-Poisson GLM results, Pseudo R^2 (Zuur et al., 2009) and Quasi-AIC (QAIC, Burnham & Anderson, 2002) were also calculated. The values required to calculate the QAIC of Quasi-Poisson models (log-likelihoods, dispersion parameter, and degree of freedom) were estimated by referring to Bolker (2022). Except for Gaussian GLM, in other models, the value of QAIC was the same as AIC for each model.

As we had a multi-species fishing fleet (Jørgensen & Fath, 2008), ordination analyzes were performed, as well. The same response variables were used for comparison of the results of regression and ordination analyses (calculated CPUE was multiplied by 2.33 and then rounded). The first DCA analysis (Detrended Correspondence Analysis) was implemented to determine the length of the gradient. The gradient length was below 3, so Redundancy analysis (RDA) analysis was conducted including a simple RDA and a transformation-based RDA (tb-RDA). The tb-RDA basically changes the response variables by transforming the data. After RDA implementation, the permutation test was carried out. Finally, the most effective ordination model - based on independent variables sequence - was selected by performing several forward regressions. The initial sequence of variables in any statistical model (ordination) was as Formula 3:

$$CPUE_{ij\ (species\ A)} + CPUE_{ij\ (species\ B)} + CPUE_{ij\ (species\ C)} + CPUE_{ij\ (species\ D)} + CPUE_{ij\ (species\ E)} + CPUE_{ij\ (species\ F)} + CPUE_{ij\ (species\ G)} + CPUE_{ij\ (species\ H)} \sim d + ds + ft_i + v + th_j \quad (3)$$

in which, $CPUE_{ij}$ is the response variable (CPUE) of one species that is affected by existing independent variables, d is the effect of depth; ds is the effect of distance from the shoreline; ft_i is the effect of fishing time of day from time i, v is the effect of the velocity of the vessel; and th_j is the effect of type of haul from type j.

For data analysis, R software version 3.6.0 was used (R Core Team, 2019). Vegan package (Oksanen et al., 2019) was included to perform ordination analyses. In regression analyses, pscl package (Jackman, 2017; Zeileis et al., 2008), lmtest package (Zeileis & Hothorn, 2002), AER package (Kleiber & Zeileis, 2008), MASS package (Venables & Ripley, 2002), and stats package (R Core Team, 2019), were used respectively for Zero-Inflated models, likelihood ratio test (comparison of Zero-Inflated models), Over-dispersion test and Durbin-Watson test (residuals independence), Negative Binomial models, and Shapiro-Wilk normality test (residuals normality) and other analyses.

Results

Descriptive Statistics of Relative Abundance

The relative abundance of cephalopods was calculated using the CPUE index. The mean, standard error, and confidence interval of CPUE of identified cephalopods are included in Table 1. Regardless of significance, the existing independent variables had different effects on the relative abundance of each species.

Table 1. The relative abundance of cephalopods (CPUE*).

species/statistics features	mean	range	standard error	confidence interval	
				lower boundary	upper boundary
weight-based CPUE					
Sepia pharaonis	5251.126	0-30300.546	±1156.672	2915.180	7587.073
Sepia stellifera	1695.297	0-5742.049	±261.1875	1167.818	2222.776
Sepia omani	905.4741	0-5477.032	±216.2013	468.8466	1342.1016
Sepia prashadi	27.67876	0-215.548	±8.066679	11.38777	43.96975
Sepia saya	0.8067381	0-11.547	±0.3996167	-0.0003041929	1.6137803834
*Uroteuthis (Photololigo) duvaucelii***	1829.772	0-5784.286	±281.2141	1261.849	2397.695
Uroteuthis (Photololigo) edulis	1.33581	0-16.971	±0.6570324	0.008905587	2.662713461
Amphioctopus marginatus	14.08529	0-158.571	±4.585215	4.825257	23.345314
number-based CPUE					
Sepia pharaonis	6.660762	0-37.158	±1.528312	3.574273	9.747251
Sepia stellifera	31.97607	0-107.597	±5.034261	21.80918	42.14297
Sepia omani	16.51721	0-102.650	±4.149911	8.13630	24.89813
Sepia prashadi	0.2209286	0-1.943	±0.06581053	0.08802151	0.35383564
Sepia saya	0.0232619	0-0.261	±0.01121224	0.0006183241	0.0459054854
Uroteuthis (Photololigo) duvaucelii	56.2016	0-176.222	±8.560342	38.91363	73.48956
Uroteuthis (Photololigo) edulis	0.02478571	0-0.300	±0.01199034	0.0005707246	0.0490007040
Amphioctopus marginatus	0.1402619	0-1.429	±0.0427355	0.05395581	0.22656800

*CPUE unit= [gr/hour] or [individual/hour]. ** Both *Uroteuthis (Photololigo) duvaucelii* look like *Uroteuthis (Photololigo) vossi*, and the correct distinction needs a microscope when field sampling. Hence, there is some probability of their mix up.

Regression analysis

Regression modeling for observed values of relative abundance revealed the effect of available estimators and helped standardize the CPUE of each species. Tables 2 & 3 show the models used to investigate the effect of estimators (independent variables) on the relative frequency variable (dependent variable or response variable). Zero-inflated models were not preferred for species with low zero values (and vice versa for species with high zero values. Readers are referred to the book by Zuur et al. (2009) for a more explanation of validation. The regression coefficients of the best-selected models obtained from the influence of independent variables on the CPUEs are shown in Table 4.

Table 2. Comparison of regression models* (weight-based CPUE).

Species / model features	regression model	significant variables§	(Q)AIC¶ & P.R^2	confirm ●/reject ¤ (description)
Sepia pharaonis (zero values in 9.52% of hauls)	ZIP	all	279209.5/-	●
	ZINB	d	823.41/-	● (excellence+ by likelihood ratio test)
	Gaussian GLM	ds,ft	918.85/57.40	●
	Poisson GLM	all	305307/61.42	¤ (over-dispersion)
	Quasi-Poisson GLM	d	40.84/61.42	●
	NB GLM	d	837.21/24.23	● (better validation than quasi-poisson)
	Bernoulli GLM (a,b,c)°	NT	-/-	-
Sepia stellifera (zero values in 4.76% of hauls)	ZIP	SMF	-/-	-
	ZINB	SMF	-/-	-
	Gaussian GLM	th	813.48/32.02	¤ (non-normality of residuals)
	Poisson GLM	all	118184/28.62	¤ (over-dispersion)
	Quasi-Poisson GLM	th	45.57/28.62	● (better pseudo-R^2 than NB GLM)
	NB GLM	none	775.66/13.94	●
	Bernoulli GLM (a,b,c)	NT	-/-	-
Sepia omani (zero values in 21.42% of hauls)	ZIP	SMF	-/-	-
	ZINB	d,ft,th	600.32/-	●
	Gaussian GLM	d,ds,ft,th	772.99/62.17	¤ (non-normality of residuals)
	Poisson GLM	all	42700/75.93	¤ (over-dispersion)
	Quasi-Poisson GLM	d,ds,ft,th	45.20/75.93	● (better validation than NB)
	NB GLM	th	617.19/32.89	●
	Bernoulli GLM (a,b,c)	NT	-/-	-
Sepia prashadi (zero values in 69.04% of hauls)	ZIP	SMF	-/-	-
	ZINB	d	189.30/-	● (better validation than quasi-poisson)
	Gaussian GLM	ft,th	512.98/44.32	¤ (non-normality of residuals)
	Poisson GLM	all	2895.6/61.38	¤ (over-dispersion)
	Quasi-Poisson GLM	all	42.43/61.38	●
	NB GLM	all	2897.1/61.38	●
	Bernoulli GLM (a,b,c)	NT	-/-	-
Sepia saya (zero values in 90.47% of hauls)	ZIP	SMF	-/-	-
	ZINB	SMF	-/-	-
	Gaussian GLM	th	276.31/17.48	¤ (non-normality of residuals)

	Poisson GLM	all	221.46/49.27	●
	Quasi-Poisson GLM	d,th	41.002/49.27	● (better QAIC than poisson)
	NB GLM	all	223.45/49.27	●
	Bernoulli GLM (a,b,c)	NT	-/-	-
Uroteuthis (Photololigo) duvaucelii (zero values in 2.38% of hauls)	ZIP	SMF	-/-	-
	ZINB	SMF	-/-	-
	Gaussian GLM	th	822.94/26.54	¤ (non-normality of residuals)
	Poisson GLM	all	119191/28.42	¤ (over-dispersion)
	Quasi-Poisson GLM	none	46.64/28.42	●
	NB GLM	ft	788.88/19.85	● (better validation than quasi-poisson)
	Bernoulli GLM (a,b,c)	NT	-/-	-
Uroteuthis (Photololigo) edulis (zero values in 90.47% of hauls)	ZIP	SMF	-/-	-
	ZINB	SMF	-/-	-
	Gaussian GLM	none	321.23/13.13	¤ (non-normality of residuals)
	Poisson GLM	d,ds,v,th	397.22/41.77	●
	Quasi-Poisson GLM	v	37.42/41.77	● (better QAIC than poisson)
	NB GLM	d,ds,v,th	399.2/41.78	●
	Bernoulli GLM (a,b,c)	NT	-/-	-
Amphioctopus marginatus (zero values in 69.04% of hauls)	ZIP	all	296.65/-	●
	ZINB	ft	203.01/-	● (excellence by likelihood ratio test)
	Gaussian GLM	none	488.12/4.45	¤ (non-normality of residuals)
	Poisson GLM	d,ft,v,th	3770.3/6.69	●
	Quasi-Poisson GLM	none	36.48/6.69	●
	NB GLM	d,ft,v,th	3771.7/6.69	●
	Bernoulli GLM (a,b,c)	NT	-/-	-

* The selected model for each species is shown in bold. SMF=software modeling failure. NT= not tried. § d=depth, ds=distance from shoreline, ft= fishing time of day, v= velocity, th= type of haul. ¶ QAIC only for Quassi-Poisson models. + Excellent by likelihood ratio test between two Zero-Inflated models. º a= using "logit" identity link, b= using "probit" identity link, c= using "cloglog" identity link.

Table 3. Comparison of regression models* (number-based CPUE).

species/model features	regression model	significant variables§	(Q)AIC¶ & P.R^2	confirm ●/reject ¤ (description)
Sepia pharaonis (zero values in 9.52% of hauls)	ZIP	SMF	-/-	-
	ZINB	d,th	311.63/-	●
	Gaussian GLM	ds,ft	369.47/49.47	●
	Poisson GLM	d,ft,th	558.35/62.59	¤ (over-dispersion)
	Quasi-Poisson GLM	d,ft,th	49.28/62.59	●
	NB GLM	d,th	297.64/42.64	● (better validation than quasi-poisson)
	Bernoulli GLM (a,b,c)º	NT	-/-	-
Sepia stellifera	ZIP	SMF	-/-	-

(zero values in 4.76% of hauls)	ZINB	SMF	-/-	-
	Gaussian GLM	th	486.36/24.29	¤ (non-normality of residuals)
	Poisson GLM	ds,ft,th	2741/22.11	¤ (over-dispersion)
	Quasi-Poisson GLM	th	48.40/22.11	● (better pseudo-R^2 than NB GLM)
	NB GLM	none	449.64/14.87	●
	Bernoulli GLM (a,b,c)	NT	-/-	-
Sepia omani	ZIP	all	881.81/-	●
(zero values in 21.42% of hauls)	ZINB	d,ft,th	331.97/-	● (excellence$^+$ by likelihood ratio test)
	Gaussian GLM	d,ft,th	443.43/59.78	¤ (non-normality of residuals)
	Poisson GLM	all	998.03/75.55	¤ (over-dispersion)
	Quasi-Poisson GLM	d,ds,ft,th	47.70/75.55	● (better validation than NB)
	NB GLM	d,ft,th	320.82/52.50	●
	Bernoulli GLM (a,b,c)	NT	-/-	-
Sepia prashadi	**ZIP**	d	67.32/-	● (relatively better AIC than ZINB)
(zero values in 69.04% of hauls)	ZINB	d	69.26/-	●
	Gaussian GLM	ft,th	116.03/40.06	¤ (non-normality of residuals)
	Poisson GLM	all	69.24/60.44	●
	Quasi-Poisson GLM	all	84.56/60.44	●
	NB GLM	all	70.99/62.17	●
	Bernoulli GLM (a,b,c)	NT	-/-	-
Sepia saya	ZIP	SMF	-/-	-
(zero values in 90.47% of hauls)	ZINB	SMF	-/-	-
	Gaussian GLM	th	23.63/18.51	¤ (non-normality of residuals)
	Poisson GLM	none	31.44/49.81	● (better pseudo-R^2 than Bernoulli)
	Quasi-Poisson GLM	th	60.85/49.81	●
	NB GLM	all	33.44/49.81	●
	Bernoulli GLM (a,b,c)	a) none b) th c) none	a) 29.28/42.12 b) 28.99/43.25 c) 29.69/40.57	● ● ●
Uroteuthis (Photololigo) duvaucelii	ZIP	SMF	-/-	-
(zero values in 2.38% of hauls)	ZINB	SMF	-/-	-
	Gaussian GLM	none	530.64/24.76	¤ (non-normality of residuals)
	Poisson GLM	all	3933/26.72	¤ (over-dispersion)
	Quasi-Poisson GLM	none	49.87/26.72	●
	NB GLM	ft	498.06/20.37	● (better validation than quasi-poisson)
	Bernoulli GLM (a,b,c)	NT	-/-	-
Uroteuthis (Photololigo) edulis	ZIP	SMF	-/-	-
(zero values in 90.47% of hauls)	ZINB	SMF	-/-	-

	Gaussian GLM	none	25.88/14.02	¤ (non-normality of residuals)
	Poisson GLM	none	32.79/42.60	● (better pseudo-R^2 than Bernoulli)
	Quasi-Poisson GLM	v	49.15/42.60	●
	NB GLM	none	34.79/42.59	●
	Bernoulli GLM (a,b,c)	a) none b) none c) none	a) 31.27/34.59 b) 31.19/34.90 c) 31.23/34.76	● ● ●
Amphioctopus marginatus (zero values in 69.04% of hauls)	ZIP	d,ds,th	71.73/-	●
	ZINB	d,ds,th	75.33/-	●
	Gaussian GLM	none	96.04/7.62	¤ (non-normality of residuals)
	Poisson GLM	none	78.21/9.04	●
	Quasi-Poisson GLM	none	57.53/9.04	● (better validation than ZINB)
	NB GLM	none	80.19/9.08	●
	Bernoulli GLM (a,b,c)	NT	-/-	-

* The selected model for each species is shown in bold. SMF=software modeling failure. NT= not tried. § d=depth, ds=distance from shoreline, ft= fishing time of day, v= velocity, th= type of haul. ¶ QAIC only for Quassi-Poisson models. + Excellent by likelihood ratio test between two Zero-Inflated models. º a= using "logit" identity link, b= using "probit" identity link, c= using "cloglog" identity link.

Table 4. Regression coefficients and significance levels of independent variables of selected models (for CPUE of cephalopods).

species	selected models weight/number-based	variables¶	estimates weight/number	P values weight/number
Sepia pharaonis	NB	(Intercept)	-17.14/-22.47	0.19/0.01*
		depth	0.06/0.07	0.04*/0.002**
		distance from shoreline	1.31/0.94	0.27/0.26
		factor(fishing time)sunrise	-0.16/-0.42	0.76/0.29
		factor(fishing time)sunset	0.15/0.38	0.80/0.37
		velocity of vessel	-0.28/0.50	0.87/0.69
		factor(type of haul) rotation	-0.55/-1.05	0.38/0.02*
Sepia stellifera	Quasi-Poisson	(Intercept)	-1.13/-3.26	0.88/0.69
		depth	-0.008/-0.001	0.66/0.92
		distance from shoreline	0.93/0.60	0.23/0.45
		factor(fishing time)sunrise	-0.20/-0.30	0.59/0.47
		factor(fishing time)sunset	-0.21/-0.14	0.61/0.74
		velocity of vessel	-0.28/0.19	0.81/0.87
		factor(type of haul)rotation	-0.99/-0.91	0.01*/0.03*
Sepia omani	Quasi-Poisson	(Intercept)	-10.28/-5.54	0.34/0.65
		depth	-0.10/-0.09	0.0001***/0.0008***
		distance from shoreline	3.17/2.38	0.004**/0.04*
		factor(fishing time)sunrise	-0.29/-0.48	0.47/0.28
		factor(fishing time)sunset	-2.58/-2.81	3.7e-05***/6.3e-05***
		velocity of vessel	-2.14/-2.11	0.11/0.15
		Factor (type of haul) rotation	-1.13/-1.38	0.004**/0.001**
Sepia prashadi	ZINB/ZIP	(Intercept)	-8.40/-20.08	0.33/0.27
		depth	-0.03/-0.07	0.018*/0.03*
		distance from shoreline	0.95/2.28	0.24/0.19

		factor(fishing time)sunrise	0.23/0.21	0.62/0.83
		factor(fishing time)sunset	0.33/-0.50	0.67/0.72
		velocity of vessel	2.06/0.44	0.21/0.89
		factor(type of haul) rotation	0.67/0.65	0.12/0.49
Sepia saya	Quasi-Poisson/Poisson	(Intercept)	73.59/68.80	0.12/0.33
		depth	0.20/0.19	0.04*/0.21
		distance from shoreline	-6.59/-6.30	0.10/0.30
		factor(fishing time)sunrise	-1.11/-1.35	0.23/0.36
		factor(fishing time)sunset	-21.57/-21.95	0.99/0.99
		velocity of vessel	-5.3/-5.49	0.17/0.37
		factor(type of haul) rotation	-4.99/-4.99	0.005**/0.07
Uroteuthis (Photololigo) duvaucelii	NB	(Intercept)	-9.99/-12.07	0.28/0.16
		depth	0.008/0.01	0.69/0.61
		distance from shoreline	0.93/0.87	0.27/0.27
		Factor (fishing time) sunrise	0.14/0.18	0.70/0.61
		Factor (fishing time) sunset	-0.95/-0.88	0.02*/0.03*
		velocity of vessel	1.75/1.46	0.16/0.21
		Factor (type of haul) rotation	-0.61/-0.58	0.17/0.17
Uroteuthis (Photololigo) edulis	Quasi-Poisson/Poisson	(Intercept)	119.36/108.37	0.18/0.36
		depth	0.13/0.11	0.27/0.47
		distance from shoreline	-8.12/-7.01	0.27/0.47
		Factor (fishing time)sunrise	-0.28/-0.35	0.78/0.81
		Factor (fishing time) sunset	-20.57/-21.57	0.99/0.99
		velocity of vessel	-11.36/-12.57	0.04*/0.13
		Factor (type of haul) rotation	-1.30/-1.65	0.44/0.46
Amphioctopus marginatus	ZINB/Quasi-Poisson	(Intercept)	-5.91/-13.45	0.58/0.39
		depth	-0.04/0.03	0.39/0.54
		distance from shoreline	1.66/0.28	0.16/0.85
		Factor (fishing time) sunrise	-0.48/-0.23	0.10/0.74
		factor(fishing time) sunset	1.33/-0.50	0.008**/0.56
		velocity of vessel	-1.59/1.46	0.15/0.54
		Factor (type of haul) rotation	0.42/-0.61	0.64/0.51

*, **, and *** indicate significance levels of 0.05, 0.01, and 0.001, respectively. ¶ References for the "fishing time of day" and "type of haul" are noon and direct, respectively.

Ordination Analysis

Ordination analyzes were implemented considering the relative abundance of several species. Here units of CPUE are "gr /2.33 hour" and "individual/2.33 hour". The gradient length was less than three, according to the DCA analysis (Figure 3). For the weight-based CPUE, axis lengths for DCA1, 2, 3, and 4 were 2.59, 1.79, 1.15, and 1.19. Also, for the number-based CPUE, axis lengths for DCA1, 2, 3, and 4 were 2.01, 2.10, 2.32, and 1.81.

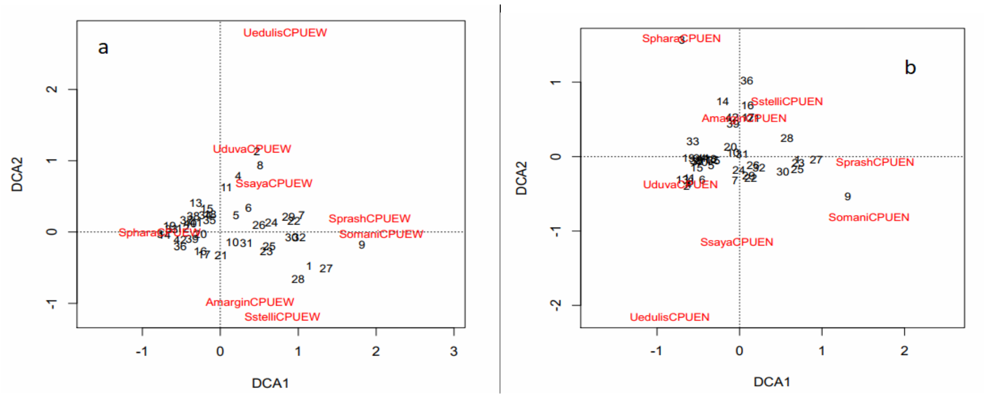

Figure 3. The DCA analyzes for CPUE. a) weight-based and b) number-based.

Simple-RDA and tb-RDA analyzes were completed after the DCA results. Independent variables had a significant impact on the observed CPUE of cephalopods, according to the permutation test (number of permutations= 999) for simple RDA and tb-RDA models (both weight- and number-based), (Table 5).

Table 5. RDAs statistics for CPUE of cephalopods.

model/statistics features	R^2/adjusted R^2	simple model test F	Pr(>F)	Permutation test F	Pr(>F)
weight-based CPUE					
simple-RDA	0.54/0.47	7.08	0.001***	7.08	0.002**
tb-RDA	0.46/0.37	5.07	0.001***	5.07	0.001***
number-based CPUE					
simple-RDA	0.30/0.18	2.52	0.01**	2.52	0.01**
tb-RDA	0.39/0.28	3.75	0.001***	3.75	0.001***

** and *** indicate significance levels of 0.01, and 0.001, respectively.

The ordination analyzes (Figures 4 and 5) showed depth, distance from the shoreline, and fishing time of day may significantly be affected the weight-based CPUE of cephalopods. The number-based CPUE of cephalopods may also be significantly affected by depth, type of haul, and fishing time of day (Table 6).

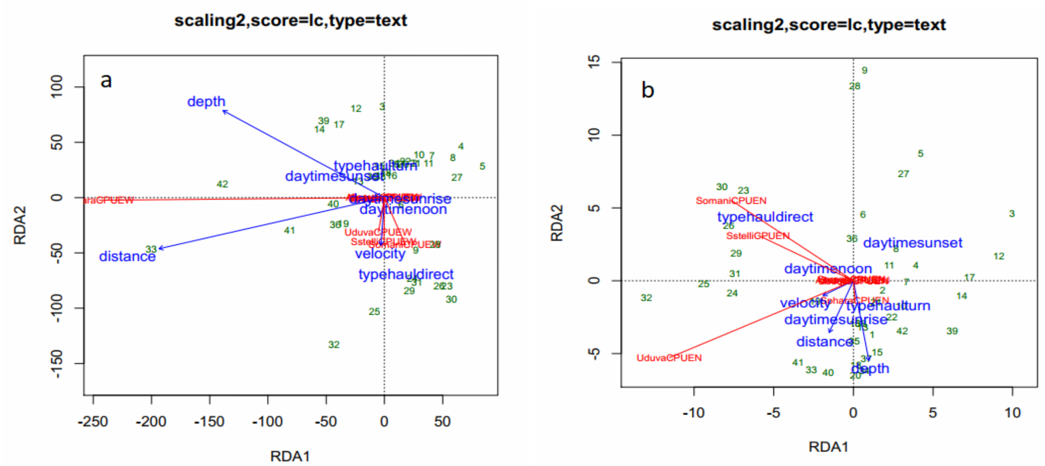

Figure 4. The simple-RDA analyzes for CPUE. a) weight-based and b) number-based.

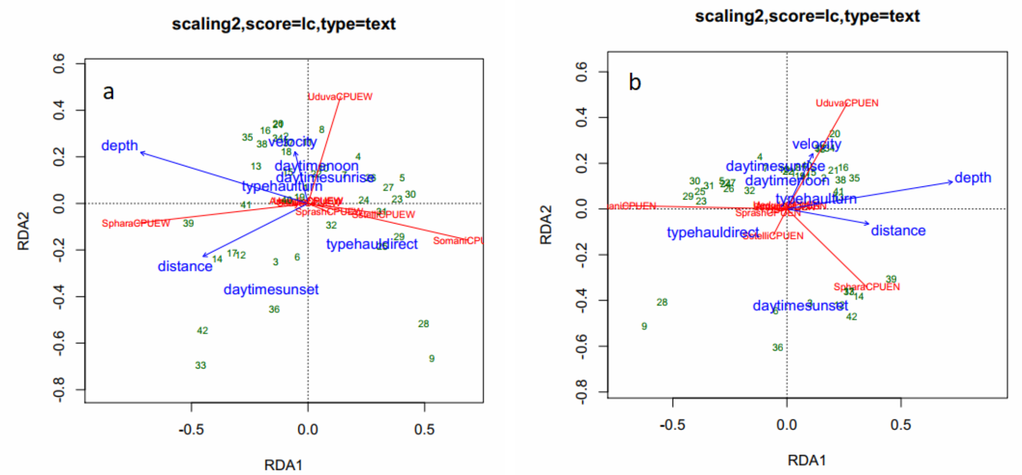

Figure 5. The tb-RDA analyzes for CPUE. a) weight-based and b) number-based.

In Figures 3, 4, and 5, "depth"=depth of haul, "distance"=distance from the shoreline, "daytime"=fishing time of day, "velocity"= the velocity of the vessel, "typehaul"= type of haul, "CPUEW"= weight-based CPUE, "CPUEN"= number-based CPUE, "Sphara"= *Sepia pharaonis*, "Sstelli"= *Sepia stellifera*, "Somani"= *Sepia omani*, "Sprash"= *Sepia prashadi*, "Ssaya"= *Sepia saya*, "Uduva"= *Uroteuthis (Photololigo) duvaucelii*, "Uedulis"= *Uroteuthis (Photololigo) edulis*, and "Amargin"= *Amphioctopus marginatus*.

Table 6. RDAs results for CPUE of cephalopods.

model/statistics features	Variables	degree of freedom	variance	F	Pr(>F)
weight-based CPUE					
simple-RDA	depth	1	75157408	16.6703	0.001***
	distance from shoreline	1	74885580	16.6100	0.003**
	fishing time of day	2	34216087	3.7947	0.026*
	velocity of vessel	1	1599240	0.3547	0.630
	type of haul	1	5663692	1.2562	0.257
tb-RDA	depth	1	0.071810	19.5869	0.001***
	distance from shoreline	1	0.006801	1.8551	0.159
	fishing time of day	2	0.026626	3.6312	0.007**
	velocity of vessel	1	0.002025	0.5522	0.564
	type of haul	1	0.004384	1.1957	0.308
number-based CPUE					
simple-RDA	depth	1	1710.1	3.1822	0.051
	distance from shoreline	1	1334.3	2.4830	0.066
	fishing time of day	2	2303.4	2.1431	0.083
	velocity of vessel	1	161.1	0.2997	0.771
	type of haul	1	2647.2	4.9260	0.012*
tb-RDA	depth	1	0.042373	11.8997	0.001***
	distance from shoreline	1	0.003304	0.9279	0.391
	fishing time of day	2	0.025661	3.6033	0.004**
	velocity of vessel	1	0.003039	0.8534	0.458
	type of haul	1	0.005813	1.6326	0.161

*, **, and *** indicate significance levels of 0.05, 0.01, and 0.001, respectively.

Discussion

The species *Sepia pharaonis* and *Uroteuthis (Photololigo) duvaucelii* had the highest relative abundance in terms of weight and number in this study. *Sepia pharaonis*, *Uroteuthis (Photololigo) duvaucelii*, and *Sepia stellifera* had the highest relative abundance values based on weight. Also, *Uroteuthis (Photololigo) duvaucelii*, *Sepia stellifera*, and *Sepia omani* had the highest relative abundance values based on their numbers. It's important to note that only octopuses - a single species by the name *Amphioptopus marginatus* - were discarded cephalopods. Compared to other cephalopod groups (i.e., squids and cuttlefishes), octopuses had the lowest relative abundance.

The increase in depth had a significant positive effect on the CPUE of *Sepia pharaonis*. *Sepia pharaonis* spends winter in offshore waters after hatching in coastal areas, making a long reproductive migration to coastal areas in the spring for fertilization and spawning (Roomiani et al., 2018). Before the start of reproductive migration, adults of this species congregate offshore (Jereb & Roper, 2005). It is likely that this species travels through the fishing grounds to get to the offshore waters, as indicated by the field sampling range in the summer and fall. Because *Sepia pharaonis* has a wide distribution range (Hanlon et al., 2018) and field operation is located near the boundary of the Gulf of Oman and the Arabian Sea (near Gavater/Gwadar Bay), even adults of this species may attempt to migrate deeper into the Arabian Sea from the Gulf of Oman ecoregion. Similarly, the increase in depth had a significant positive effect on the weight-based CPUE of *Sepia saya*. This is no surprise because this species was first found in the western Indian Ocean (Saya-de-Malha Bank). Maybe this species is an oceanic cephalopod that is more visible at greater depths. Unlike the previous two species, the increase in depth had a significant negative effect on the CPUE of *Sepia prashadi* and *Sepia omani* because the habitat of these two species is naturally limited to the shallow waters of the neritic region (continental shelf area).

Similar *to Sepia pharaonis* (number-based CPUE), rotation (turn) haul had a significant negative effect on the CPUE of *Sepia stellifera*. Even the CPUE of *Sepia omani* and weight-based CPUE of *Sepia saya* decreased significantly with rotation (turn) haul, too. The last three above-mentioned cuttlefishes were small-size (Jereb & Roper, 2005). Also, some *Sepia pharaonis* caught were small (there were specimens with under 10 cm ML). A species of the Decapodiformes superorder (*Doryteuthis pealeii*) was observed at the mouth of the drop-chain bottom trawl exhibiting swimming, escape-jet, jet-swim, and drift behaviors (Bayse et al., 2016). Therefore, the aquatic animals of this superorder (including squids and cuttlefishes) can show active and diverse movements when facing the trawl. Although there was no underwater camera to record the interactions between the trawl and the cephalopods during the rotation (turn) of the vessel, considering the swimming and intelligence of these aquatics, probably some of them escaped from the trawl gear. To implement this trawling technique, the towing warp must be gathered by the drums until the trawl net approaches water surface. After the rotation (turn) of the vessel, the trawl reaches the bottom with the reverse movement of the drum.

Although it was a little improbable, *Sepia omani*'s CPUE significantly increased with its distance from the shoreline. The longest distance from the shoreline was seen for Gavater/Gwadar Bay. Indeed, if we analyze the study area's map, we will see that increasing the distance from the shoreline does not always result in an increase in depth due to the relatively rough bottom (Figure 2a). The peak CPUE of *Sepia omani* and some other species were observed between hauls 20-30 (and the hauls close to them), where the depth of the hauls compared to the 10-20 and 30-42 hauls dropped. This probably indicates that the trawl gear entered the desirable habitat of some of the cephalopods of this study during the aforementioned hauls. In addition, fishing around sunset also had a significant negative effect on the CPUE of *Sepia omani* which is a demersal sepcies. As a result, it might veer slightly from the bottom at sunset or migrate vertically like some other cephalopods, particularly squids (Cabanellas-Reboredo et al., 2012). The Sepiidae species (such as *Sepia omani*) generally bury themselves in the bottom during the day and emerge at night to feed (Roper & Young, 1975). Therefore, they are easily caught by bottom trawl gear during the day. On the other hand, there is a possibility of school formation by cuttlefishes (Yasumuro et al., 2015, especially the smaller ones). So the school formation and its temporary dissolution at sunset is another hypothesis for the decrease of CPUE. Fishing around sunset also had a significant negative effect on the CPUE of *Uroteuthis (Photololigo) duvaucelii*. Fishing around sunset also had a significant positive effect on the weight-based CPUE of *Amphioctopus marginatus.* There was a possibility of non-observation of this species despite its presence in some initial sampling hauls. Vertical migration is common in most squids (Roper & Young, 1975), and it is the result of their different day and night activity patterns (Cabanellas-Reboredo et al., 2012; Jereb & Roper, 2005). Finally, the weight-based CPUE of *Uroteuthis (Photololigo) edulis* decreased significantly with increasing velocity of the vessel.

Overall, ordination analyses revealed that the weight- and number-based CPUE of cephalopods, respectively, were significantly affected by depth, distance from the shoreline, and fishing time of the day, and also depth, type of haul, and fishing time of day. Because the two species *Sepia pharaonis* and *Uroteuthis (Photololigo) duvaucelii* were well-known from earlier field studies whether they involved commercial fisheries data or scientific survey data, their predominance was predictable. Valinassab et al. (2006) classified the above two species among the commercial demersal stocks of the Persian Gulf and the Gulf of Oman. One research at the northern continental shelf area of the Gulf of Oman (25°21'00" to "25°13'00" N and 59°00'00" to 60°37'60" E) by a commercial bottom trawler (with 3-knot mean velocity) showed 203.1 kg/haul CPUE and 1948 kg/nm^2 CPUA on average for *Sepia pharaonis* (move-on rule: 8 nautical miles from the shoreline (Salahi-gezaz et al., 2016). The difference in their CPUE values compared to the current research is due to the different distances from the shoreline and study coordinates. Additionally, it's possible that in contrast to our research, they conducted field sampling during the beginning or middle of the fishing season. Another research based on a scientific survey of the northern continental shelf of the Gulf of Oman (58°55' to "61°25' E) in August and September by a bottom trawler showed on average 351 kg/nm2 CPUA for *Sepia pharaonis* (depths: 10-100 meters (Abbaspour Naderi et al., 2018). The decrease in CPUA observed in the study of Abbaspour Naderi et al. (2018) may be due to the reduction of stocks of the mentioned species in the year of sampling, the implementation of the research at the end of the fishing season, and operation on shallow water. Their study area was close to the nursery grounds in shallow waters and far from the depth of offshore adult accumulation. Their study area was also slightly different from the study of Salahi-gezaz et al. (2016). Abbaspour Naderi et al. (2018) found that the central areas of the Gulf of Oman have significantly lower CPUA for *Sepia pharaonis* than the eastern areas (our study area) with depths of 50-100 m compared to 10-20 m. Therefore, it is not surprising if the relative abundance (CPUE) of *Sepia pharaonis* was lower in the present study compared to the study of Salahi-gezaz et al. (2016).

In addition to demersal cephalopods, the relative abundance of *Sthenoteuthis oualaniensis* - representative of pelagic cephalopods - has been investigated in the Gulf of Oman ecoregion (Paighambari et al., 2012; Paighambari et al., 2022). The CPUE of the mentioned species was 4.495 kg/hour by the jigging method (central and eastern Gulf of Oman, Paighambari et al., 2012) and 7.584 kg/hour (and 19.062 individuals/hour) by the mid-water trawling method (western Gulf of Oman, Paighambari et al., 2022). Depth was the significant influencing factor on the relative abundance of *Sthenoteuthis oualaniensis* in both studies (the distance traveled by trawler vessel also had a significant effect). Apparently, the relative abundance of *Sthenoteuthis oualaniensis* caught in mid-water trawl was higher, but the composition of its catch includes discarded cephalopods (Paighambari et al., 2022).

It is worth considering that *Sepia omani* has been observed in both common bottom trawl (present study) and mid-water rope trawl (Paighambari et al., 2022) fleets. The weight-based and number-based CPUE by midwater trawl were 1345.016 gr/hour and 18.250 individuals/hour, respectively (Paighambari et al., 2022). The values observed by Paighambari et al. (2022) were slightly higher than the values of the present study. In the study by Paighambari et al. (2022), the move-on rule was at least 12 nautical miles, and depth, study area, fishing gear, and techniques were different. They obtained these results with the mid-water rope trawl, fishing in the water column with higher depths (often more than 200 meters), and in the western Gulf of Oman. Additionally, compared to the study by Paighambari et al., (2022), it's possible that the rotation trawling technique and sunset fishing with a sizable negative effect in the current study were effective in lowering *Sepia omanis*' CPUE. Their vessel was a lanternfish trawler with a smaller cod-end mesh trawl that operated only before and after noon. But the variables of fishing time of day, depth, and trawling distance had no significant effect on the obtained abundance of *Sepia omani* in their study.

Conclusion

The results of field research based on commercial fisheries data on the demersal cephalopods in the neritic zone of the northeastern Gulf of Oman showed that *Sepia pharaonis* and *Uroteuthis (Photololigo) duvaucelii* had the highest relative abundance based on weight and number, respectively. We determined the relative abundance, or catch rate, of cephalopods in the northeast of the Gulf of Oman using a commercial fishing vessel (bottom trawl). The results of this study were obtained in the new move-on rule (distance of 12 nautical miles from the shoreline) with greater depths (often more than 100 meters) by two techniques of trawling (direct and rotation), which is infrequent in aquatics research of demersal cephalopods of the Gulf of Oman. According to the uneven topography of the study area, both in regression and ordination analyses, the depth variable had the greatest effect on the relative abundance of cephalopods.

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