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Estimation of Energy Budget for Gonadal Development, Migration and Spawning of eels (*Anguilla anguilla* L.) inhabiting the Egyptian Lagoons

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ABSTRACT. The total body energy stores of European silver eel (*Anguilla anguilla* L.) at the start of migration is sufficient to fulfill all biological activities which begin with active migrations. We used a slightly modified model to evaluate the energy budget of eel during gonadal development, migration and spawning.

Lipid and protein are the main energy components of eel body; lipid is the principal source and protein represents the second source of energy. Lipid energy, as a percentage of total energy, was 58.2 for male and 67.9 for female yellow eels. These values were smaller than those calculated for male (76.3) and female silver eels (80.1).

Lipid energy of immature testes amounted to 72.5%, while immature ovaries contained 83.9%. Further gonadal development showed an increase in lipid energy up 80.3% at time of formation of spermatozoa in the ripe male and 86.4% at the time of ripe ova in the female ovary.

About 25.1% and 20.3% of the total energy expenditure seemed to be utilized in oogenesis and spermatogenesis, respectively. Approximately 17.1 and 15.8% of total energy was utilized for ovulation and spermiation, respectively. During migration and simultaneous routine metabolism (E_R) about 35.7 and 34.2% of the total energy was utilized by female and male silver eels, respectively. The energy of routine metabolism was higher in male than in female silver eel, with values of 9.6% and 6.0%, respectively.

Spawning migration and gonadal development by migrating silver eel (*Anguilla anguilla* L.) requires endogenous reserve sources of energy, since during migration the eels are totally fasting.

There is no conflict that prior to migrating, the silver eel is a fatty fish (Love 1970, Amin 1984). Deposition of fat takes place in most of the organs (Amin 1984). Lipid and protein are considered as major sources of energy for migration and gonadal development (Boetius and Boetius 1980).

For the study of energy cost during the starved migration of silver eel, several varying parameters such as temperature, distance, swimming speed and oxygen consumption, are prerequisites. Davidson (1949) reported that the swimming speed increases with current rate, and the eels 7 cm long swimming almost twice as rapidly as salmon 3.5 cm long. Brett *et al.* (1958) demonstrated that the optimum cruising speeds occured at 15°C, for sockeye and at 20°C for coho, maximum sustained levels fell mainly between 30 and 45 cm per second. Brett (1964) reported that the greatest scope for activity of young sockeye salmon occured at 15°C with an average active metabolic rate of 895 mg O_2/kg/h for a swimming speed of 4.1 body lengths per second, just maintained for 1 hr. Above 15°C active metabolism was limited, apparently by oxygen availability. Ellis (1966) recorded that swimming speeds for salmon based on water velocity, the range of sustained swimming speeds usually exhibited was 0.9-1.7 body lengths L/sec (1.75-3.18 ft/sec) for both sockeye and coho. The maxima in these ranges agree with the values obtained earlier at 1.7 body lengths L/sec (3.4 ft/sec). Yuen (1966) observed that, swimming speeds of tunas ranged from 0.5 to 14.4 body lengths per second (0.3 to 6.9 m per second).

Unpublished data of Holmberg and Sainders, from Schmidt-Neilson (1972), showed that the energy cost of locomotion of yellow eel (mean weight, 238 g) and silver eel (mean weight, 248 g) ranged from 0.329 to 0.417 cal/g/km at a swimming speed ranging from 35 to 65 cm/sec. Galaktionov (1978) reported that the swimming speed of silver eel, during its migration in the Kurisk Bay, ranged from 0.8 to 0.9 km/h. Boetius and Boetius (1985) reported that during starvation of male silver eels, calculations of energy loss from lipid or protein (cal/kg/day) showed that the two energy reserves are mobilized in such a way that they contribute almost equally to the total metabolism. During the entire period of starvation the energy released from lipid surpasses that of protein.

The present study was undertaken to assess the amount of energy required for migration and sexual development of migrating male and female silver eels.

Materials and Methods

A total of 100 live specimens each of yellow eels (not ready for the current spawning migration) and silver eels (ready for the current spawning migration) were taken from the commercial catch in lake Edku (northern Egypt) during the period August, 1986 to March, 1987. Induction of gonad maturation was carried out on 30 silver eels, using human chorionic gonadotropin hormone (HCG) and carp pituitary injections to induce their gonad maturation (Fontaine *et al.* 1964, Yamamoto *et al.* 1974, Kokhnenko *et al.* 1977, Boetius and Boetius 1980, Amin 1986, 1988). These treated specimens were also used after attaining a certain stage of induced gonadal maturation.

Contents of water, lipid, protein and ash in the muscles, liver, skin, intestine, bones (vertebrae) and gonads were determined. Seventy fresh samples of the organs were weighed and dried at 80°C to a constant weight before being ground. A solvent mixture of chloroform-ethanol (2:1) was used for fat extraction by Soxhselt apparatus. Nitrogen was determined by the Kjeldahl technique and derived values were multiplied by 6.025 to provide protein content. Ash was determined by ignition of dried samples in an electric muffle furnace at 600°C.

Total energy content of fish bodies was defined as the sum of lipid and protein energies. Energy content of lipid and protein were calculated using factors of 38.9 $\times 10^3$ J/g and 17.2 $\times 10^3$ J/g, respectively, for converting lipid and protein into Joules (J). The model of Boetius and Boetius (1980) expressing such energies was adopted:

$E_T = E_G + E_{Loss} + E_S + E_{M1}$, where

E_T is the eel's total amount of energy at the start of the experiment.

E_G is the energy stored in the gonads during the experiment.

E_{Loss} is the energy lost during the experiment.

E_S is the energy residue in the eel's spent body after having spawned in the breeding area.

E_{M1} is the energy left available for migration activities at the end of experiment.

Oxygen consumption was determined at 15 and 26°C in a respiration apparatus as described by Jones (1947) to estimate the energy of routine metabolism (E_R) of male and female silver eels.

Results

I—Biochemical analysis of body

Lipid contents in the body of both male and female increased gradually in yellow eel and sharply in silver eel (Table 1). Protein and ash, on the other hand,

Table 1. Initial composition in whole eels and utilization of their main biochemical components

Sex	Avg. body length		Avg. body weight		Percentage composition										Avg. total energy		Avg. lip energy in percent of total energy	
					water		lipid		protein		ash		residue					
	cm	moving avg.	g	moving avg.	w	moving avg.	l	moving avg.	p	moving avg.	a	moving avg.	r	moving avg.	J/kg	moving avg.	%	moving avg.
yellow ♂	20.0		20.0		69.0		10.0		18.5		1.01		4.0		7.08		54.90	
yellow ♂	22.0	21.0	25.0	22.5	67.5	68.2	10.5	10.2	19.1	18.8	1.11	1.06	4.5	4.2	7.38	7.59	55.42	55.16
yellow ♂	24.0	23.0	26.0	25.5	65.4	66.4	10.8	10.6	19.5	19.3	1.05	1.08	4.3	4.4	7.55	7.47	55.63	55.53
yellow ♂	26.0	25.0	31.0	28.5	63.0	64.2	13.5	12.1	20.1	19.8	1.07	1.06	5.1	5.0	8.72	8.14	60.21	57.92
yellow ♂	28.0	27.0	33.0	32.0	63.0	63.0	14.1	13.8	20.0	20.0	1.05	1.06	5.0	5.0	8.92	8.82	61.43	60.82
yellow ♂	30.0	29.0	35.0	34.0	57.1	60.0	14.3	14.2	20.1	20.0	1.10	1.08	5.0	5.0	9.02	8.97	61.64	61.54
yellow ♀	30.0	30.0	40.0	37.5	57.2	57.1	16.1	15.2	20.0	20.0	1.11	1.11	5.3	5.1	9.66	9.34	64.39	63.02
yellow ♀	32.0	31.0	48.0	44.0	58.7	57.9	18.8	17.4	20.5	20.2	1.11	1.11	5.5	5.4	10.84	10.25	67.44	65.92
yellow ♀	34.0	33.0	50.0	49.0	58.0	58.3	18.5	18.6	20.0	20.2	1.01	1.06	4.9	5.2	10.64	10.74	67.67	67.56
yellow ♀	36.0	35.0	66.0	58.0	55.5	56.7	23.5	21.0	20.5	20.2	1.07	1.04	5.3	5.1	12.67	11.66	72.14	69.91
silver ♂	36.0	36.0	86.0	76.0	46.4	50.9	28.6	26.0	20.6	20.5	1.18	1.13	4.9	5.1	14.67	13.67	75.87	74.01
silver ♂	38.0	37.0	107.0	96.0	45.6	46.0	28.6	28.6	20.5	20.5	1.16	1.17	4.6	4.7	14.66	14.67	75.92	75.90
silver ♂	40.0	39.0	110.0	108.0	46.0	45.8	28.5	28.5	20.4	20.4	1.16	1.16	4.5	4.5	14.59	14.63	75.94	75.93
silver ♂	42.0	41.0	139.0	124.5	44.9	45.4	29.5	29.0	19.9	20.1	1.15	1.15	5.0	4.7	14.90	14.75	77.05	76.50
silver ♂	44.0	43.0	142.0	140.5	45.0	44.9	29.0	29.2	19.8	19.8	1.13	1.14	5.0	5.0	14.69	14.80	76.79	76.92
silver ♀	54.0	49.0	326.0	234.0	40.5	42.7	33.0	31.0	20.0	20.0	1.14	1.14	5.4	5.2	16.28	15.49	78.87	77.83
silver ♀	58.0	56.0	350.0	338.0	41.0	40.7	33.0	33.0	20.0	20.0	1.15	1.15	5.5	5.4	16.28	16.28	78.87	78.87
silver ♀	68.0	63.0	600.0	475.0	42.4	41.7	34.5	33.7	19.6	19.8	1.13	1.14	5.8	5.6	16.71	16.50	79.83	79.35
silver ♀	70.0	69.0	800.0	700.0	41.0	40.5	34.8	34.6	19.0	19.3	1.13	1.13	6.0	5.9	16.69	16.70	80.41	80.12
silver ♀	72.0	71.0	650.0	720.0	40.0	40.5	34.3	34.5	19.0	19.0	1.11	1.12	5.9	5.9	16.61	16.65	80.31	80.36
silver ♀	74.0	73.0	850.0	745.0	41.1	40.5	34.5	34.4	19.0	19.0	1.12	1.12	5.7	5.8	16.69	16.65	80.41	80.36
silver ♀	76.0	75.0	824.0	837.0	40.0	40.5	33.5	34.0	18.8	18.9	1.11	1.12	5.5	5.6	16.26	16.48	80.14	80.28
silver ♀	78.0	77.0	1060.0	942.0	40.0	40.0	33.8	33.6	18.5	18.6	1.11	1.11	5.6	5.5	16.33	16.30	80.53	80.34

were deposited at the same rate. Percentage of the remainder (R) varied from 4 to 6 with an average of 5.1.

The calculated total energy of male yellow eel ranged from 7.08×10^6 to 9.02×10^6 J/kg with an average of 8.11×10^6 J/kg. The average total energy of male silver eel was extremely higher than that of male yellow eel (8.11×10^6) and amouned to 14.70×10^6 J/kg. The average percentage lipid energy of the total energy increased from 58.2 to 76.3, while average percentage protein energy of the total energy decreased from 41.3 to 23.7.

Female yellow eel was found to contain a total energy content of 10.95×10^6 J/kg, whereas the female silver eel contained 16.51×10^6 J/kg. The average lipid energy as a percentage of the average total energy was 67.9% in the female yellow eel and 80.1% in the female silver eel. The protein energy as a percentage of the total energy was higher in the female yellow eel (32.1) than in the female silver eel (19.9).

The percentages of lipid derived from muscles and liver of silver male eel were previously estimated as 72.2 and 27.7 respectively, whereas the contribution of lipid in females was mainly comming from muscles which contributed 76.4%, whereas liver contributed 23.7 (Amin 1984).

In Fig. (1), it was obvious that the lipid energy started to be formed when the eel was still yellow and increased with the initiation of the spawning migration. Silver males were found to attain their maximum lipid energy at smaller lengths than females.

In Fig. (2), lipid and water contents are represented. Similar contents are often found in fatty fish. Accumulation of lipid is mainly in the muscles of eel (Love 1970, Amin 1984).

II—The total energy budget for maturation, migration and spawning

A — Male silver eel

The accumulated energy (J/kg) during the period of successive induction of the male silver eel differed with the degree of testicular development (Table 2). The total energy of the body was estimated to be 16.71×10^6 J/kg when the testes of induced male silver eels became nearly ripe after 35 days. At the same time, the lipid energy (as percentage of total energy) amounted to 81.4%. After 45 days the testes became completely ripe, the total energy of the body decreased to 8.36×10^6 J/kg and lipid reserve energy (as a percentage of total energy) also decreased to 72.3%.

Table 2. Total energy and percentage of biochemical components, water (W), lipid (L), protein (P), ash (A) and remainders (R), in the eel's body and testes through different stages of maturation

Body								Testes						
Av. weight g	No. of fish	W %	L %	P %	A %	R %	Total energy J × 10^6	Av. weight g	W %	L %	P %	A %	R %	Total energy J × 10^6
Immature stage														
110	20	45.0	28.0	20.5	1.13	5.4	14.45	0.06	75.7	10.5	9.0	0.7	4.1	5.57
Nearly ripe stage														
90	20	40.0	35.0	18.0	1.15	5.9	16.71	4.50	70.0	15.5	9.0	0.7	4.3	7.75
Ripe stage														
80	20	64.0	15.0	13.0	1.15	5.9	8.36	5.00	70.0	16.2	9.0	0.5	4.2	7.85
Spent stage														
60	20	77.6	9.0	1.18	1.18	3.0	5.05	0.05	84.1	4.0	7.0	0.7	4.0	2.76
Corr. Coeff.		0.86	0.77	0.97	0.97	0.69	0.82	Corr. Coeff.	0.85	0.68	0.58	0.64	0.67	0.88

On the other hand, the energy gained by immature testes after attaining the nearly ripe and completely ripe conditions was 5.57×10^6 J/kg and 7.85×10^6 J/kg, respectively. Percentage of lipid energy in testes increased from 72.5 to 80.3.

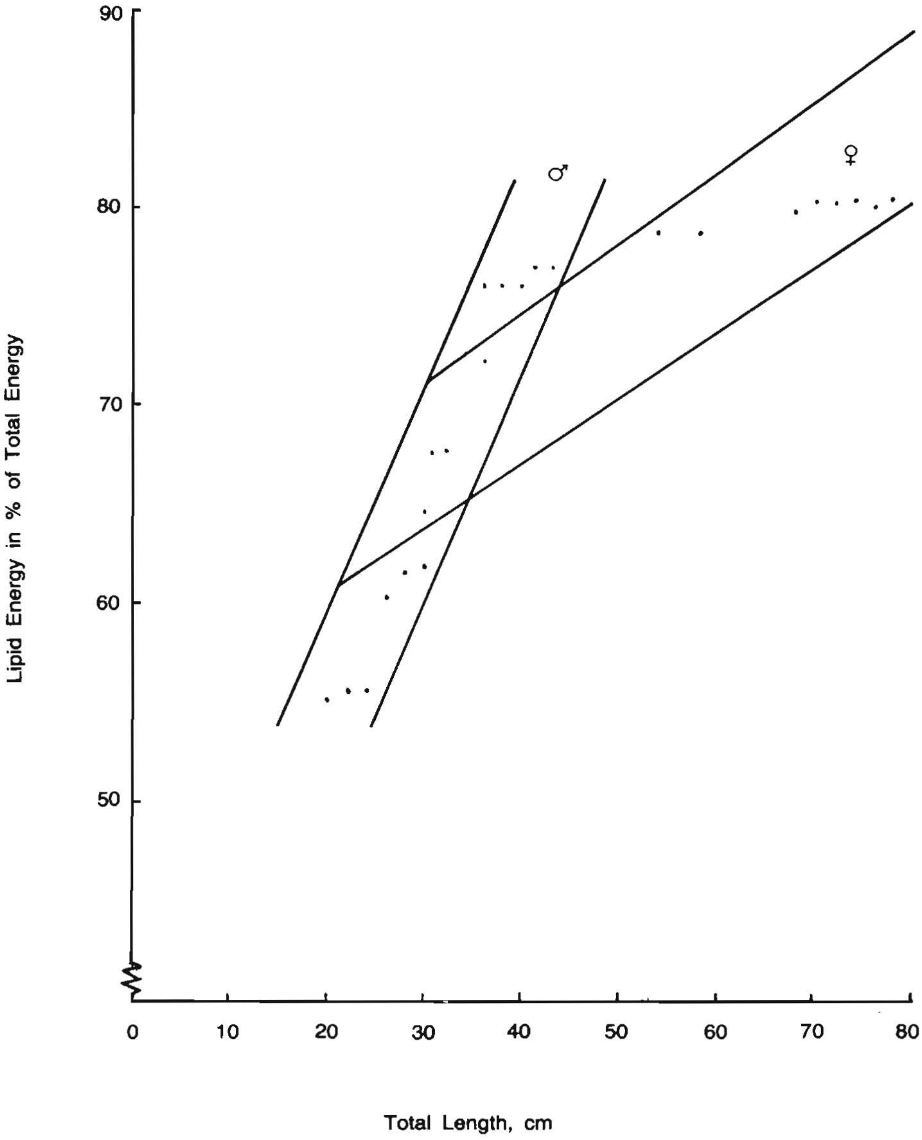

Fig. 1. Lipid energy in percentage of total energy plotted against total lengths.

In the spent condition, after the release of milt and the continuation of the period of starvation which extended to 85 days, the calculated total energy of the body of male silver eel was 5.05×10^6 J/kg and the lipid energy (as a percentage of total energy) was 69.3%. The energy of testes 'after spermiation' amounted to a minimum value of 2.76×10^6 J/kg and the lipid energy (as a percentage of total energy) was 56.4%.

The energies needed for gonadal maturation, spawning, routine metabolism and migration are derived mainly from the initial total energy (E_T) of silver eel at the start of migration. The value amounted to 14.45×10^6 J/kg.

In the following we tried to estimate relative individual energy pools, taking into consideration that the total initial energy (E_T) is equal to the sum of the pools and is thus fixed at 100%.

We modified the model of Boetius and Boetius (1980) to become:

$E_T = E_G + E_D + E_S + E_M$, where

E_D is the energy needed for gonadal development.

To estimate the amount of energy stored in gonads during maturation (E_G), we substracted the value of final energy of the gonad gained at ripe stage of gonadal maturation from the initial value of energy formed at the immature condition. The result was 2.28×10^6 J/kg (Table 3).

For the estimation of energy required for gonadal development E_D, we calculated the energy lost from the body during the experiment, *i.e.* during sexual maturation. This energy is equal to the sum of two energies, the energy of gonadal

Table 3. The determined values of the energies in gonads E_G and body E_B of ripe eels

Sex	E_T	E_G		E_B	
	$J \times 10^6$	$J \times 10^6$	% of E_T	$J \times 10^6$	% of E_T
♂	14.45	2.28	15.78	8.36	57.85
♀	16.11	2.75	17.07	8.88	55.12

development (E_D) and the energy of routine metabolism (E_R), as follows:

$E_{loss} = E_D + E_R$, where

$E_{loss} = 100 - (E_G + E_B)$, where

E_B is the energy of the body without gonads at ripe stage of maturation. The value of E_B was found to be equal to 8.36×10^6 J/kg or 57.8% of E_T (Table 3), therefore

$$E_{loss} = 100 - (15.78 + 57.85) = 26.37\%$$

The energy of routine metabolism (E_R) in the formula is often determined from rate of oxygen consumption. This rate increases with rise of water temperature and proportionally decreases with increasing body weight (Jones 1964, Matsui 1979). The mean oxygen uptake of acclimatized eels at a water temperature during the experiment of 26°C and at average body weight 110 g amounted to 61.23 mg O_2/kg/h. On conversion to energy units (1 mg O_2 = 13.3 J), the deduced value was 814.36 J/kg/h and over the developmental period, the routine metabolism (E_R) was estimated as:

$$E_R = 814.36 \times 45 \times 24 = 0.88 \times 10^6 \text{ J/kg}$$

$$= 6.09\% \text{ of } E_T$$

thence $E_D = 20.28\%$

To calculate E_S (the energy residue in the eel's spent body) from the obtained data in the laboratory; the resultant value of E_S as a percentage of E_T was 34.95% (Table 4).

Table 4. The determined values of energy in spent condition E_S and energy of gonadal development E_D

Sex	E_S		E_D	
	$J \times 10^6$	% of E_T	$J \times 10^6$	% of E_T
♂	5.05	34.95	2.93	20.28
♀	5.05	31.35	4.03	25.08

For the estimation of the energy of migration (E_M), we applied the modified formula adopted from the Boetius and Boetius model as follow:

$$\begin{aligned} E_M &= 100 - (E_G + E_D + E_S) \\ &= 100 - (15.78 + 20.28 + 34.95) = 28.99\% \\ &= 0.29 \times 14.45 \times 10^6 \text{ J/kg} \\ &= 4.19 \times 10^6 \text{ J/kg} \end{aligned}$$

This estimated value of E_M represents the energy of migration together with the value of routine metabolism within the time of the experiment.

B – Female silver eel

The induced female silver eel attained a nearly ripe condition of ovaries after 30 days, as illustrated in Table (5). The calculated total body energy at this stage of ovarian sexual maturation was to 18.66×10^6 J/kg. Lipid energy constituted 83.4% of the total energy. Forty days after induction the female ovaries became completely ripe (Fig. 3). Whence, the body energy decreased to 8.88×10^6 J/kg; consequently, the lipid fraction decreased to 70.9%. At the ripe condition, the energy gained by ovaries amounted to 15.48×10^6 J/kg, whereas the lipid fraction of ovary energy increased from 83.9 to 86.4%.

According to our modified model for the estimated energy budget (Table 3), the gonad energy (E_G) was calculated as 2.75×10^6 J/kg, constituting 17.1% of the initial total energy (E_T). The value of energy lost (E_{loss}) was estimated as 27.8%.

The average energy of routine metabolism (E_R) carried out by female silver eels (average weight 800 g) in sea water 26°C) was 456.19 J/kg/h, 34.3 mg O_2/kg/h. For calculation of E_R over the developmental time, we obtained the followings:

$$\begin{aligned} E_R &= 456.19 \times 40 \times 24 = 0.44 \times 10^6 \text{ J/kg, or} \\ &= 2.73\% \text{ of } E_T\text{, therefore} \end{aligned}$$

$$\begin{aligned} E_D &= E_{loss} - E_R \\ &= 25.08\%. \end{aligned}$$

The energy of spent fish (E_S) was impossible to be estimated in the laboratory because all induced females died after induction, therefore we used the previously obtained E_S of males which amounted to 31.35 of E_T of female silver eel (Table 4).

Table 5. Total energy and percentage of biochemical components, water (W), lipid (L), protein (P), ash (A) and remainders (R), in the eel's body and ovaries through different stages of maturation

Body								Ovaries						
Av. weight g	**No. of fish**	**W** %	**L** %	**P** %	**A** %	**R** %	**Total energy** J × 10^6	**Av. weight** g	**W** %	**L** %	**P** %	**A** %	**R** %	**Total energy** J × 10^6
Immature stage														
824	20	40.5	33.0	19.0	1.18	6.0	16.11	5.79	56.0	27.5	12.0	0.5	4.1	12.73
Nearly ripe stage														
830	10	34.5	40.0	18.0	1.16	6.2	18.66	110.0	50.0	33.0	12.2	0.4	4.4	14.94
Ripe stage														
855	10	61.5	16.2	15.0	1.16	6.2	8.88	150.0	48.5	34.4	12.2	0.4	4.4	15.48
Corr. Coeff.		0.92	0.89	1.0	0.65	0.65	0.91	Corr. Coeff.	0.96	0.96	0.89	0.89	0.89	0.96

The energy of migration (E_M), was deduced from the modified model as follow:

$$
\begin{aligned}
E_M &= 100 - (E_G + E_D + E_S) \\
&= 26.50\% \text{ of } E_T \\
&= 0.27 \times 16.11 \times 10^6 \\
&= 4.35 \times 10^6 \text{ J/kg}
\end{aligned}
$$

The theoretical covered distance during the 85 day experimental period was estimated at 2856 km, considering the speed of swimming was 1.4 km/h (35 cm/sec), according to Schmidt-Neilson (1972). The calculated energy of migration

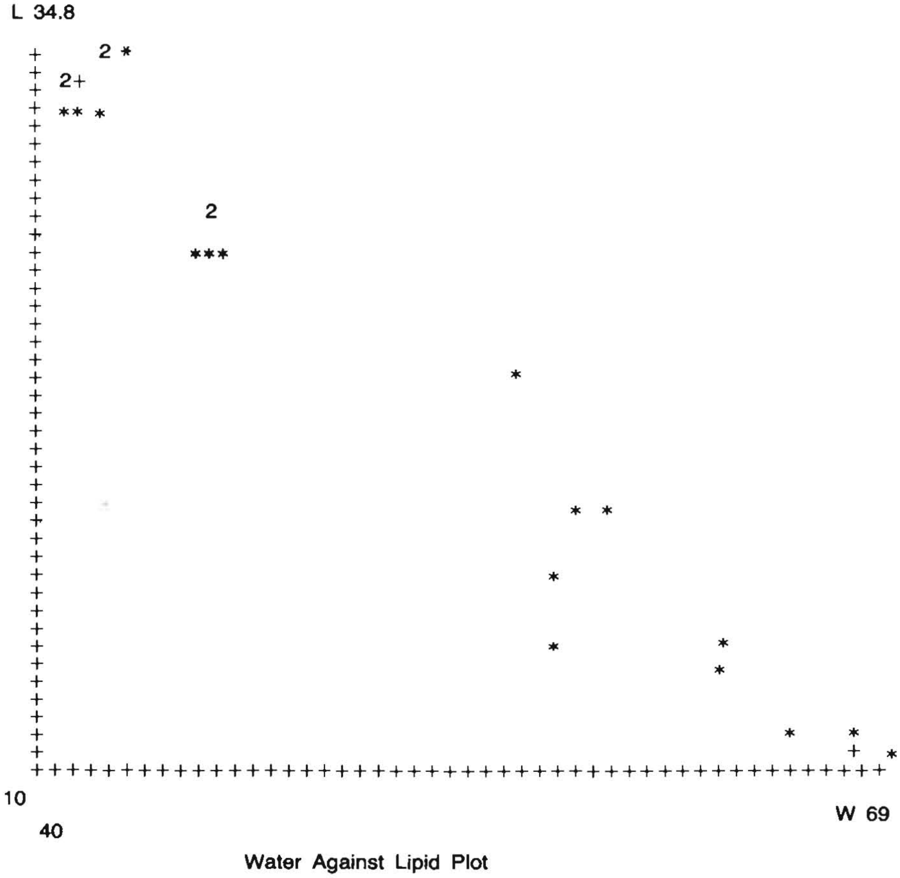

Fig. 2. Lipid-water relationship determined from data listed in Table 1.

E_M (without E_R) during the experimental period was estimated at 2.53×10^6 J/kg for males and 3.42×10^6 J/kg for females. Where such values were adjusted to fit the natural distance of migration (4000 km), E_M became 3.54×10^6 J/kg for males and 4.79×10^6 J/kg for females.

The respiration rate of eels at water temperature of 15°C was estimated at 36.43 mg O_2/kg/h for males and 25.32 mg O_2/kg/h for females. Changing to Joules over a natural migration time of 120 days, the values of routine metabolism became:

$$E_R = 36.43 \times 13.3 \times 120 \times 24 = 1.40 \times 10^6 \text{ J/kg for males}$$

$$E_R = 25.32 \times 13.3 \times 120 \times 24 = 0.97 \times 10^6 \text{ J/kg for females}$$

These values of E_R were added to the previously deduced values of E_M (estimated for the natural condition) to get the total energy of migration expected in the natural habitat, which is 4.94×10^6 or 34.2% of E_T for males and 5.76×10^6 J/kg or 35.7% of E_T for females.

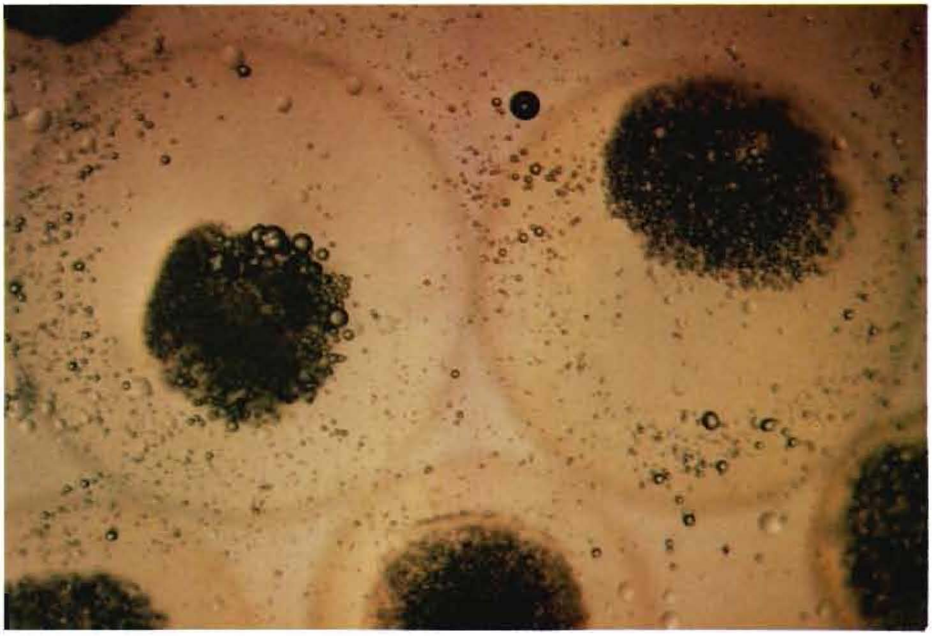

Fig. 3. A ripe eggs of the European eels *Anguilla anguilla* L.

Discussion

Utilization of lipids from the muscles during progressive spawning migration and starvation were suggested for several migratory fishes (Ando *et al.* 1985).

The change from yellow to the migratory silver eel is precisely accompanied with certain physiological events. It was proved that such changes extremely affect the body composition. To ascertain and estimate the selective mobilization of such energetic substances, the following assumptions were considered:

1. Dynamic accumulation of lipid in body eel increased with increasing growth (Amin 1979).
2. The muscle of *Anguilla anguilla* L. (especially in posterior body region) is the major source of lipid, also skeleton, skin, intestine, liver and gas bladder store fat but in lesser percentages (Amin 1984).

The most significant change is the increase of body lipid with increase of body energy during the period of maturation. This insures sufficient energy to exhaust during the long and tedious swim to the spawning grounds, whence the fish is completely fasted. Furthermore, gonadal development and consequent spawning share a considerable part of such energy.

The degree of loss in body lipid is shown to be greater in females than in males (Tables 2,5), this may suggest that maturation of gonads is responsible for the consumption of body lipid reserves, such difference may be attributed to the variations in both E_G and E_D in male and female silver eel. Precisely, the energy needed for ovarian maturation and thence for ovulation is greater than the energy destined to testicular maturation and spermiation (Kohnenko *et al.* 1977).

The mean values of metabolic rates at 15°C, *viz.* 25.3 mg O_2/kg/h and 36.4 mg O_2/kg/h for females and males increase rapidly above 15°C and amount to 34.3 mg O_2/kg/h and 61.2 mg O_2/kg/h for females and males at 26°C. These changeable levels of metabolism suggest the presence of limiting factor suspected as being oxygen consumption and body lipid used as energy source for different physiological processes.

According to the data of Schmidt-Nielsen (1972) the energy cost of locomotion of yellow and silver eels ranged from 0.329 to 0.417 cal/gm/km. On adjusting these data to our formulated parameters, *viz.*, joule (cal); weight (gm) of experimented male and female silver eels and distance (km):

0.329 to $0.417 \times 4.185 \times 110 \times 4000 =$
6.05×10^6 to 7.67×10^6 J/kg for male silver eel

0.329 to $0.417 \times 4.185 \times 824 \times 4000 =$
4.54×10^6 to 5.75×10^6 J/kg for female silver eel

According to such mathematical treatment, it may be concluded that the estimated energy of migration (E_M) for male and female silver eel is fairly consistent with the data of Schmidt-Nielsen (1972) and also with the results of Boetius and Boetius (1980) deduced for female silver eel. Therefore, the initial energy gained by either male or female at the start of migration is virtually sufficient to fulfill different biological activities expressed by active migration, gonadal development and furthermore spermiation or ovulation.

In addition to the estimated energy cost of migration (E_M) which is about similar to that estimated by the previously noted authors, we could estimate the energy left after spawning (E_S). The death of eels after completion of spawning, may have led to some underestimation. This assumption is further confirmed by the appearance of acute anemia in the blood of the silver eels fasted for five months and after developmental maturation (Amin 1990).

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تقدير الطاقة المبذولة لنضوج المناسل والهجرة والتوالد في ثعبان السمك الأوروبي في اللاجونات المصرية

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عند حساب كمية الطاقة الكلية المختزنة في جسم ثعبان السمك الأوروبي المستعد لهجرة التوالد وجدت أنها كافية للقيام بجميع العمليات البيولوجية اللازمة أثناء فترة الهجرة التي تعتبر من أشق وأطول الهجرات بين أنواع الأسماك على الإطلاق.

اعتمدت نتائج هذا البحث على التجارب التي أجريت لتفريخ ثعبان السمك في المعمل أثناء عمليات إنضاج الخلايا الجنسية في الاناث والذكور وشملت الثعبان الأصفر وهي أسماك لا تظهر عليها أعراض هجرة التوالد وأيضاً الثعبان الفضي وهي الأسماك التي اكتملت بها كل خصائص الهجرة.

يعتبر الدهن والبروتين أساس الطاقة في جسم السمكة وإن كان الدهن يمثل المصدر الرئيسي يليه البروتين كمصدر ثان للطاقة. من النتائج التي أمكن الحصول عليها أن متوسط الطاقة الكلية المختزنة لذكور الثعبان الأصفر هو ٨,١١ × $١٠^{٦}$ جول/كجم، في حين زادت هذه القيمة بمعدل كبير في الأسماك الفضية لتصل إلى ١٤,٧٠ × $١٠^{٦}$ جول/كجم، وأن نسبة الطاقة المستمدة من الدهن بالنسبة للطاقة الكلية المختزنة في الجسم هي ٥٨,٢ ٪ للأسماك الصفراء غير المهاجرة أما بالنسبة للأسماك الفضية فقد أرتفعت هذه النسبة إلى ٧٦,٣ ٪ .

بلغ متوسط الطاقة الكلية المختزنة في الاناث الصفراء ١٠,٩٥ × $١٠^{٦}$ جول/كجم وارتفع في الأسماك الفضية المستعدة للهجرة إلى ١٦,٥١ × $١٠^{٦}$ جول/كجم، كما بلغ متوسط طاقة الدهن بالنسبة للطاقة الكلية للأسماك الصفراء ٦٧,٩ ٪ وأرتفعت قيمته إلى ٨٠,١ ٪ للأسماك الفضية.

لحساب كمية الطاقة المستخدمة في عملية إنضاج المناسل وفي التبويض، وأيضاً اللازمة للهجرة استخدمت المعادلة الرياضية الخاصة بـ Boetius and Boetius لعام ١٩٨٠ ولكن بعد إدخال بعض التغيرات عليها لتصبح :

$$E_T = E_G + E_D + E_S + E_M$$

باستخدام هذه المعادلة أمكن حساب كمية الطاقة المستخدمة لانضاج خلايا الذكور وبلغت نسبتها ٢٠,٢٨ ٪ من الطاقة الكلية للأسماك، أما كمية الطاقة المستخدمة في إخراج هذه الخلايا الناضجة فكانت ١٥,٧٨ ٪ وبلغت كمية الطاقة المستخدمة في الهجرة ٣٤,٢٠ ٪ من الطاقة الكلية أيضاً مما يبّين أن كمية الطاقة المتبقية في الاسماك بعد جميع العمليات الحيوية ٢٩,٧٤ ٪ .

ولقد أمكن حساب كمية الطاقة المستخدمة لانضاج البويضات والتبويض عند الاناث والهجرة وكذلك الطاقة المتبقية في الاسماك فكانت على التوالي ٢٥,٠٨ ، ١٧,٠٧ ، ٣٥,٧٠ ، ٣١,٣٥.

ويمكن تلخيص الناتج في نقاط ثلاث هي :ـ

١ ـ أن أكثر التغيرات الواضحة على الأسماك أثناء تجربة النضوج الجنسي تمثلت في زيادة نسبة الدهن وبالتالي زيادة كمية الطاقة التي تستخدم في جميع العمليات البيولوجية المذكورة.

٢ ـ درجة فقدان الدهن من الجسم في الاناث أكثر من الذكور وهذا يوضح أن كمية الطاقة اللازمة لنضوج البويضات ومن ثم التبويض أكبر من كمية الطاقة اللازمة لهذه العمليات في الذكور.

٣ ـ معدل التحول الغذائي لذكور تلك الأسماك (٩,٦ ٪) أكبر من معدله في الاناث (٦,٠ ٪) في حين إزداد هذا المعدل بشكل عام في كل من الذكور

والاناث مع زيادة درجة حرارة الماء من ١٥° م إلى ٢٦°م. لكنه نقص بزيادة وزن الجسم في الاناث.

ونتائج البحث تمكننا من الاجابة على بعض التساؤلات على بيولوجية التوالد والهجرة لتلك الأسماك وخاصة موت الآباء والأمهات بعد توالدها في منطقة التوالد.