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Study of some ecological and biological parameters on European eel *Anguilla anguilla* in Umm Hufayan brackish lagoon, Eastern Libya Mediterranean Sea

Etude de quelques paramètres écologiques et biologiques de l'anguille européenne Anguilla anguilla dans la lagune saumâtre d'Umm Hufayan, en mer Méditerranée orientale de la Libye

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Abstract. Monthly random samples of European eel *Anguilla anguilla* were obtained from Umm Hufayan brackish lagoon, eastern Libya, Mediterranean Sea, from January to December 2015. Number of studied eel samples was 205 specimens captured from the lagoon during their seaward migration. Maximum surface water temperature in the lagoon was 28.7°C in summer and 23.8°C in autumn, whereas minimum temperatures were 13.6°C in winter and 18.4°C in spring. Maximum salinities were 27.7‰ in summer and 25.9‰ in autumn, whereas the minimums were 20.1‰ in winter and 21.3‰ in spring. Dissolved oxygen concentrations were 12.9 mg/L in autumn, 11.7 mg/L in winter, 11.3 mg/L in spring and 9.3 mg/L in summer. Seasons of entry of elver eels to the lagoon and of exiting of migrating silver eels were spring, around mid-April, roughly from day 10 to 24, and winter from the beginning of October to the beginning of February but climaxing around mid-December in order. Eels entered the lagoon when average surface water temperature was around 18.4°C, salinity=21.3‰ and dissolve oxygen=11.3 mg/L, and left the lagoon to sea when the average temperature was around 13.9°C, salinity=20.1‰ and dissolve oxygen=11.7 mg/L. Total length of the studied eels ranged from 23.1 to 44.4 cm, corresponding to total weights of 199.9 to 2922.9 g. The Length (L)-Weight (W) relationship was estimated as: $W=0.0159*L^{3,2276}$. The highest values of Fulton (K_F) and Clark (K_C) condition factors were recorded for spring and summer.

Key words: European eel, Length-weight relationship, condition factors, migration, Libya.

Résumé. Des échantillons mensuels de l'Anguille européenne *Anguilla anguilla* ont été pris aléatoirement de janvier à décembre 2015 dans la lagune saumâtre d'Umm Hufayan située au niveau de la mer Méditerranée à l'Est de la Libye. Au total, 205 anguilles ont été étudiées. Elles ont été capturées dans la lagune lors de leur période de migration vers la mer. La température maximale de l'eau de surface dans la lagune était de 28,7°C en été et de 23,8°C en automne, tandis que les températures minimales étaient de 13,6°C en hiver et de 18,4°C au printemps. Les salinités maximales étaient de 27,7‰ en été et de 25,9‰ en automne, alors que les minimums étaient de 20,1‰ en hiver et de 21,3‰ au printemps. Les concentrations d'oxygène dissous étaient de 12,9 mg/L en automne, 11,7 mg/L en hiver, 11,3 mg/L au printemps et 9,3‰ en été L'entrée des civelles dans la lagune et la sortie des anguilles argentées migratrices ont lieu au printemps du 10 au 24 avril et en hiver du début octobre à début de février, mais l'optimum se situe vers la mi-décembre. Les anguilles entrent dans la lagune lorsque la température moyenne de l'eau de surface est d'environ 18,4°C, la salinité=21,3‰ et l'oxygène dissout=11,3 mg/L. Elles quittent la lagune vers la mer lorsque la température moyenne atteint environ 13,9°C, la salinité=20,1‰ et l'oxygène dissout=11,7 mg/L. La longueur totale des anguilles étudiées varie de 23,1 à 44,4 cm correspondant respectivement aux poids total de 199,9 et 2922,9g. La relation longueur (L)-poids (W) a été estimée avec la relation : $W = 0,0159 * L^{3.2276}$. Les valeurs les plus élevées des facteurs des conditions de Fulton (K_F) et Clark (K_C) ont été enregistrées pour le printemps et l'été.

Mots-clés: Anguille européenne, relation longueur-poids, facteurs de milieu, migration, Libye.

INTRODUCTION

Although Libya has a vast coastline of 1970 km on the Mediterranean Sea, fisheries production is very low when compared with the available resources (Lambouef & Reynolds 1994). Most of the catch is obtained by artisanal boats working with nets (trammel and gill nets), hand lines and long lines. The European eel *Anguilla anguilla*, though is known to inhabit brackish lagoons scattered along the Libyan coast, is not common in the catch.

Umm Hufayan (or Zawiyat Umm Hufayan as it is sometimes called) is a brackish water lagoon within the Gulf of Bomba on eastern Libya Mediterranean coast, which is characterized mainly by a rocky shoreline and sandy beaches (Reynolds *et al.* 1995).

The family Anguillidae (eels) consists of 15 species worldwide, only a single species, *Anguilla anguilla*, occurs in the Mediterranean sea (Golani *et al*. 2006). *A. anguilla* spawns in the Sargasso Sea in the Caribbean at depths of 100 – 450 m (Rossi 1976). The transparent leaf like larvae, known as *Leptocephalus*, drift for 1-3 years with the Gulf Stream to reach the European coasts as glass eel and an additional year to reach the Mediterranean shores (Albert *et al.* 2006) as elver eels that enter coastal fresh water streams, creeks and brackish lagoons (upward or riverward migration). After few years residence in the fresh or brackish water they grew to silver eels that return to sea (downward or seaward migration) in order to come back to the Sargasso Sea for reproduction.

The IUCN status of *A. anguilla* is: critically endangered (Jacoby & Gollock 2014). Since the 1970s, the numbers of eels reaching Europe is thought to have declined by around 90% (possibly even 98). Eel farming is responsible for over 90% of all *Anguilla*production worldwide (averaging at 280 000 tons per year since 2007; FAO 2013).

Objective of the present study

Anguilla anguilla is critically endangered. Artificial breeding is very difficult, since eels are generally only able to reproduce after having swum a distance of 6,500 km (Integrated Taxonomic Information System 2006). A strong interaction between swimming and sexual maturation is expected (Palstra & van den Thillart 2010). Therefore, all studies concerning this species are important for planning conservation and revival measures. Despite the importance of eel as future potential farm fish in eastern Libya, little is known about its biology in the region. Therefore, the general objective of the present study is to avail basic information on some aspects of the ecology and biology of *A. anguilla* in eastern Libya. The specific objectives are to determine:

- Some environmental parameters of the eel habitat in Umm Hufayan, a brackish water lagoon on eastern coast of Libya typical of those found scattered along the coast and house significant population of eel that is commercially exploited.
- Major characteristic of fish and eel fisheries in the lagoon
- Length-weight relationship.
- Condition factor
- Seasons of the upward and downward migration of the eel to and from the lagoon

MATERIAL AND METHODS

Characteristics of eel habitat

Umm Hufayan is a brackish water lagoon located in the Gulf of Bomba at latitude 32° 33' 13.5" N and longitude 23°05' 57.2" E about 80 km east of Darna in direction of Tobrok (Figs. 1 and 2). It is a long cove, its length is 2 km and width1 km wide, and covers a surface area of about 2 Km^2.

The lagoon is shallow with depth ranging from 0.5 to 3 m. It is connected to the open sea by a gate sized about 0.5 Km, through it seawater enters the lagoon at high tide. Underground springs of semi fresh water (salinity about 11‰) discharge in the inner side of the Lagoon. Large "wadies" (seasonal streams) also discharge in the lagoon during autumn.

The lagoon contains several plants and algae, which serve as a protective, breeding, feeding and nursery site for several commercial fishes, such as those of the families Sparidea, Mugilidae, Serranidae and Carangidae. In particular the common reed, *Phragmites communis*, surrounds the inner sides of the lagoon and provides shelter, food for some fish species including *A. anguilla*. The beaches of the lagoon are nesting sites for turtles and feeding and resting sites for marine and migratory birds.

Fish and eel fisheries in Umm Hufayan lagoon is an important artisanal fishing ground on eastern Libyan Mediterranean Sea (Badalament 2011, Reynolds *et al*. 1995). The lagoon is rented by the government to a fisherman (the one who provided the eel samples) who capture fish and eels from it. It is rich in fish but the fishery is a small scale artisanal one with this fisherman and his colleagues using small wooden boats of two kinds: batah and flouka. Trammel nets, gill nets, lines and traps are the most common fishing gear. Daily fish production ranges between 30 to 200 kg and is composed mainly of introduced mixed Tilapias, *Lithognathus mormyrus* (Sparidae), Mugilidae species and *Sparus aurata* (Sparidae). The ability of different Tilapia species to survive in this brackish lagoon (salinity range = 20.1 to 27.7‰), reproduce and build up viable population that is commercially exploited is of great interest and will be a subject of further research by the authors.

Eels are captured from the lagoon by pound nets when they are leaving the lagoon during their seaward migration. Few nets would be set up in strategic sites within the lagoon at the onset of the exiting season. The gear is composed of a hedge or leader, which is a long straight net that leads intercepted eels towards the kill room (crib) where actual capturing takes place. Several units may be used. Eel production during the season ranges between 700 to 900 kg, and is bought by wholesaler with price from 20 to 25 Libyan Dinar/kg. The production is exported to Tunisia, then to Europe.

Two factors of greatest concern to the habitat of the lagoon and to the owner of the lagoon were observed during our visits: the regular spatial and temporal use of explosives as a common mean of fishing (illegal but practiced without fear) in Gulf of Bomba, and the excessive hunting of marine and migratory birds. In a transect 100m long, 2m wide along the lagoon shore, the authors counted 461 empty cartridges that were used in this year and in the past years. Hunters' huts and artificial lures erected to attract flying birds to set on were common along the shore.

During study period, the followings were taken monthly:

- Surface water temperature, salinity and dissolved oxygen concentration were measured using a portable probe sensor and recorded.
- Information about fish and eel fisheries in the lagoon was collected through sighting, direct observations and discussion with the owner (renter) of the lagoon.

Determination of seasonal eel movement in in the lagoon

This information was provided by the owner of the lagoon who has been in the business of catching fish and eels (during their seaward migration) from the lagoon for more than thirty years.

Collection of eel samples

Monthly random samples of eels *Anguilla anguilla* (Linnaeus 1758) were obtained from Umm Hufayan lagoon, from January to December 2015. The numbers of eel samples were 205 specimens. Eel samples were kept in ice box and transported to the Laboratory for further examination.

The laboratory Studies

In the laboratory, the eels were identified as *A. anguilla* according to Golani *et al*. (2006). Total length in cm and corresponding total weight to the nearest 0.1 g were obtained

for individual eels. Then, the eels were dissected and alimentary tracts and gonads were removed from the body cavity, then gutted weight was obtained to the nearest 0.1 g for each eel.

Estimating Length-Weight relationship for studied eels

Length-Weight relationship was determined according to Beckman (1948): $\mathbf{W} = \mathbf{a}L^{\mathbf{b}}$, where **W** is the total weight (g), **L** is the total length (mm), **b** is the coefficient of allometry, also called the slope of the regression line (usually varies between 2.5 and 4 in different fish species) and **a** is a constant, the point of intersection of the regression line with the Y-axis.

Estimating condition factor for studied eels

Condition factor were determined according to Fulton (1902) – K_f - and Clark (1928) – K_c - respectively:

$\mathbf{K_F} = 100*\mathbf{W}/\mathbf{L}^3$, where: **W** is the total weight (g) and **L** is the total length (mm).

$\mathbf{K_C} = 100*\mathbf{G.W}/\mathbf{L}^3$, where: **GW** is the Gutted fish weight (g) and **L** is the Total length (mm).

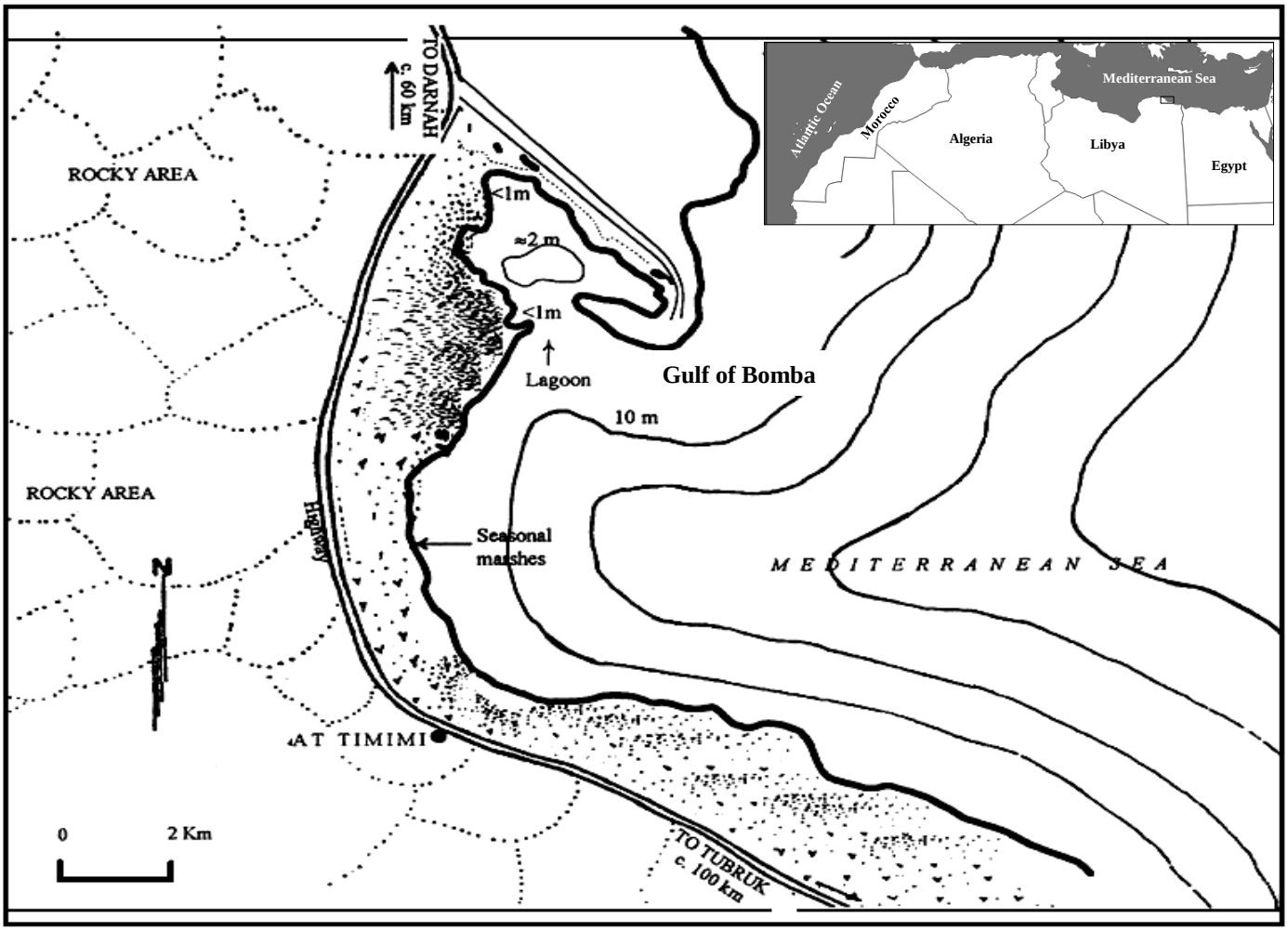


Figure 1. Gulf of Bomba in which Umm Hufayan lagoon is located. Source: Adapted from IAC (1981) by Reynolds *et al*. (1995).

Figure 2. Umm Hufayan lagoon (Google earth 2017).

RESULTS AND DISCUSSION

The environmental parameters

Results of temperature, salinity, and dissolved oxygen in the lagoon were: maximum temperatures were 28.7°C in summer and 23.8°C in autumn, whereas minimums were 13.6°C in winter and 18.4°C in spring.

The maximum salinities were 27.7‰ in summer and 25.9‰ in autumn, whereas minimums were 20.1‰ in winter and 21.3‰ in spring. The maximum dissolved oxygen concentrations were 12.9 mg/L in autumn, 11.7 mg/L in winter and 11.3 mg/L in spring whereas the minimum concentration was 9.3 mg/L in summer (Tab. 1).

Table 1. Average seasonal surface water temperature, salinity and dissolved oxygen in Umm Hufayan lagoon (January to December 2015). ***Minimum Values; **Maximum Values***

Season	Temperature (°C)	Salinity (‰)	Dissolved oxygen (mg/L)
Winter	13.9*	20.1*	11.7
Spring	18.4	21.3	11.3
Summer	28.7**	27.7**	9.3*
Autumn	23.8	25.9	12.9**

Seasons of eel migration in lagoon

From observations of the owner, the fisherman who captures fish and eels from the lagoon, the seasons of entry of juvenile eels to the lagoon and of exiting of migrating eels from were as follows:

The season of entering is spring, around mid-April, roughly between days 10 to 24. In the present study, this was found to correspond to a temperature of 18.4°C, a salinity of 21.3‰, and dissolve oxygen of 11.3 mg/L. Entering elver eels ranged in length from 10 to 15 cm and in weight from 70 to 80 g.

The season of exiting is winter, from the beginning of October to the beginning of February, in the present study the climax was around mid-December, when temperature was about 13.9°C, salinity 20.1‰ and dissolve oxygen 11.7 mg/L. Exiting silver eels ranged in length from 50 to 70 cm corresponding to weights of 600 g and more, occasionally up to 4 kg.

Porcher (2002) stated that unlike other migratory species for which upstream movement in a watercourse involves migration of adults for breeding purposes, the progression of eels upstream in a watercourse is for colonization purposes and involves the juveniles of the species (elvers and small yellow eels). The migratory activity of small eels is seasonal. It coincides with the period of warmer temperatures every year (April-September, maximum activity between May and July) and allows the migrators to progressively colonize the whole catchment area. Downstream migration affects sub-adults as they become sexually mature.

Kucuk *et al.* (2005) found that the entry season for *A. anguilla* Elvers in Gozlen Creek, Turkey, was between February and July. Pecorelli *et al*. (2013) reported that the upstream freshwater migration of *A. anguilla*, starts in mid to late April each year on the River Thames. Acou *et al*. (2009) established that young pigmented *A. anguilla* elvers (total length 133.7 ± 29.6 mm) were recruited in eel-passes in a small coastal catchment in the Frémur River, north-west France, from February to October, but the main runs followed a modal curve from April to September with a peak centered in May to June.

The silver eel descent of the watercourse generally occurs in autumn (e.g. Bertin 1951, Klein Breteler *et al*. 2007). In Ulla River, NW Spain, silver *A. anguilla* eels move downstream mainly in autumn, with a peak in October, while yellow eels move downstream in summer, with a peak in June/July (Cobo *et al*. 2014). Macnamara (2014) reported that silver *A. anguilla* migration from Vistonis Lake, Northern Aegean Sea, Greece, typically occurs between October and March.

Length Weight relationship

Total length of the studied eels ranged from 23.1 to 44.4 cm corresponding to total weights of 199.9 to 2922.9 g. The owner of the lagoon however, mentioned that lagoon eels sometimes reach up to 70 cm long and occasionally weigh up to 4 kg. *A. anguilla* can reach a length of 133 cm TL (female) in exceptional cases, but are normally around 60–80 cm. Maximum female weight can be 6.6 kg, and for a male 2.8 kg (Verreycken *et al*. 2011, Dekker *et al*.1998, Babick & Peffer 1993, 1998, Bauchot 1986, Deedler 1984). Length-Weight relationship of *A. anguilla* in the present study was (Fig. 3):

$W=0.0159*L^{3.2276}$, n=205, $R^2=0.9651$ where L=Total length, and W=Total weight.

R^2 value (0.9651) reveals a strong correlation between length and weight. The fit was highly satisfactorily and the values observed and calculated were close. The calculated slope "b" (b = 3.2276) indicates positive allometric growth indicating that the habitat is favorable.

There are few published works on length-weight relationship and condition factors of eel fish (Boetius 1976, Tesch 1978, Deelder 1984, Dekker *et al*. 1998, Tsukamoto & Arai 2001). A number of factors are known to influence the length weight relationship in fishes including growth phase, sex, size range, temperature and preservation techniques (Clark 1928).

Beckman (1948) mentioned that the coefficients of length-weight relationships were different not only between species but sometimes between stock of the same species due to sex, season and maturity stage. When the values of b equal 3, the growth is called isometric i.e. close to the predicted theoretical where length and weight increase during growth by similar ratios, if b is less or more than 3 the growth is described as –ve or +ve allometric. Length weight relationship is important in fisheries; many fisheries and growth models incorporates it.

Boulenger *et al*. (2015) estimated the length–weight relationships of the silver *A. anguilla* in six countries (13 catchments) along the latitudinal gradient in the area of distribution as $W=0.0010\ L^{3.148}$. Piria *et al*. (2014) stated that b ranged between 2.5959 and 2.8155 for adult *A. anguilla* in Karstic rivers in Croatia. Length/weight relationship for wild *A. anguilla*, collected from a Danish stream in May 1989 was: $W=1.0^{-10}L^{385}$ (Bisgaard & Michael 1991). Prior to release (October 1990), the length/weight relationship determined from cultured eels was: $W=7.8\ 10^{-4}\ L^{3.22}$. The relationship between length (L_t) and total weight (W_t) for *A. anguilla* in Aveiro Lagoon, Portugal was established by Gordo & Isabel (1991) as: $W_t = 0.000619\ L_t^{3.281}$, W_∞=3168 g. Kucuk *et al*. (2005) examined 3 different groups of *A. anguilla* in Gozlen Creek: group I; 0.166±0.007 g, group II; 0.392 ± 0.02 g, group III; 0.800 ± 0.06 g. Average total length (L) group I; 56.16 ± 0.06 mm; group II; 64.39±0.11 mm and group III; 82.02 ± 0.18 mm. The length-weight relation of elvers was determined as follows: group I; $W=0.0020*L^{2.5327}$, group II; $W=0.0015*L^{2.9516}$, and group III; $W=0.0023*L^{2.7090}$. Dulčić & Glamuzina (2006) found high value of b (3.470) for eels from estuarine system of the River Neretva (the Adriatic Sea drainage area). Glamuzina *et al*. (2008) mentioned that b value for eels from the Hutovo Blato Wetland was 2.843. Costa-Dias (2010), studied ecology and trophic dynamics of *A. anguilla* in two northwestern Iberian estuaries. Length-to-mass relationships were explored in the log-linear form: Log (mass, g)=a+b Log (length, mm) where a, and b are constants. a ranged between -5.37 to -6.13, b between 2.58 to 2.9. Macnamara *et al*. (2014) reported that *A. anguilla* migrating from Vistonis Lake, Northern Aegean Sea, Greece, had body length – body weight relationship described by the equation:

$\log_{10}$ body length = (0.290 x log10 body weight) + 2.015.

The length-weight relationship for the same species in the English Chalk stream was described by Burnet (1952): a=0.0166 and b=3.111. In the present study the value a was 0.0159 and b=3.2276. The positive allometric growth indicates that the lagoon is a very good habitat for the growth of *A. anguilla*.

Condition factors (K_F and K_C)

The monthly average values of the condition factors K_F and K_C for *A. anguilla* were illustrated in (Fig. 4). The factors recorded highest values in spring and summer where the values in March were (K_F=4.037 and K_c=3.34), April (K_F=4.12 and K_c=3.76), May (K_F=4.33 and K_c=3.98), June (K_F=4.11 and K_c=3.77), July (K_F=3.98 and K_c=3.06) and August (K_F=3.78 and K_c=2.88).

Le Cren (1951) indicated that monthly variation in the condition factors is affected by feeding activities which may show their reflection on the body condition. The highest condition factor values obtained in the present study were recorded in spring and summer which coincided with high feeding intensity of the target species due to the food availability.

Simon (2007) found that for yellow female *A. anguilla*, 21.6–66.2 cm long, in six lakes in the River Havel system, Germany, the condition and the growth rate varied between eels within single lakes and between lakes. Fulton's condition factor ranged from 0.10 to 0.24. These were consistent with the values observed in eels in Lake Võrtsjärv, Estonia in 1998 by Kangur & Kangur (0.16–0.24) and Jörgensen (1988) for yellow eels in the upper River Havel (0.149 – 0.212).

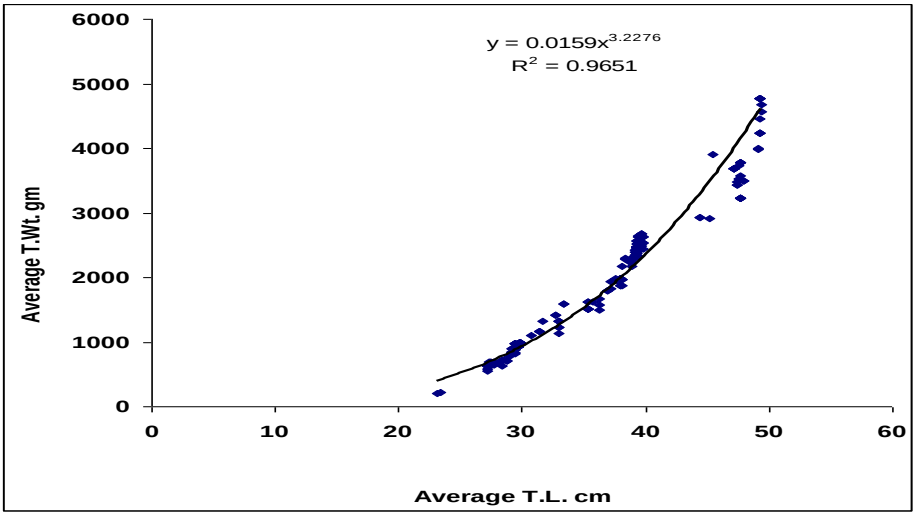
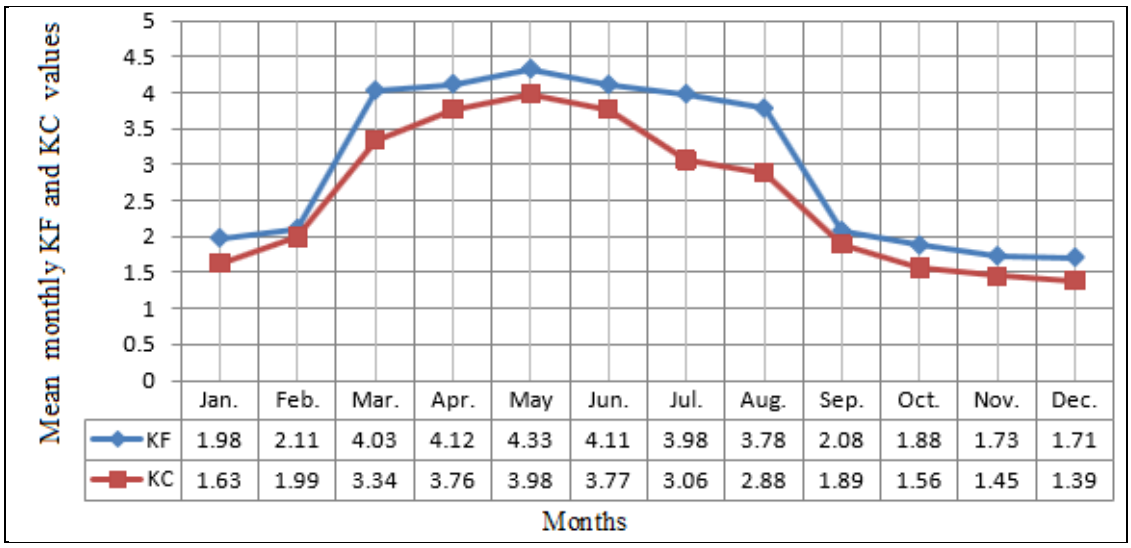


Figure 3. Length-Weight relationship for *A. anguilla* from Umm Hufayan lagoon.



	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
KF	1.98	2.11	4.03	4.12	4.33	4.11	3.98	3.78	2.08	1.88	1.73	1.71
KC	1.63	1.99	3.34	3.76	3.98	3.77	3.06	2.88	1.89	1.56	1.45	1.39

Figure 4. Monthly variations in K_F and K_C condition factors of *A. anguilla* in Umm Hufayan lagoon from January to December 2015.

Costa-Dias (2010) reported that the condition factor of *A. anguilla* (10 to 34 cm) at the upper-most La Viella site in the Iberian Peninsula (K=0.78) increased slightly at intermediate sites (Chanona, K=0.82; Choudral, K=0.80) to maximize in the estuary (K=0.90). Eels with 2, 3 and ≥ 4 parasites exhibited higher condition (K=0.86-0.88) than eels with only one or no parasite (K = 0.82).

Van Liefferinge (2012) showed that *A. anguilla* caught in the Lippenbroek, Belgium (K': 0.0665 ± 0.008; K": 1.11±0.14) seemed to be in better condition than eels caught in the River Schelde (K': 0.0625±0.012; K": 1.04±0.19). Macnamara *et al.* (2014) obtained a condition factor range of 0.202 to 0.292 for female silver *A. anguilla* migrating from Vistonis Lake, Northern Aegean Sea, Greece. Haenen *et al.* (2010) studied the health status of European silver eels, *A. anguilla*, in the Dutch River Rhine Watershed and lake Ijsselmeer. They concluded that the silver eels of this river had a proper Fulton condition factor (values 2.0 to 2.26 which were close to the values obtained in the present study (K_F: 1.71 to 4.33; K_C: 1.30 to 3.98).

CONCLUSION

Umm Hufayan is a brackish water lagoon typical of those found scattered along eastern Libya Mediterranean Sea and harbors significant populations of *Anguilla anguilla.* Total length of the studied eels ranged from 23.1 to 44.4 cm, corresponding to total weights of 199.9 to 2922.9 g. The Length (L)-Weight (W) relationship was: $W = 0.0159*L^{3.2276}$. The highest values of Fulton (K_F) and Clark (K_c) condition factors were recorded for spring and summer.

Maximum temperatures of surface water in the lagoon were 28.7°C in summer and 23.8°C in autumn, whereas minimum

temperatures were 13.6°C in winter and 18.4°C in spring. Maximum salinities were 27.7‰ in summer and 25.9‰ in autumn, whereas the minimums were 20.1‰ in winter and 21.3‰ in spring. Dissolved oxygen concentrations were 12.9 mg/L in autumn, 11.7 mg/L in winter, 11.3 mg/L in spring and 9.3 mg/L in summer.

Elver eels entered the lagoon from sea in spring when average surface water temperature was around 18.4°C, salinity: 21.3‰ and dissolve oxygen: 11.3 mg/L. Migrating silver eels exited the lagoon to sea in winter when the average temperature was around 13.9°C, salinity: 20.1‰ and dissolve oxygen: 11.7 mg/L.

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