RESEARCH JOURNAL OF FISHERIES AND HYDROBIOLOGY
2016. 11(2): 10-18
ISSN: 1816-9112
Journal home page: http://www.aensiweb.com/JASA/

First data ongrowth and silvering process of European eel *Anguillaanguilla* of the lake Oubeïra (Algerian northeast).

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Received 22 January 2016; accepted 25 February 2016; published 28 February 2016

ABSTRACT

The first objective of this study consists of an exhaustive description of growth of the eels living in the lake Oubeïra (Parc National of El Kala, Algerian northeast) by the application of both external (size, length of the pectoral fin and ocular diameter) and internal (weight of the liver, the gut and the gonads) anatomic criteria, according to their degree of silvering of EelRep (2005), over a period of 3 years. 95% were females, of which more than half were silvered and they exhibited an extremely fast rate of growth with OI > 8.72, FI>5% and relatively high mean somatic index (GSI-HSI-GIs =1.37%-1.85%-1%),the silvering transition occurs at a very young age (5±0.87 years). Onemale was identifiedin this investigation, against < 5 % of non-sexually differentiated individuals. The relationship between the size and the weight revealed a majorantallometry ($Wt=1E\text{-}07Lt^{3,3973}$) and finally, a positive correlation was noted between: GSI - size (r^2=60%), GSI - weight (r^2=60%), and negative between GIs-weight, GIs-size and GIs-age of eels (r^2 varying between 50 and 62%).

Key words: *Anguilla anguilla*, growth, morphology, somatic index, Silvering, Algerian northeast.

INTRODUCTION

The European eel *Anguilla anguilla*, recently considered 'outside safe biological limits' [21] andhas become red-listed as 'Critically Endangered species' [19], Miller et al. [26] highlighted the fact that the three northernHemisphereanguillid species experienced recruitment declines at similar times and that this implies common causes of the declines. Forthis,the European Union adopted a regulation "establishing measures for the recovery of the eel stock" [21].

Therecent study of Amilhat et al. [3] shows that female eels from the Mediterranean area are capable of migrating into the Atlantic Ocean and may, therefore, contribute to the spawning stock; the authors added that despite the large distances that the eels travelled, even those that escaped to the Atlantic were still several thousand km from the assumed their spawning area. But before, they have to get ready for this migration and acquiring so the characters of marine fish of big depth; by suffering a whole series of physiological, anatomic and morphological transformations. Among the most spectacular, we name: increased eye diameter [4,36,30,5]; enhancement of silver-colour-body and decreased of gut weight [4,32,25,14]; increased of length of the fins [22] and weight of gonads [16,17,5,25,14]…etc

In the light of this information and pushed by the lack of data on the growth of the European eel of South Mediterranean perimeter, we envisaged this study, that the primary purpose is to describe the external and internal anatomic characters of this fish as well as the silvering metamorphosis to begin its transoceanic migration.

To Cite This Article: MardjaTahri and Mourad Bensouilah., First data ongrowth and silvering process of European eel Anguillaanguilla of the lake Oubeïra (Algerian northeast). **Research Journal Of Fisheries And Hydrobiology**, 11(2): 10-18, 2016

MATERIAL AND METHOD

Lake Oubeïra is a fresh water lake with a surface area thatcovers 2 200 hectares and that have a maximal depth of 4m. It is located approximately 4 km from the shores of the Mediterranean Sea, at N36°50, E08°23 (Fig. 1). It is fed by four important watercourses: OuedDemetRihana (North), OuedBoumerchene (Northeast), OuedDeyL'Graa (East) and OuedMessida (South). This lake is a designated wilderness area (registered with the "RAMSAR" Convention) of the Parc National d'El Kala that has the unique distinction of hosting the most important wetland complex of the Maghreb area. The average air temperature is 17.50 °C,for January (the coldest month) this value is 11.65 °C and for August (the hottest month) it is 25 °C [8].

There is currently no hydraulic management framework for thelake, and recruitment of the populations of eels is done by natural means.

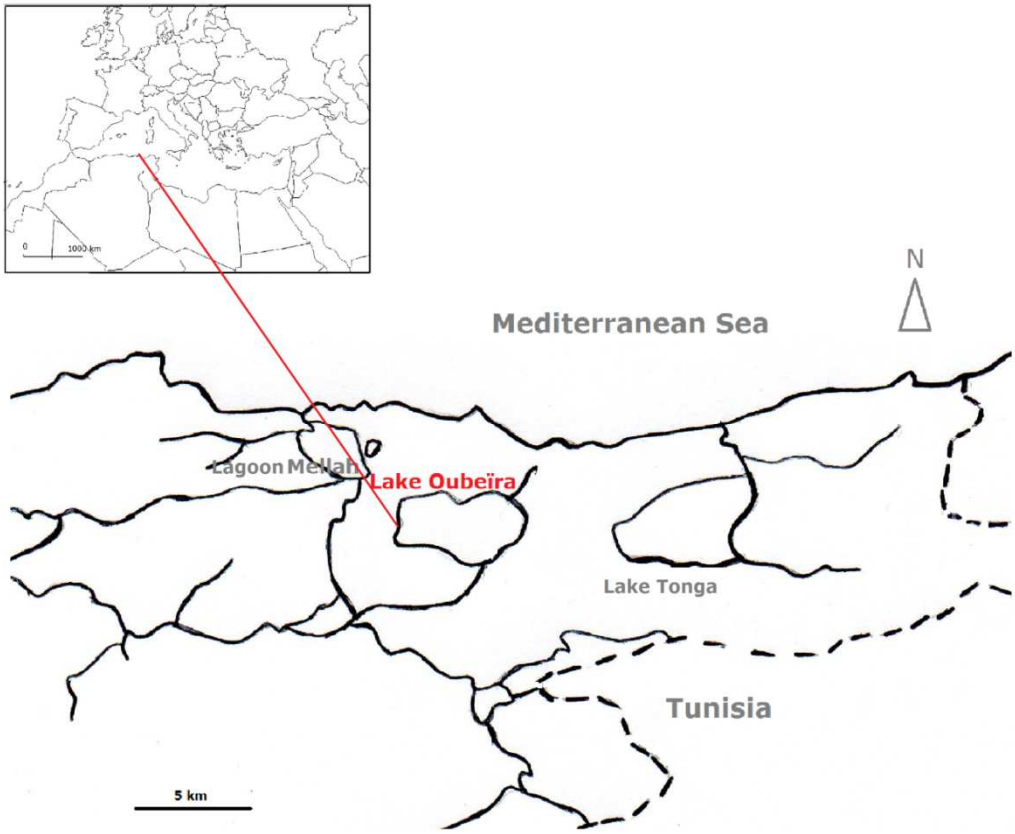

Fig. 1: Lake Oubeïra, in northeastern Algeria.

Capture and treatment of the eels:

Sampling was carried out monthly betweenNovember 2010 and February 2012.Eels were captured using nets with a 10 mm mesh, they were brought back alive to the laboratory on ice and then weighed (total mass, Wt, to thenearest of g) and measured (total length, Lt, to the nearest of mm).

Morphological criteria:

The horizontal and vertical diameters of the right (A_r, B_r) and left (A_l, B_l) eyes and the length of pectoralfin (Lf) were measured (to the nearest tenth ofmm), to calculate the Ocular Index "OI" [30] and the pectoral Fin Index "FI" [12] (Tab. 1)

Table 1: Characteristics and coding of the criteria used to describe the silvering state of eels

Criteria	formula	Application
FI (%)	FI (%) = (Lf/Lt) × 100	FI< 4% = yellow eel FI ≥ 5% = silver eel
OI	OI = {((A_r +B_r)/4×((A_l + B_l)/4)×π/Lt}	OI ≤ 6.5 = yellow eel OI > 6.5 = silver eel

Somatic index:

After dissection and evisceration of eels, we weighed their gonads, liver and empty gut (to the nearest tenth of g), to calculate the Gonado-Somatic-Index"GSI", Hepato-Somatic-Index "HSI"and Gut-Index "GIs"[13] (Tab. 2).

Table 2: Somaticindex determination

Indice interne	formule	Application
GSI (%)	GSI (%) = (Wgonads/Wt) × 100	GSI < 0.4% = yellow eel GSI ≥ 1.4% = silver eel
HSI (%)	HSI(%) = (W liver/Wt) × 100	HSI >1.5% = yellow eel HSI ≤1.5% = silver eel
GIs (%)	GIs (%) = (Wgut/Wt) × 100	GIs >1.5% = yellow eel GIs≤1.5% = silver eel

Silvering index:

The degree of silvering was deduced using the REPRODUCTIVE capacity of the European EELs [15].

Length-weight relationship:

As fish grow in length, they increase in weight. The length–weight relationships were calculated using theequation:

$W(t) = aL^b$

a is a coefficient relative to body form;

b is an exponent indicating isometric growth when equal to 3.0, allometrymarjorantwhen >3 and allometryminorantwhen <3 [20].

Modelling of growth:

For modeling of growth of the eel population in question, weused the following von Bertalanffy equation:

$Lt = L\infty\ (1\text{-}exp^{-K(t-t0)})$

This model is perhaps one of the most widely usedmodels to describe age and growth relationships of fishes. The above equation describes how an individual'slength (Lt), is predicted as a function of its age (t)as a result of the values of the parameters kand L∞. kis the instantaneous growth rate (units of time, $year^{-1}$) and L∞ isthe maximum length attained by an average individual in thepopulation.

We also usedgrowth according to weight, represented by the following equation:

$W_t = W\infty\ (1 - exp^{-K(t-t0)})^b$

Otolith analysis:

Age was estimated by counting of the otlithswinter rings of captured eels [29].

Statistical analysis:

Fit of the model to the data was measured by the coefficient of Pearson's r-squared, r^2.

Results:

Growth of eel:

The weight of 328 eels captured during this study, was ranged from 45 to 1330 g; the relationship between length and weight was: $Wt=1E\text{-}07Lt^{3,3973}$,the allometry coefficient b is higher than 3 (b=3.3973) reflecting that growth is a majorantallometric.

The Von Bertalanffy equation for the theoretical growth of captured eels was:

$Lt=811.529(1\text{-}exp^{-0.035(t-(-2.57)}$)for size ($r^2$=0.68) and $W_t=939.345\ (1- exp^{-0.05(t-5.32)})^{3.397}$ for weight (r^2=0.64).

Morphological criteria:

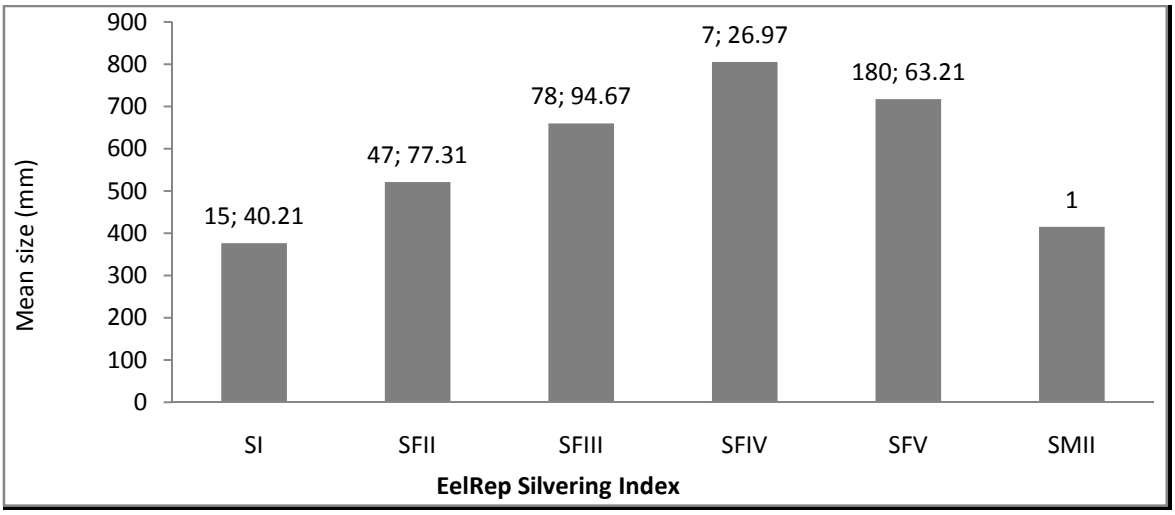

Fig. 2: Meansize distribution of captured eels in terms of the degree ofsilvering (number of eels; ±S.E.).

According to the EelRep classification of the degree of silvering (Fig. 2), we encountered:

15 eels that were not sexually differentiated (SI) (mean size = 376.2 ± 40.21 mm);

312 females eels, of which 60 % were migrants (size > 700± 26.97 mm), ¼ were pre-migrants and 15 were residents ;

One male was identified measuring 415 mm.

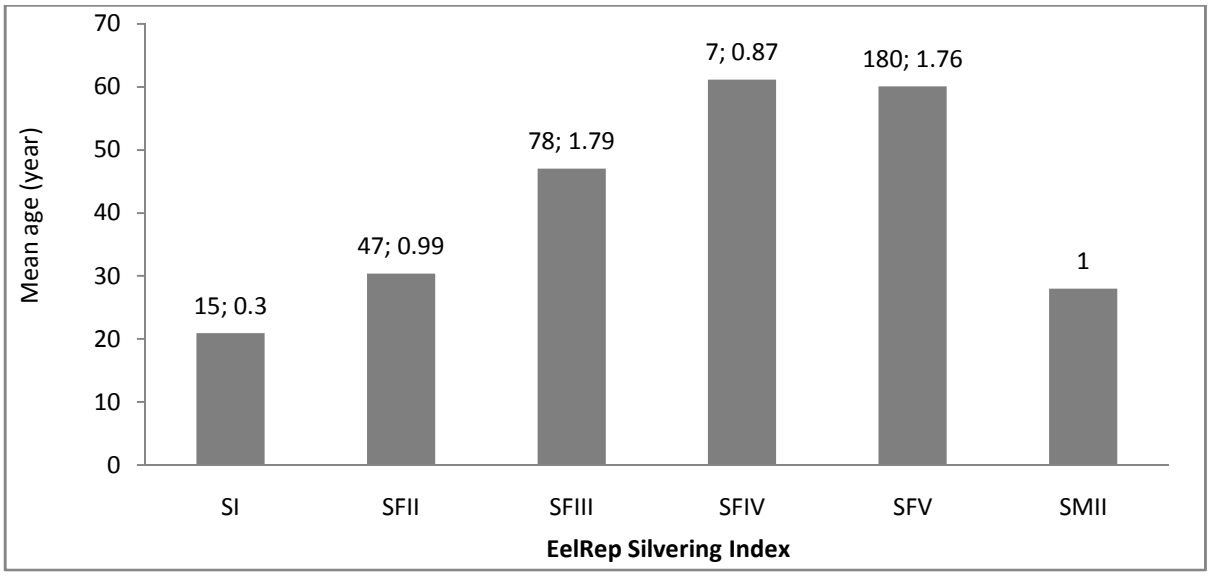

Fig. 3: Mean age distribution of captured eels in terms of the degree of silvering (number of eels; ±S.E.).

Aged of 5±0.87 years only, the females of the lake Oubeïra can be already considered as silvers migrants (Fig. 3).

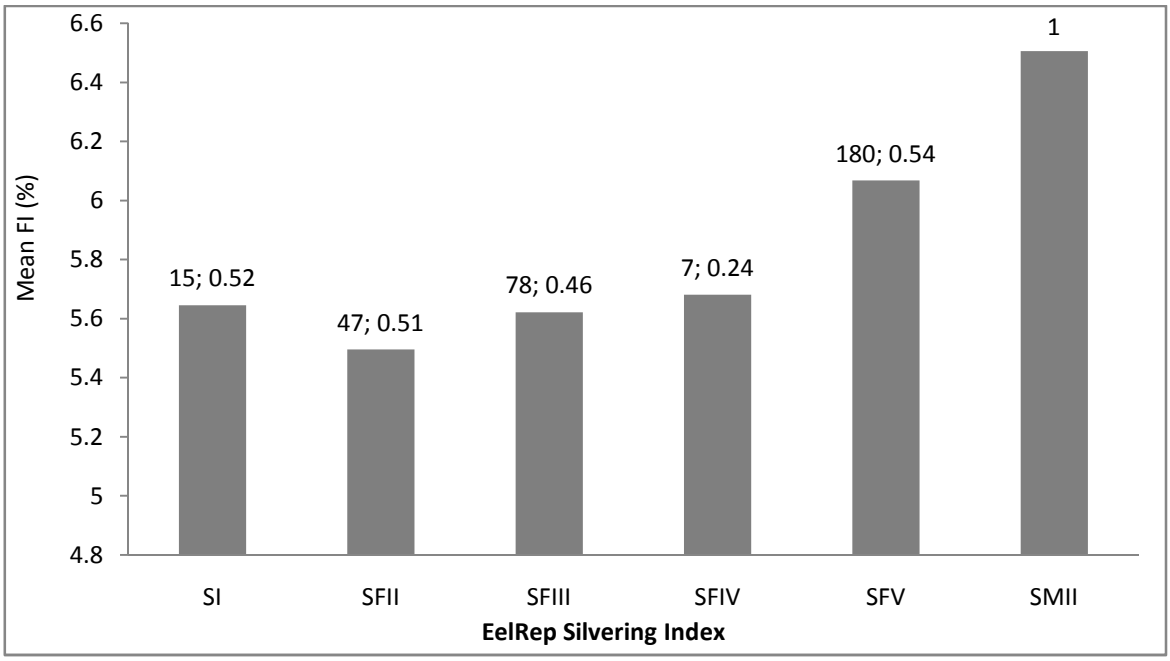

Fig. 4: Mean FI distribution of captured eels in terms of the degree of silvering (number of eels; ±S.E.).

We found that all mean FI (%) are superior to 5.5 %, whatever is the stage of eels captured (Fig. 4).

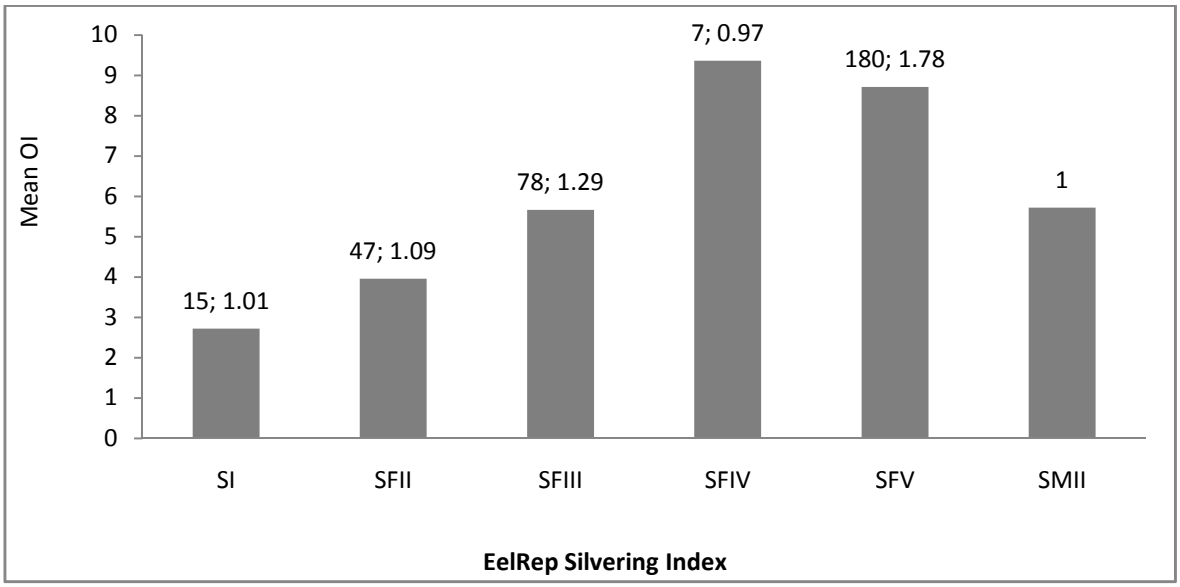

Fig. 5: Mean OI distribution of captured eels in terms of the degree of silvering (number of eels; ±S.E.).

The male, the indeterminate as well as the females (residents and pre-migrants) have a mean OI < 6; on the other hand, mean OI of the silver female generally exceeded 8.72 ± 1.77 (Fig. 5).

Somatic Index:

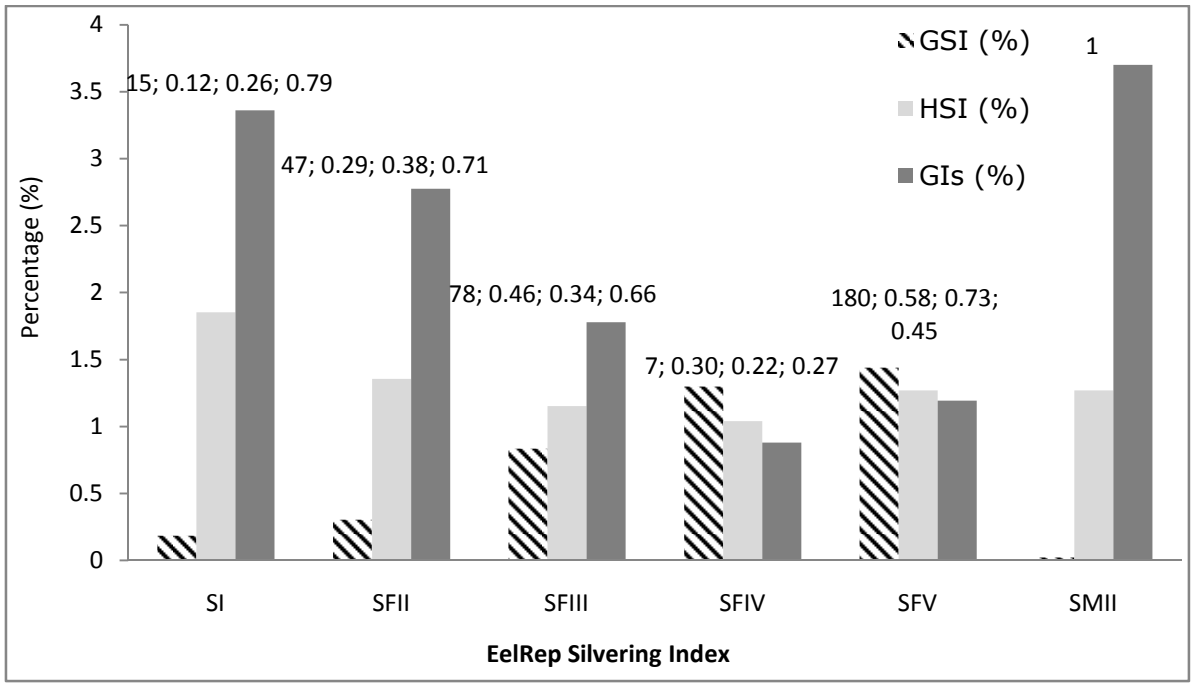

Fig. 6: Mean GSI, HIS and GI (%) distribution of captured eels in terms of the degree of silvering (number of eels; ±S.E.of GSI, HIS and GI respectively).

We noted that mean GIs (%) of residents is 3X that of migrants; besides, the GSI decreased from 1.85 ± 0.26 % (of residents) to 1 ± 0.22 % (of migrants). Finally, the silver migrants females showed the higher GSI (1.44 ± 0.58 %) (Fig. 6).

As regards morpho-anatomic relationships, we determined positive correlation between GSI-size (r^2=60%) and GSI-weight (r^2=60%) of captured specimens; on the other hand, GIs is negatively correlated with fish age, size and weight (r^2 varying between 50 and 61%).

Discussion:

Our results demonstrate, for the first time, that the eels of the lake Oubeïra (Algerian northeast) exhibited an extremely fast rate of growth; their sex-ratio is very widely dominated by the females (95 % among which more half is considered as silvers migrants against <5 % of not sexually differentiated resident individuals).This may be explained by the effect of the environment's temperature on the specimens (the average temperature of the lake being close to 17 °C).

Of the 328 eels captured during the study period (November2010-February 2012), the fishsizes, weights and ages are ranged from 300-895 mm, 45-1330 g and 1.6-6.58 years respectively. This size distribution is similar to the one observed by other investigators at the same study site (330-380 mm); on the other hand, eels were found to be much smaller (230-630 mm) in the Mellah lagoon [11]. In Europe, the size ofthe silver females that were captured at38 different sites ranged from 450 to 863 mm [41]. Regardingthe other species of eels; their American neighbor *Anguillarostrata*has been reported to have a mean size of 853 mm [40], while female Japanese *Anguilla japonica* are 614±40.5 mm insize [39] and the mean size of Australian *Anguilla australis*is945 mm [35].

The mean size of females silvering increasedwith the size of the watershed, indicating that the physicalcontext of the watershed exercised a degree of control over thesexual differentiation of the eels [2] and thus also over thereproductive potential of the watershed. This preponderance oflarge female eels was also a reflection of the use of nets with a10 mm mesh. Due to the selectivity of the fishing gear, thedistribution of the observed sizes does not perhapsfully reflect the sizedistribution of the whole eel population in Lake Oubeïra.

Furthermore, a high degree of variation in size for a given agewas observed for a population, and substantial differences insize ranges have been reported for the various age groups of*Anguilla Anguilla* [4,34,27,28]. These disparities could bepartially due to interpretation of their age, while the largediversity in environments that the eels occupy may alsocontribute to the observed variation in growth, as a result ofthe productivity of the environment (e.g. availability of food)and the density of eels (e.g. competition). Lastly, eel size hasbeen shown to increases as the distance from the sea increases [7,10].

In our study, the length-weight relationship revealeda majorantallometry ($Wt=1E07Lt^{3,3973}$), what does mean that the weight increase more quickly than the length.It is in accordance with theresults of Boulenger et al.

[7] on length-weight relationship for silver eels captured from 13 European catchments, who highlights that b varied between 2.446 and 3.326 (male / female=2.348-3.405 / 2.507–3.670).

During the metamorphosis from yellow to silver eel, increases in eye diameter and retinal surface area occur in *A. anguilla* [31], *A. japonica* [43], *A. dieffenbachii*and *A. australis* [38,23]. An Ocular Index (OI) relating total body length to external surface area of the eyes can be calculated to assess the degree of silvering transformation of the eel, avoiding the need to sacrifice individuals to assess internal development of the gonads. OIs of artificially matured eels can attain the value of 27 [6], but, the threshold values of OI indicating an eel has naturally started its silvering process are lower but vary widely in the literature. Pankhurst [30] estimated that silvering occurred at OIs>6.5. Fontaine [17] showed that individuals not having started the pre-silvering stage had OIs of 4.33 ± 0.24 (min-max=2.94-5.70), while OIs in the later stages were 8.48 ± 0.42 (min-max=5.58-11.4). Marchelidon et al. [25] and Acou et al. [1] estimated the critical OI was 8. Durif [12] concluded that the value of 6.5 is valid only for the classification of male eels (size < 450 mm) and that the borderline value is 8 for the females. The author added that if Ocular Index is alone used for the evaluation of silvering, the percentage of error increases up to 10 % (while there will be 3 % for the males). As regards our study, mean OI of the silver female generally exceeded 8.72 ± 1.77, while that of other eels did not exceed 6.

As with OI, the fin indexFI (%) is assumed to be indicative of preparation for transoceanic migration. All eels captured in this study had FI > 5 %, categorizing them clearly as silver eels according to Durif et al. [13].

The hepato-somatic index,HSI (%), of eels was found to decrease from 1.72 ± 0.59 % to 1.24 ± 0.30% during metamorphosis by Durif et al. [13] because the eel ceases feeding before migration. In addition, their comparative study found GSI increased progressively from 0.21 in female yellow eels to ≥ 1.5% in silver eels with increases of follicular diameter, thickening of follicular wall and appearance of many lipidic vesicles [18,24]; this increase in gonad size was shown to be a good criterion to estimate the state of advancement of the silvering process in the different eels [25,13]. Finally, the gut of sexually maturing eels atrophies and feeding ceases once migration begins, although reversals have been observed [37,13]. The cessation of feeding prior to migration means that the metabolic demands of migration and spawning must be met from a stored reserve, accrued before migration begins and recently isotopic analysis indicates that eels do not feed during long spawning migration [9]. Durif et al. [13] found gut indices (GIs) decreased from >4.6% in non-migrant to ≤1.8 in late stage silver females

All external and internal somatic indices recorded indicate silver eels in lakeOubeïra were at advanced states of maturation and confirm the extremely fast growth rates estimated. Indeed, for residents, we recorded means for GIs, HSI and GSI of 2.78%, 1.36% and 0.3% respectively, compared to 1 %, 1.16 % and 1.4 % for migrants. GSI (%) exhibited positive correlation with fish size and weight, but GIs was negatively correlated with eel age, size and weight.

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