The yellow European eel (Anguilla anguilla L.) may adopt a sedentary lifestyle in inland freshwaters

Pascal Laffaille, Anthony Acou, Jérôme Guillouët

To link to this article: DOI: 10.1111/j.1600-0633.2005.00092.x
URL: http://dx.doi.org/10.1111/j.1600-0633.2005.00092.x

The yellow European eel (*Anguilla anguilla* L.) may adopt a sedentary lifestyle in inland freshwaters

Laffaille P, Acou A, Guillouët J. The yellow European eel (*Anguilla anguilla* L.) may adopt a sedentary lifestyle in inland freshwaters.

Abstract – We analysed the movements of the growing yellow phase using a long-term mark–recapture programme on European eels in a small catchment (the Frémur, France). The results showed that of the yellow eels (>200 mm) recaptured, more than 90% were recaptured at the original marking site over a long period before the silvering metamorphosis and downstream migration. We conclude that yellow European eels >200 mm may adopt a sedentary lifestyle in freshwater area, especially in small catchment.

P. Laffaille[1,2], A. Acou[2], J. Guillouët[1]

[1]Fish Pass, ZA Parc rocade sud, Chantepie, France, [2]Equipe de Recherche Technologique 52 'Biodiversité Fonctionnelle et Gestion des Territoires', Université de Rennes 1, Campus de Beaulieu, Rennes cedex, France

Keys words: *Anguilla anguilla*; yellow eel; freshwater habitat; behaviour; mark–recapture

P. Laffaille, Fish Pass, 8 allée de Guerlédan, ZA Parc rocade sud, 35135 Chantepie, France; e-mail: plaffaille@hotmail.com

Un resumen en español se incluye detrás del texto principal de este artículo.

Introduction

European eel (*Anguilla anguilla* L.) is a catadromous species. It spawns in the Sargasso Sea. The Gulf Stream distributes the leaf-like larvae, leptocephali, along the Atlantic coast of North Africa and Europe. The larvae metamorphose to glass eels at their arrival on the continental shelf and migrate inshore to coastal waters, estuaries and streams, where they become pigmented elvers. Some elvers stay in salt or brackish water along the coast while others penetrate rivers and streams to complete the growing phase in freshwaters. Finally, they transform into silver eels and migrate downstream back to the Sargasso Sea (Tesch 1977).

During the growing phase (i.e. the yellow stage) of the European eel, distance from the sea (mesohabitat scale) is the most significant factor that influences the spatial organisation of the freshwater subpopulations (e.g. Lobon-Cervia et al. 1995; Ibbotson et al. 2002; Feunteun et al. 2003). However, microhabitat analysis has shown that, although this species occurs over a wide range of habitats, variations in habitat preference is related to eel size (Laffaille et al. 2004). Indeed, small eels are mainly found in shallow habitats with abundant aquatic vegetation, whereas large yellow eels tend to be found in intermediate to greater depths with a low to intermediate abundance of aquatic vegetation (e.g. Laffaille et al. 2003). Studies of habitat colonisation by *Anguilla* sp. are complicated by factors such as local and seasonal migrations between habitats (e.g. Parker 1995; Baisez 2001; Jellyman & Sykes 2003). In addition fishing pressure and slow or reduced recolonisation (Lobon-Cervia et al. 1990) could play a role, although some studies have shown that recolonisation can be relatively rapid (Mann & Blackburn 1991), depending on site, time of year and average size of eels (generally smaller eels). The present study, based on an 8-year sampling programme, explored the mobility patterns of the yellow eel stage.

Material and methods

The Frémur is a small river in northern Brittany (France) (Fig. 1). Its catchment covers about 60 km^2 comprising 17.5 km for the main stream and 45 km for tributaries. Despite its small size, the Frémur contains a wide range of habitats from high velocity streams to lentic waters in downstream areas, man-made ponds and reservoirs, wetlands, etc. Therefore,

doi: 10.1111/j.1600-0633.2005.00092.x

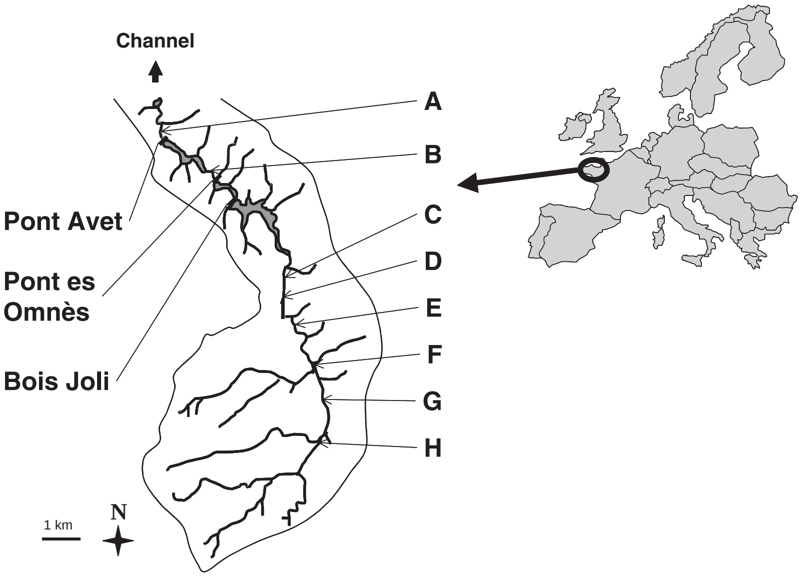

Fig. 1. The Frémur catchment, main river sampling sections (from A to G), downstream trap and eel passes.

this river appears to be representative of many small coastal catchment areas of north-western France (see Feunteun et al. 1998; Laffaille et al. 2003). However, the natural connectivity has been disturbed by three major dams: Pont Avet, Pont es Omnès and Bois Joli. Dam of Bois Joli was equipped with an eel lift and Pont Avet and Pont es Omnès dams with eel passes to permit elvers to migrate upstream. A downstream trap was installed in the Pont es Omnès dam.

Eel samples were collected by electrofishing in September from 1996 to 2003 with an EFKO® apparatus (EFKO Elektrofishfanggeräte GmbH, Germany) operating at 100–500 V and 0.8–10 A. Because of the shallowness of the stream, capturability was very high; on average, $P = 0.70$ (see Laffaille et al. 2003). Eight river sections, located in the main stream between 4 km from the estuary and 17 km upstream, were sampled all year. The river sections ranged from 430 to 1500 m^2 and the bank length from 150 to 500 m (Table 1). One river section was located downstream of the three dams (section A), one between Pont Avet and Pont es Omnès dams (section B) and the six others upstream. After the end of each electrofishing, eels were measured (total length, to the nearest mm), the stage was identified and they were marked and released back to the sampling area. Moreover, eels were collected by the Pont es Omnès trap every day from 1996 to 2003. This trap was designed to capture the majority of descending eel >200 mm under practically every flow conditions (see Feunteun et al. 2000).

Table 1. Main river section characteristics.

Sections	Distance from the sea (km)	Total bank length (m)	Total water surface (m^2)
A	4.6	358	1 075
B	8.6	144	430
C	9.5	497	1 490
D	11.4	288	865
E	12.6	396	1 190
F	14.7	413	1 240
G	16.5	228	685
H	17.0	184	550

All >200 mm individuals captured by electrofishing were marked (799 yellow eels) using Trovan® Passive Integrated Transponders (PIT) tags (EID Aalten BV, The Netherlands) (Prentice et al. 1990). PIT tags were injected with a syringe into the abdominal cavity. Each tag had a unique code which was recorded annually in a database. In order to identify marked eels, we used Trovan® apparatus (LID500 Portable reader).

The eel stages (yellow, yellow/silver and silver) were identified using three criteria: colour of the back and belly, presence of a well-marked lateral line and eye diameter according to Feunteun et al. (2000). Only yellow eels >200 mm were tagged in this study because of the following reasons: (i) the migratory behaviour of silver eels (e.g. Feunteun et al. 2000), (ii) eels <200 mm are still in the process of colonisation (Laffaille et al. 2000) and (iii) small eels (<200 mm) were not usually PIT tagged (high-induced mortality and PIT tag rejection). Moreover, European eels change their behaviour and microhabitat preferences at about a size of 300 mm (Baisez 2001; Laffaille et al. 2003, 2004). Subsequently, recapture analyses were made according to the following length groups (200–300 mm and >300 mm).

Results

A total of 799 yellow eels >200 mm (mean total length ± SD = 312.7 ± 77.5 mm, max. = 700 mm)

Table 2. Number of eels recaptured each year according to date of initial tagging.

Year of initial tagging	Number of eels tagged	Years of recapture								Total of recaptures
		1996	1997	1998	1999	2000	2001	2002	2003	
1996	386	–	53	14	7	14	4	5	1	98
1997	127		–	24	7	11	4	7	2	55
1998	58			–	7	7	2	1	2	19
1999	0				–	–	–	–	–	0
2000	100					–	6	12	5	23
2001	69						–	7	5	12
2002	59							–	8	8
2003	–								–	0
Total of eels tagged	799	–	53	38	21	32	16	32	23	215

were Pit tagged between 1996 and 2002 in the Frémur catchment (Table 2). None were tagged in 1999 and in the downstream section A, where captured eels were in high majority <200 mm (see Feunteun et al. 1998; Laffaille et al. 2003). In all 371 tagged eels (46.4%) were recaptured between 1997 and 2003: 182 at the silver stage, 26 at the yellow/silver stage and 163 at the yellow stage.

Of the 182 silver eels recaptured, 150 were captured in the downstream trap (see Feunteun et al. 2000) and 32 in the river during electrofishing operations. Among these, 27 were recaptured in the same section where they were originally tagged and five (4% of total silver eels recaptured and 16% of silver eels recaptured during electrofishing operations) in a section different from where they were originally tagged.

Of the 26 yellow/silver eels captured, 12 were caught in the downstream trap and 14 in the river but all in the same section where they were originally tagged.

Thus, 162 eels (150 silver and 12 yellow/silver eels) were recaptured in the downstream trap. None were at the yellow stage. Twenty per cent of all tagged yellow eels were caught as migrant (at silver or yellow/silver stages) during the downstream migration.

Of the 163 yellow eels >200 mm recaptured (mean ± SD = 356.3 ± 79.5 mm; max. = 710 mm), 45% were <300 mm. A total of 215 recaptures were made in the river (mean ± SD = 1.3 ± 0.8 recaptures per marked eel; max. = 5 recaptures). No eels were recaptured in the downstream section A at the yellow stage. A total of 125 fish (77% of the yellow eels recaptured) were only recaptured once, 28 two times, seven three times, two four times and one five times. The remaining tagged eels were never recaptured. All the recaptures in the river occurred from 1 to 7 years after tagging (Table 2), most after only 1 (49%) or 2 years (21%); 92% (from 89% to 94% depending on size class) of eels tagged and recaptured at the yellow stage were recaptured in the same section (Table 3), representing about 25% of all eels tagged. The percentage of recaptured yellow eel where they were originally tagged showed no significant difference according to eel size classes (chi-squared test with

Table 3. Number of yellow eels recaptured by river sections according to river sections where eels were eels were initially marked.

River sections where eels were initially marked	River sections where eels were recaptured								Total
	A	B	C	D	E	F	G	H	
Eels between 200 and 300 mm									
A	0								0
B		1	1						2
C			2	1					3
D			1	24					25
E				3	37	1			41
F					1	8			9
G				1			5		6
H							1	8	9
Total	0	1	4	29	38	9	6	8	95
Eels >300 mm									
A	0								0
B		0							0
C			2						2
D		1	1	29		1			32
E				1	47				48
F				1		14			15
G							6		6
H						2		15	17
Total	0	1	3	31	47	17	6	15	120

Yates correction, d.f. = 1, $P = 0.312$) and according to the time at liberty between the tagging and recapture procedure (G-test, $G_{adj} = 1.463$, d.f. = 7, $P > 0.9$). Moreover, only 17 yellow eels (8% of total yellow eels recaptured) were not recaptured in the section of release, and 11 of these were recaptured in the section adjacent to the section of release. In addition, only four had moved upstream, whereas 13 had moved downstream and one three sections away.

Discussion

Studies have showed plasticity in yellow eels in their choice of habitat (marine, estuarine and freshwater areas), especially for *Anguilla anguilla* (Tzeng et al. 1997; Daverat et al. 2004) and *Anguilla rostrata* (Jessop et al. 2002). Some distinct behavioural groups were identified by temporal changes in Sr:Ca ratios in their otoliths (Jessop et al. 2002; Daverat et al. 2004) and particularly a group with freshwater residence for 1 year or more before engaging in periodic, seasonal movements between estuary and freshwater areas until the silver eel stage. In our study, no PIT tagged yellow eels were recaptured in the downstream trap and in the downstream section (section A, river section located downstream of the three dams), at the yellow stage. All migrants caught in the downstream trap were at the silver or yellow/silver stage. This suggests that seasonal movements of yellow eels are not common in the Frémur River upstream 4 km from the estuary.

A limited number of studies have recognised the sedentary character of some anguillid eels. These studies emphasized the fidelity behaviour of eels to a particular site (e.g. Baras et al. 1998; Baisez 2001; Jellyman & Sykes 2003). These and other studies on the freshwater yellow eel phase (e.g. Bozeman et al. 1985; Chisnall & Kalish 1993; Oliveira 1997) indicate that eels have limited movements, suggesting the existence of a home range in the sense of Lévêque (1995). Moreover, a study of a stocked long-finned eel population (*A. dieffenbachii*) in a New Zealand Lake showed that eels dispersed throughout the lake, but that the density was highest close to the point of release (Beentjes & Jellyman 2003). Finally, various mark–recapture studies have shown that the majority of eels were recaptured at the same site of original capture: in a coastal marsh (Baisez 2001), in the estuarine environment (Secor & Morrison 2001) and in freshwater areas (Baras et al. 1998; this study). During the present study, 46% of tagged yellow eels were recaptured. We showed that of those yellow eels recaptured, most (about 90%) were recaptured at the original marking sites over a long period (up to 7 years) before silver metamorphosis and downstream migration. Moreover, among of the 17 eels not recaptured in the section of release, 13 had moved downstream. The latter may have already begun the metamorphosis to the silver stage. In fact, Kleckner & Krueger (1981) showed that the length of the swim bladder in yellow American eels had increased significantly by August despite the lack of changes in external morphology. This suggests that these 13 eels were certainly at the yellow/silver or silver stage and that the yellow eel stage was not defined correctly by macroscopic criteria. In summary, we can conclude that yellow European eels >200 mm may adopt a sedentary lifestyle in continental areas, especially in small catchments. The behaviour of migratory silver eels and yellow/silver eels contrast greatly with the sedentary nature of this yellow eel group.

The fate of the 64% of the yellow eels not recaptured is unknown. Several hypotheses can be postulated. (i) Some fish may have reached the sea without being caught in the downstream trap. Escapement tests were regularly conducted by releasing batches of eel at the top of the downstream trap. The escapements were about 0–37% according to river flow (see Feunteun et al. 2000). (ii) Our sampling effort failed to recapture the marked eels (only 2.5% of the river length was sampled annually), suggesting that they were still dwelling somewhere in the river. Some eels might have moved to non-electrofished areas. Subsequent sampling campaigns may enable us to understand the fate of these eels according to the new fast sampling method developed by Laffaille et al. (2005). (iii) The yellow eel stage was not defined correctly by macroscopic criteria (Kleckner & Krueger 1981; Durif et al. 2000). This suggests that a yellow eel index is needed to correctly assess the size of the ‘sedentary eel’ subpopulation. (iv) Natural mortality might have reduced the tagged population. Usually, eel mortality is rather low in ‘natural populations’, about 5–10% per year (e.g. Baisez 2001). In the Frémur, mortality is perhaps higher than 5–10%. (v) Possible biases and sampling errors related to electrofishing, the sites chosen, sampling only in September and the choice of eel sizes to analyse. (vi) Handling mortality and PIT tag rejection by eels could be greater than in our tests, where 14% of the tags were rejected within 1 h after the injection. After this period, tag losses are very low (e.g. Feunteun et al. 2000; Baisez 2001). In addition, some of the tributaries dry up in September. This could drive eels residing in them into the main river and consequently increase the number of recaptures. Moreover, the high eel densities in the Fremur River (Feunteun et al. 1998; Laffaille et al. 2003) could be a factor influencing migratory/sedentary behaviours.

However, the recapture of about 10% of eels farther away suggests the existence of alternative behaviour (nomads and emigrations caused by the very high density) linked with the high behavioural plasticity of this fish (Feunteun et al. 2003). Invasion mechanisms in river systems are poorly documented. One recent theory developed (Feunteun et al. 2003) is based upon the identification of distinct movement behaviours: (i) founders that colonise rivers until they settle in the first suitable available habitat they encounter; (ii) pioneers that migrate upstream to the upper boundaries of the system; (iii) home range dwellers that establish in a given area for several months to several years for growth. (iv) The last group consists of 'nomads', or erratic eels, that undertake a general upstream shift as they search for suitable areas to forage and/or to settle. Overall, our study suggests that most yellow eels have limited home ranges in the Frémur.

Resumen

1. Analizamos los movimientos de individuos en la fase amarilla de *Anguilla anguilla*, utilizando técnicas de marcado-recaptura a largo plazo en una pequeña cuenca de Francia: el río Frémur. Los individuos fueron colectados con pesca eléctrica en ocho secciones del río. 799 anguilas amarillas >200 mm fueron marcadas y 371 (46.4%) fueron re-capturas: 182 en fase plateada, 26 en fase amarillo-plateada y 163 en fase amarilla.
2. Los resultados mostraron que más del 90% (del 89 al 94% dependiendo del tamaño) de la anguilas amarillas >200 mm fueron re-capturadas en la localidad original de marcaje durante un largo período de tiempo, antes de la metamorfosis a la fase plateada y de la migración aguas abajo. No aparecieron diferencias significativas de acuerdo a las clases de tamaño ni al momento de ser liberadas, entre el marcaje y la re-captura.
3. Varios estudios han mostrado plasticidad en la elección de hábitat y movimientos periódicos entre estos hábitats hasta el estadio plateado. De acuerdo a nuestro estudio concluimos que las anguila amarillas >200 mm pueden adaptar un estilo de vida sedentaria en agua dulce especialmente en pequeñas cuencas donde ciertamente tienen ''home ranges'' limitados.

Acknowledgements

This study was funded by the ''Fédération de Pêche et de Protection des Milieux Aquatiques d'Ille et Vilaine'', the ''Contrat de Plan Poissons Migrateurs'', and various regional and local councils.

References

Baisez, A. 2001. Optimisation des suivis des indices d'abondances et des structures de taille de l'anguille européenne (*Anguilla anguilla*, L.) dans un marais endigué de la côte atlantique: relations espèce–habitat. Ph. D. Thesis. Toulouse, France: University of Toulouse.

Baras, E., Jeandrain, D., Serouge, B. & Philippart, J.-C. 1998. Seasonal variations in time and space utilization by radio-tagged yellow eels *Anguilla anguilla* (L.) in a small stream. Hydrobiologia 371/372: 187–198.

Beentjes, M.P. & Jellyman, D.J. 2003. Enhanced growth of longfin eels, *Anguilla dieffenbachii*, transplanted into Lake Hawea, a high country lake in South Island, New Zealand. New Zealand Journal of Marine and Freshwater Research 37: 1–11.

Bozeman, E.L., Helfman, G.S. & Richardson, T. 1985. Population size and home range of American eels in a Georgia tidal creek. Transactions of the American Fisheries Society 114: 821–825.

Chisnall, B.L. & Kalish, J.M. 1993. Age validation and movement of freshwater eels (*Anguilla dieffenbachii* and *A. australis*) in a New Zealand pastoral stream. New Zealand Journal of Marine and Freshwater Research 27: 333–338.

Daverat, F., Elie, P. & Lahaye, M. 2004. Première caractérisation des histories de vie des anguilles (*Anguilla anguilla*) occupant la zone aval du basin versant Gironde-Garonne-Dordogne: apport d'une méthode de microchimie. Cybium 28: 83–90.

Durif, C., Elie, P., Dufour, S., Marchelidon, J. & Vidal, B. 2000. Analyse des paramètres morphologiques et physiologiques lors de la préparation à la migration de dévalaison chez l'anguille européenne (*Anguilla anguilla*) du lac de Grand-Lieu (Loire Atlantique). Cybium 24: 63–74.

Feunteun, E., Acou, A., Guillouët, J., Laffaille, P. & Legault, A. 1998. Spatial distribution of an eel population (*Anguilla anguilla* L.) in a small coastal catchment of Northern Brittany (France). Consequences of hydraulic works. Bulletin Français de la Pêche et de la Pisciculture 349: 129–139.

Feunteun, E., Acou, A., Laffaille, P. & Legault, A. 2000. European eel (*Anguilla anguilla*): prediction of spawner escapement from continental population parameters. Canadian Journal of Fisheries and Aquatic Sciences 57: 1627–1635.

Feunteun, E., Laffaille, P., Robinet, T., Briand, C., Baisez, A., Olivier, J.M. & Acou, A. 2003. A review of upstream migration and movements in inland waters by anguillid eels: toward a general theory. In: Aida, K., Tsukamoto, K. & Yamauchi, K., eds. Eel biology. Tokyo: Springer-Verlag, pp. 191–213.

Ibbotson, A., Smith, J., Scarlett, P. & Aprhamian, M. 2002. Colonisation of freshwater habitats by the European eel *Anguilla anguilla*. Freshwater Biology 47: 1696–1706.

Jellyman, D.J. & Sykes, J.R.E. 2003. Diel and seasonal movements of radio-tagged freshwater eels, *Anguilla* spp., in two New Zealand streams. Environmental Biology of Fishes 66: 143–166.

Jessop, B.M., Shiao, J.-C., Iizuka, Y. & Tzeng, W.-N. 2002. Migratory behaviour and habitat use by American eels *Anguilla rostrata* as revealed by otolith microchemistry. Marine Ecology Progress Series 233: 217–229.

Kleckner, R.C. & Krueger, W.H. 1981. Changes in swim bladder retial morphology in *Anguilla rostrata* during premigration metamorphosis. Journal of Fish Biology 18: 569–577.

Laffaille, P., Feunteun, E., Acou, A. & Lefeuvre, J.-C. 2000. Role of European eel (*Anguilla anguilla* L.) in the transfer of organic matter between marine and freshwater systems. Verhandlungen Internationale Vereinigung für Limnologie 27: 616–619.

Laffaille, P., Feunteun, E., Baisez, A., Robinet, T., Acou, A., Legault, A. & Lek, S. 2003. Spatial organisation of European eel (*Anguilla anguilla* L.) in a small catchment. Ecology of Freshwater Fish 12: 254–264.

Laffaille, P., Baisez, A., Rigaud, C. & Feunteun, E. 2004. Habitat preferences of different European eel size classes in a reclaimed marsh: a contribution to species and ecosystem conservation. Wetlands 24: 642–651.

Laffaille, P., Briand, C., Fatin, D., Lafage, D. & Lasne, E. 2005. Point sampling the abundance of European eel (*Anguilla anguilla*) in freshwater areas. Archiv für Hydrobiologie 162: 91–98.

Lévêque, C. 1995. L'habitat: être au bon endroit au bon moment? Bulletin Français de la Pêche et de la Pisciculture 337/338/339: 9–20.

Lobon-Cervia, J., Bernat, Y. & Rincon, P.A. 1990. Effects of eel (*Anguilla anguilla*) removals from selected sites of a stream on its subsequent densities. Hydrobiologia 206: 207–216.

Lobon-Cervia, J., Utrilla, C.G. & Rincon, P.A. 1995. Variations in the population dynamics of the European eel *Anguilla anguilla* (L.) along the course of a Cantabrian river. Ecology of Freshwater Fish 4: 17–27.

Mann, R.H.K. & Blackburn, J.H. 1991. The biology of the eel (*Anguilla anguilla* L.) in an English chalk stream and interactions with juvenile trout *Salmo trutta* L. and salmon *Salmo salar* L. Hydrobiologia 218: 65–76.

Oliveira, K. 1997. Movements and growth rates of yellow-phase American eels in the Annaquatucket river, Rhode Island. Transactions of the American Fisheries Society 126: 638–646.

Parker, S.J. 1995. Homing ability and home range of yellow-phase American eels in a tidally dominated estuary. Journal of the Marine Biological Association of the United Kingdom 75: 127–140.

Prentice, E.F., Flaggs, T.A. & Cutcheon, M.C. (1990). Electronic tag. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. American Fisheries Society Symposium 7: 317–322.

Secor, D.H. & Morrison, W.E. (2001). Movement and habitat use by yellow phase American eels in estuaries. In: Aida, K., Tsukamoto, K. & Yamauchi, K., eds. Proceeding of the International Symposium 'Advances in Eel Biology', Tokyo, Japan, pp. 43–45.

Tesch, F.W. 1977. The eel. Biology and management of anguillid eels. London, UK: Chapman and Hall.

Tzeng, W.N., Severin, K.P. & Wickström, H. 1997. Use of otolith microchemistry to investigate the environmental history of European eel *Anguilla anguilla*. Marine Ecology Progress Series 149: 73–81.