Morphometric variation and growth rate of *Uroteuthis duvaucelii* (Cephalopoda: Loliginidae) in the Persian Gulf and Oman Sea using gladius increments

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Introduction

Loliginid squids occur in temperate and tropical coastal waters where they have been considered economically important (Valinassab et al., 2006; Anderson, 2000). *Uroteuthis* (*Photololigo*) *duvaucelii* (Orbigny, 1835) or Indian squid is the most abundant group of Teuthida (Family Loliginidae) in the Persian Gulf and Oman Sea (Valinassab, 1993). These squids demonstrate complex population structures, and are generally characterized by different biological features such as growth rates, size and age of maturity. Over the past 30 years age determination through interpretation of growth increments in the microstructure of the hard structures of squids has accounted for many of the issues and limitations. Naef (1921) was the first to identify growth increments on gladius. The gladius is the internal chitinous shell present in squids, which supports mantle muscles, fins and inner organs. Increments were observed in the middle plate on the dorsal surface of the gladius (Arkhipkin *et al*., 2012). The series of increments of gladius indicate the amount of daily growth in these species (Perez *et al*., 2006).

Gladius microstructures were investigated for their suitability as a tool for age and growth studies in the cephalopoda used by Bizikov (1991).

Despite the high abundance of *U. duvaucelii* in the Iranian waters, relatively little information is available on the population and daily growth rate of this species. This study presents the

first record of the population structure by discriminant function analysis and daily growth rate by increment structures in *U. duvaucelii* in the Persian Gulf and Oman Sea.

Materials and methods

In this study, Indian squids (*Uroteuthis duvaucelii*) were sampled by bottom trawl fishery in four regions from 50º 15`E to 61º 25` E, between August 2011 to January 2012 (region A: Bushehr waters; region B: Western Strait of Hormuz in the Persian Gulf) and (region C: North-west Oman Sea; region D: North-east Oman Sea), using R/V Ferdows-1 (Fig. 1). The total coastline of the study areas, the Persian Gulf and Oman Sea, has different ecosystems (depth, currency, chemical parameters). Because of the ecological differences and extension of the study area, four stations were selected for further determination of population differentiation and to control any changes in growth rate in different positions, namely the Persian Gulf as shallow waters and the Oman Sea as deep sea waters. Samples were frozen on board and transferred ashore to the laboratory for further analysis.

A total of 213 Indian squids were sampled and analyzed. Measurements of the body and gladius based Liao *et al.* (2010), included 21 morphometric parameters: mantle length (ML), mantle width (MW), fin length (FL), fin width (FW), both fins width (FW*2), head length (HL), head width (HW), total body weight (W), nuchal cartilage length (NcL), funnel length (FcL), eye diameter (ED), length of first arm (AL_I), length of second arm (AL_{II}), length of third arm (AL_{III}), length of forth arm (AL_{IV}), gladius length (GL), gladius width (GW), gladius weight (GWg), rachis width (RW), mantle circuit (MC), and finally gill length (Gill L).

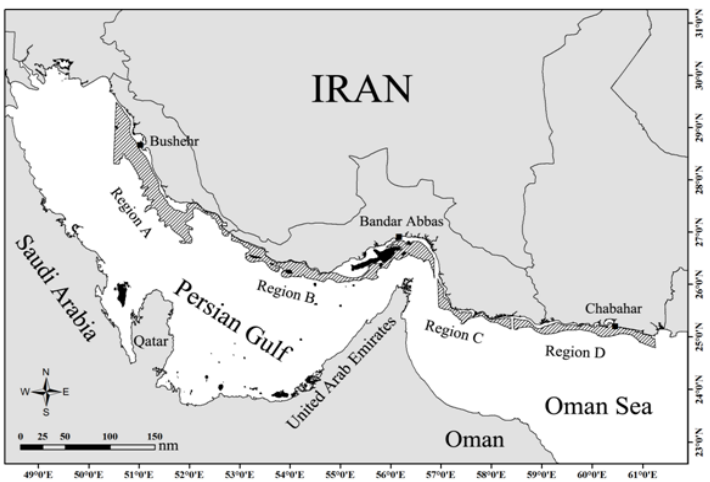


Figure 1: Sample locations (shaded areas) of the Indian squid (*Uroteuthis duvaucelii*) in the Persian Gulf and Oman Sea.

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Measurements were done with pointer calipers to the nearest 0.02 mm except for the ML and MW that were measured to the nearest 1 mm. Weights of the total body and gladius were obtained on a digital scale to the nearest 0.01g and 0.001g, respectively.

Gladii were extracted and stored in formalin 4% (as advised in Bizikov, 1995). Each gladius was measured for total length (GL) to the nearest mm. Gladii was prepared using the general methods introduced in Bizikov (1995). Each gladius was rinsed in water and marked at 10 mm intervals from the posterior (fins) to the anterior end (head). To count the increments, the dorsal surface of the gladius was examined under a dissecting microscope at 20-30X. Growth increments were counted from the anterior (head) to the posterior end (fins) until the time that the increments were no longer visible. Growth rate (mm/day) was calculated by dividing 10 mm by the number of growth increments counted in a gladius length interval (GINC). The Bizikov's technique was used as an expression of a mean growth increment, in which it was assumed that one increment equals to one day of growth. In accordance with the studies of Perez and O`Dor (2000) and Schroeder and Perez (2010), the series of GINC was used the following formula:

$0.25\ GINC_1 + 0.5\ GINC_2 + 0.25\ GINC_3$ and called GINC` (Schroeder and Perez, 2010). GINC` represents the amount of gladius growth during one day (Perez and O`Dor, 2000). The relationship between mantle length and gladius length was described using the linear regression model, GL= aML + b (Sparre *et al*., 1998).

The one-way ANOVA was used to find any significant difference between growth rate of males and females.

A total of 21 variables were selected to perform a discriminant analysis to classify the *U. duvaucelii* caught from the four regions of the Persian Gulf and Oman Sea. The discriminant power was described with Wilks' lambda index (0.0 and 1.0), which was used to compare the differences between all groups (Thioulouse *et al*., 1997).

Results and discussion

In this study, dorsal mantle length of the squids sampled varied from 32 to 190 mm and from 80 to 144 mm among the Persian Gulf and Oman Sea, respectively. Statistical summary of 21 morphological parameters of squids from four selected regions is illustrated in Table 1.

Morphometric comparison showed that the gladius morphology of *U. duvaucelii* from the four regions was similar but differed significantly between males and females.

Daily growth rates in the *U. duvaucelii* based on gladius microstructure was determined for the four regions.

Increments were more clearly observed on the dorsal surface of the rachis.

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Table 1: **Morphometric variables (Mean ±SD) of *Uroteuthis duvaucelii* in four selected regions in the Persian Gulf and Oman Sea**.

Variable	Region A		Region B		Region C		Region D	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ML (mm)	126.62	19.67	82.62	23.97	103.85	12.21	111.97	13.84
MW (mm)	36.49	4.71	27.47	6.37	33.02	3.88	34.10	3.43
W (g)	67.97	26.94	27.74	15.14	37.02	11.51	45.29	12.09
FL (mm)	65.11	12.10	40.33	12.29	50.31	9.35	54.75	9.23
FW (mm)	25.83	4.69	16.87	4.37	20.19	3.04	21.65	3.30
FW*2(mm)	69.57	12.27	48.02	12.19	53.69	7.41	58.60	7.20
HL (mm)	25.58	3.18	18.09	4.85	22.42	3.08	23.70	2.59
HW (mm)	19.89	2.76	16.78	3.69	15.83	2.79	18.12	2.73
ED (mm)	21.83	2.04	14.00	2.97	19.73	3.78	19.53	1.74
AL_{I} (mm)	44.40	6.64	27.62	10.00	33.42	6.44	35.75	5.54
AL_{II} (mm)	53.85	6.51	34.16	12.57	43.00	7.22	45.65	6.91
AL_{III} (mm)	60.43	6.58	38.00	9.81	49.92	7.19	53.30	8.21
AL_{IV} (mm)	54.81	7.24	35.73	8.41	44.02	7.74	47.03	6.34
NcL (mm)	16.34	2.53	11.13	2.52	13.56	1.86	14.87	1.69
FcL (mm)	24.43	3.16	15.84	4.30	19.35	3.48	20.70	4.01
GL (mm)	128.43	19.60	84.64	24.47	108.19	12.55	114.98	12.96
GW (mm)	22.02	4.89	13.98	3.67	16.13	3.18	17.72	2.76
GWg (g)	0.47	0.21	0.21	0.11	0.24	0.09	0.30	0.10
RW (mm)	8.83	1.38	5.81	1.64	7.46	1.04	8.20	1.76
MC (mm)	84.87	10.56	63.20	11.89	72.83	6.12	77.85	6.31
GillL (mm)	40.66	6.33	27.07	7.88	44.02	6.38	46.78	5.66
	n=53		n=45		n=52		n=60	

However, increments on the posterior end of the gladius were faint, and could not be easily distinguished. In the *U. duvaucelii*, almost 2/3 of the total number of gladius increments was visible. Nevertheless, no significant differences were observed in the daily growth rate of the *U. duvaucelii* between the males and the females (p>0.05).

The results demonstrated a daily growth rate (GINC`) of 0.15 - 0.32 mm in region A, 0.12 - 0.27 mm in region B, 0.13 – 0.20 mm in region C and 0.14–0.32 mm in region D (Table 2). Thus, *U. duvaucelii* in the Strait of Hormuz (regions B and C) has a slower growth rate than in the other two regions. In this study, mean daily growth rate (GINC`) in the four regions ranged between 0.16 and 0.22 mm (Table 2).

The growth rate in *U. duvaucelii* is strongly influenced by the temperature and the diet of each specimen (Perez *et al*., 2006). Different growth rates of *U. duvaucelii* were observed in the study area.

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Table 2: Daily growth rate of gladius (GINC`) of *Uroteuthis duvaucelii* in the four regions in the Persian Gulf and Oman Sea.

Region	Sex	n	Max (mm)	Min (mm)	Mean (mm)	SD
A	Male	7	0.32	0.14	0.19	0.061
	Female	14	0.27	0.15	0.20	0.031
B	Male	11	0.19	0.14	0.17	0.016
	Female	20	0.20	0.13	0.17	0.019
C	Male	26	0.24	0.12	0.16	0.024
	Female	10	0.27	0.15	0.18	0.039
D	Male	10	0.32	0.16	0.22	0.045
	Female	12	0.26	0.15	0.19	0.036

Since the two water bodies of the Persian Gulf and Oman Sea have more or less the same temperature therefore the most effective factor on growth rate can be considered as different feeding regime due to significant ecological differences between the two seas such as depth in that the Persian Gulf is a semi-closed area with an average depth of 35 m but the Oman Sea has deep sea characteristics with a maximum depth of up to 3400 m and higher production. Also, different squid species have different growth rates. For instance, the daily growth rate of *Sthenoteuthis oualaniensis*, purple-back flying squid (Ommastrephidae) is very fast (0.86–1.54 mm) (Bizikov, 1995) compared to the Indian squid (0.16–0.22 mm).

All regressions were statistically significant (p<0.05). The relationship between gladius length and mantle length was described by the linear regression model, which showed a strong linear correlation (Table 3).

As the discriminant analysis results indicate, all the 21 variables were included in the models to separate the three populations of *U. duvaucelii*. Morphometric characters in this species show distinct differences between regions A, B from the Persian Gulf and C, D (with high overlapping) from the Oman Sea (Fig. 2); and in total the populations in the two water bodies should be considered as different populations and it means that any further fisheries management should be applied separately. The Wilks` Lambda value for three different populations is found to be lower than 1 (Table 4).

Table 3: Relationship between gladius length (GL) and mantle length (ML) of *Uroteuthis duvaucelii* in four selected regions in the Persian Gulf and Oman Sea.

Region	N	GL vs. ML	R^2
A	53	GL = 0.9852 ML + 3.6916	0.98
B	45	GL= 1.024 ML – 1.0311	0.94
C	52	GL = 0.9925 ML + 5.1279	0.93
D	60	GL = 0.9266 ML + 11.912	0.90

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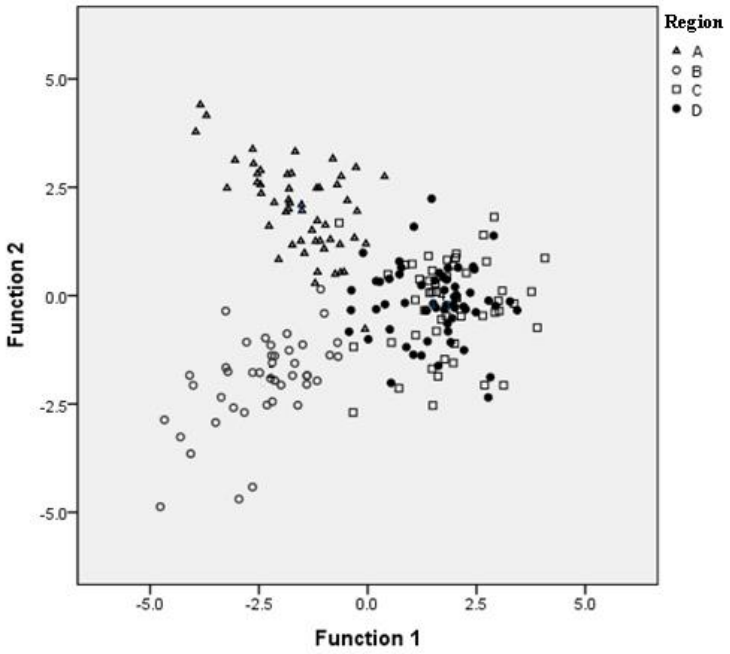


Figure 2: Plot of canonical variables (Function 1 and 2) of morphometric variables of *Uroteuthis duvaucelii* in the Persian Gulf and Oman Sea.

Table 4: **Summary of canonical discriminant functions, Wilks`λ ,Chi-square tests of morphometric variables of *Uroteuthis duvaucelii* in the Persian Gulf and Oman Sea.**

Function	Eigenvalue	Canonical Correlation	Wilks` Lambda	Chi-square	df	*p* level
1	2.707	0.855	0.089	488.396	18	0.000
2	1.722	0.795	0.330	223.710	10	0.000
3	0.112	0.317	0.899	21.462	4	0.000

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