Forty Years of Decline and 10 Years of Management Plan: Are European Eels (*Anguilla Anguilla*) Recovering?

Eric Feunteun and Patrick Prouzet

Abstract The genus *Anguilla* is worldwide distributed. Part of humanity's heritage, it represents a resource of proteins for many people. Most stages of the species within the genus Anguilla have experienced a drastic decrease of their abundance since at least the middle of the twentieth century. It is the case for European eel (*Anguilla Anguilla*) largely impacted by the climate change. To restore the population, an European Eel Management Plan has been implemented in 2010: fishery regulation, restocking, improvement of eel habitats, the first effects of which are expected to have improved eel abundance from 2013. Are we able to detect that such an increase has occured in the centre of the eel distribution area (north of the Iberian Peninsula, Gulf of Biscay)? Are the different potential management actions defined in the Eel Management Plan implemented? What are the necessary improvements to restore the eel population in Europe?

Keywords Eel · *Anguilla anguilla* · Eel management plan · UE · France

1 Introduction

Freshwater eels of the genus *Anguilla* are worldwide distributed. They are present in all the oceans (except the Arctic) and in all continents (except Antarctic). They have an outstanding biological cycle, with a birthplace in intertropical offshore pelagic habitats, and growth habitats located in inland waters or coastal waters from tropical to temperate regions. Eels are able to colonise most inland habitats from marine coastal zones (lagoons, estuaries, bays) to freshwaters including still waters, rivers and creeks of altitudes up to 1000 m (Tesch 1977; Adam et al. 2008).

Part of humanity's heritage, they represent a resource of proteins for many people, including native people as there are present in a large number of ecosystems. There

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behaviour (nocturnal, able to creep out of water, hiding and burrowing) and the mystery of their reproduction have always been a source of many legends, stories and even cults throughout the world (Kuroki and Tsukamoto 2012). A diversity of ancestral techniques have been developed throughout time and space to harvest all the continental stages from glass eels, to yellow eels during their sedentary growth stage and to silver eels on the onset of their spawning migration back to the ocean (Prouzet et al. 2010, 2018; Feunteun and Robinet 2013; Feunteun 2012).

Due to the high market prices of adult eels in Far East Asia, especially in Japan and China, and a lack of Japanese glass eels that have declined since the 1980s, an international trade for European glass eels has emerged in the late 80s and developed between the 1990s and early 2000s (Nielsen and Prouzet 2008). This situation has provoked an unprecedently high market price that culminated at up to around 1200€ kg^{-1} from 2003 to 2007 when the European eel was listed on the red list of critically endangered species and more than 13,000 euros per kg for the Japanese eel (Omori 2017 oral communication).

Despite considerable research effort, the biology and ecology of European eels still remain very badly understood. The exact state, distribution patterns and abundance of the stock are still very poorly described and evaluated. Although the panmixia is a well-accepted fact, the exact genetic architecture (Côté et al. 2015; Pavey et al. 2015) and the geographical distribution of the morphological and life-history traits are still insufficiently described to be able to conclude on the existence of geographically singular stocks that would induce distinct management issues. Spawning places still remains a mystery. What leptocephali eat still not clearly understood. Migration routes and duration are still debated as the age of the glass eels when they arrived on the European coast. Migration routes and duration of silver eels are still not clearly described despite huge progress thanks to satellite telemetry (Aarestrup et al. 2009; Righton et al. 2016; Amilhat et al. 2016) (Fig. 1).

2 A General Decrease of the Abundance of the Main Commercial Eel Species

A drastic decline is recorded since the sixties for the Japanese eel, *Anguilla japonica*, since the eighties for the European eel, *Anguilla anguilla,* and more recently since the nineties for the American eel, *Anguilla rostrata* (Fig. 2).

In France, the main producer of glass eel in Europe and located in the centre of the eel distribution area (see Fig. 1), the trend of glass eel catches is similar to that of the Loire river (the main production area) where a drastic diminution of the catches occurred after the end of the seventies (Figs. 2, 3).

But the fishing constraints defined after the implementation of the French Eel Management Plan (see below): definition of a catch quota per eel management unit and splitting in a quota for human consumption and another one for restocking, impairs the quality of the signal since the season 2010 (Fig. 4).

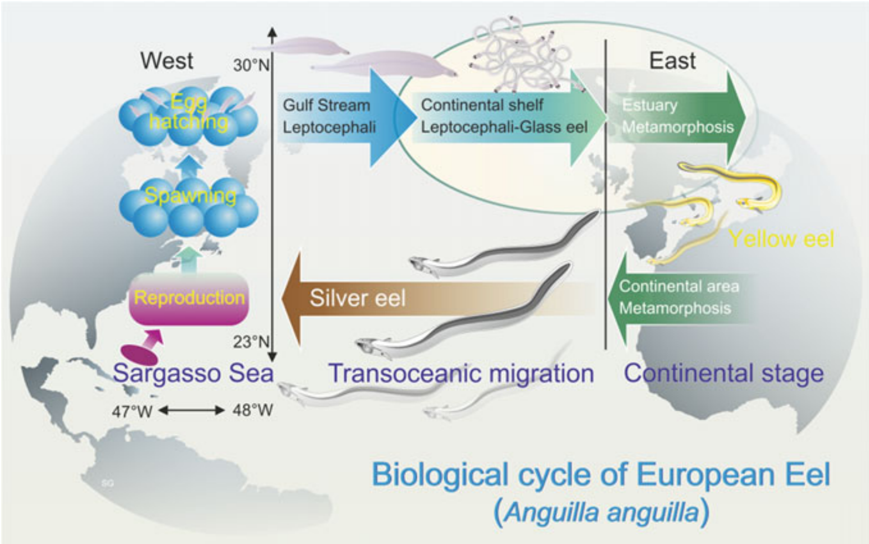


Fig. 1 Main gaps on the knowledge of the biology of European eel (from Indicang project, Adam et al. 2008)

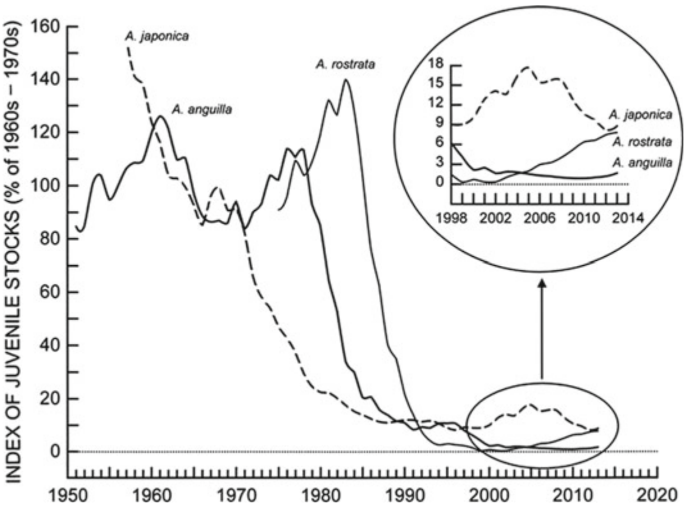


Fig. 2 Decline of the main commercial eel species. Adapted from Dekker and Casselman 2014

Since 2009, a national quota is defined annually by a scientific group and then discussed with the French administration and the fisher representatives (CNPMEM[1]

[1]National Committee for Fisheries and Marine Aquaculture.

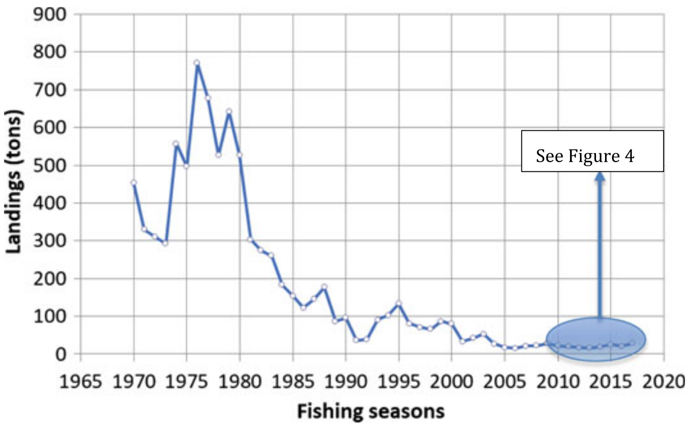


Fig. 3 Evolution of the glass eel landings on the Loire River during the period 1965–2017

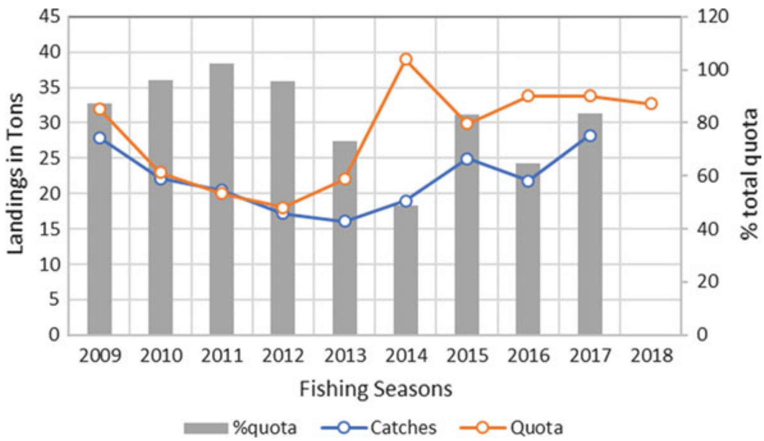


Fig. 4 Evolution of the Loire glass eel catches and the Loire quota on the period 2009–2017 and percentage of the Loire quota used

and CONAPPED[2]) in order to find a trade-off between economic and environmental criteria. A part of this national quota is allocated, to each Eel Management Unit and split according to a ratio defined by the UE Eel Management Plan in a sub-quota for consumption and another one for restocking (Table 1).

Figure 5 shows that the constraint imposed by the quota does not allow on the period 2009–2017 to land annually on the Loire catchment more than 28 t in average if the quota is fully used. A level lower than the average landings of the period 2000–2008: 34 t. In addition, the quota is not fully used since 2013 linked to a slack glass eel restocking market with not very attractive prices for the fishers (Fig. 5).

[2]National Committee of Inland Professional Fishers.

Table 1 UE key of dispatching of the glass eel production for consumption and restocking

Year	% for restocking	% for consumption
2009	40	60
2010	45	55
2011	50	50
From 2012	60	40

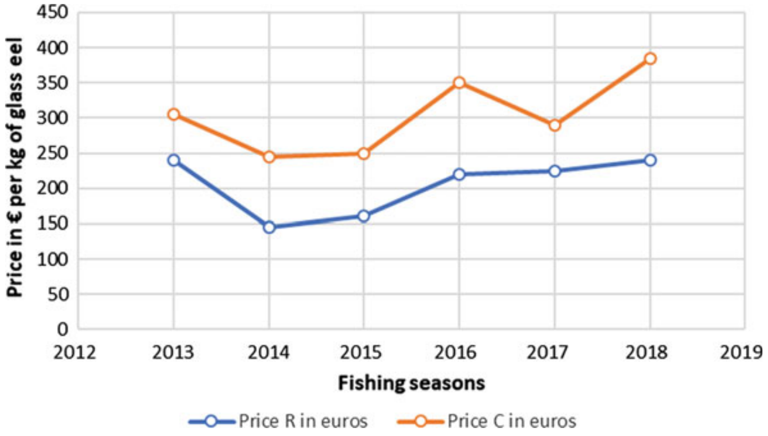


Fig. 5 Evolution of the UE prices for restocking R and consumption C on the period 2013–2018 (from French administration data)

So, in France, global catches are certainly not a sufficient indicator to measure the true evolution of the trend of recruitment in these recent years after the implementation of the UE Eel Management Plan. Consequently, it is necessary to have some more precise indices such as the CPUE or the length of the fishing season to reach the consumption quota (see § 7). However, if the CPUE are clearly the best proxy of glass eel abundance, they need to be interpreted cautiously. Indeed, their values depend on fishing effort, glass eel abundance, catchability and attractivity of market prices of glass eels. The variation of CPUE can reflect a variation of abundance of the glass eels and/or a variation of the fishing strategy. This situation has been revealed in 2018 on the Loire management unit, by a survey of the professional fishermen that have deeply modified their fishing habits (unpublished data). This observation is probably true for a pushed sieve fishery, but does not apply for a hand-sieve fishery (see Fig. 13), due to lower exploitation costs. When the market price is high and no quotas are applied, fishermen work as much as possible to favour captures. In this case, CPUE reflect variations of abundance. When the market price is controlled and catches are limited by quotas, it is more cost-effective to fish when there is a high abundance, especially for the push-sieve fishery. In this case, the CPUE tend to overestimate abundance. Therefore, it is likely that (i) the significance of CPUE, especially from the push-sieve fishery, has changed since the quotas and market prices

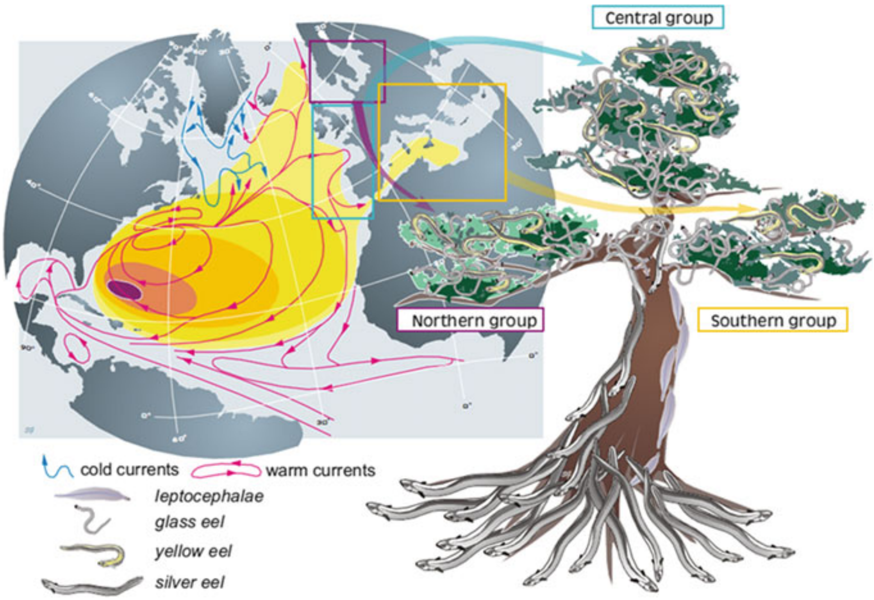


Fig. 6 Eel tree (from Indicang project https://www.indicang.fr and from Adam et al 2008, p. 15). *Comment*: This "eel tree" can only work if its roots, anchored in the Sargasso Sea, are rich in spawners, i.e. silver eels. It can only flourish if sap rises or falls along its trunk, this represents the oceanic circulation. This circulation cannot stop or even slow down, otherwise the "leptocephalus" larvae (ascending sap) will not be oriented and transported eastwards at an appropriate speed, and the silver eels (descending sap) might loose orientation cues back to the spawning grounds. Hence the unanswered question: what will be the effect of climate change on oceanic circulation and hence on the functioning of this population? Finally, the tree can only prosper if glass eels, originating from larvae, colonise the different parts of its foliage (representing the river basins) and of course, if continuously thinned, the tree will eventually die

were fixed in 2009, and (ii) the significance of the CPUE differs between quotas for consumption (~300 €/kg) and for restocking (~200 €/kg) (see Fig. 5).

Consequently, there is an urgent need to better reconsider the significance of the recruitment indexes produced yearly by ICES which are mainly based on fishery-dependent surveys in the "elsewhere Europe" series. This is of uppermost importance to be able to assess the effects of the management plan on recruitment.

3 A Too Short-Sighted View of the Environmental Pressures Responsible for the Eel Population Decline

Despite the weakness of the recruitment indices and, more broadly, on the exact status of the European eel's population abundance, evolution, distribution and demography,

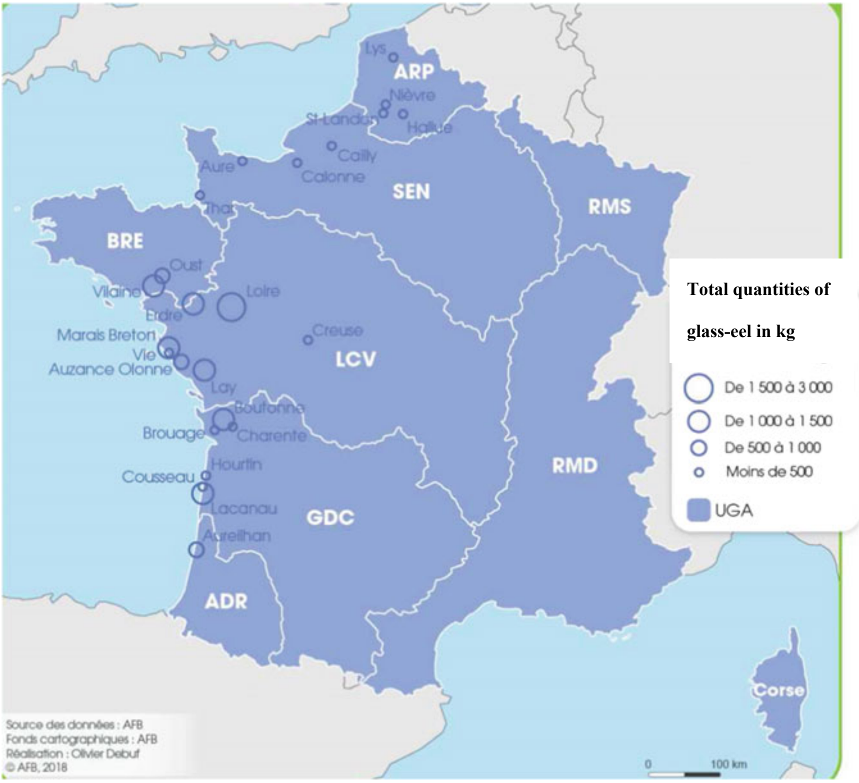


Fig. 7 Restocking sites of glass eel between 2011 and 2016 (in Anon. 2018)

there is a general consensus to acknowledge the reality of the decline based on the analysis of the recruits throughout Europe.

If there is still a debate about the reasons and the hierarchy of the causes of the decline (Feunteun 2002; Adam et al. 2008; Miller et al. 2016), they all take their roots from anthropogenic activity and impacts that act both in continental and marine environments and hit all the biological stages of eels locally (direct mortality and habitat degradation) and/or globally (global warming, oceanic regime shifts) (Adam et al. 2008; Prouzet et al. 2010; Bonhommeau et al. 2008; Miller et al. 2016; Drouineau et al. 2018).

This situation likely results from the fact that eel management has been taken up by fishery experts. Indeed, traditionally in Fishery biology and management, for a reason of simplification, the value of the natural mortality (M) is considered, for a given stage of life, as a constant. F, the fishing mortality, is then regarded as an adjustment variable to ensure that the target population is not overexploited (Gros and Prouzet 2014). Thus, the (M) parameter of the catch equation is deemed as a black box in order to reduce the complexity of the system by considering that the other pressures (natural or anthropogenic), apart from fishery, are constant or negligible.

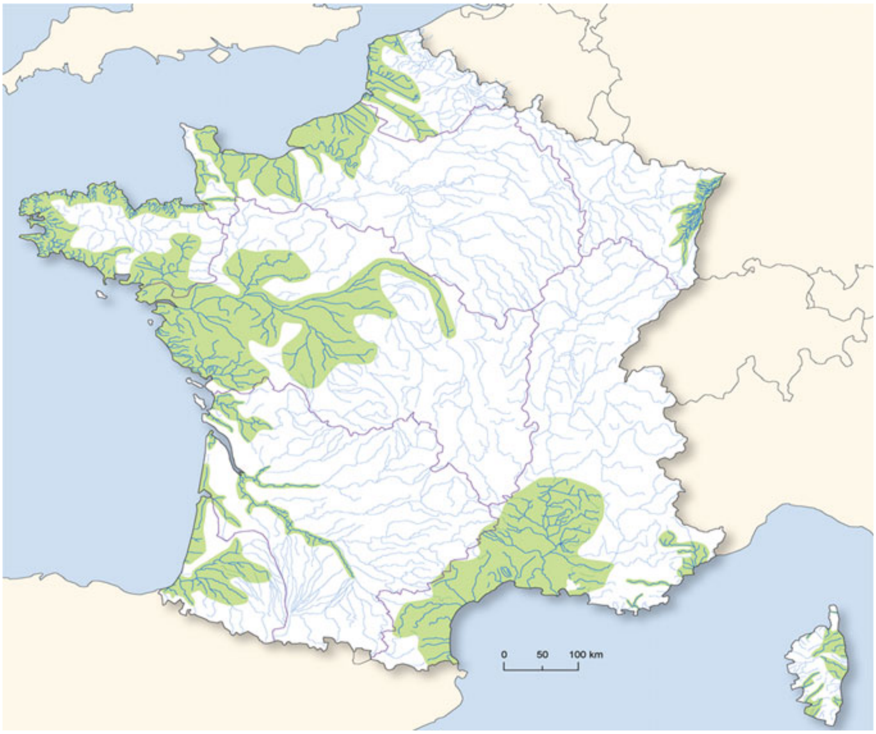
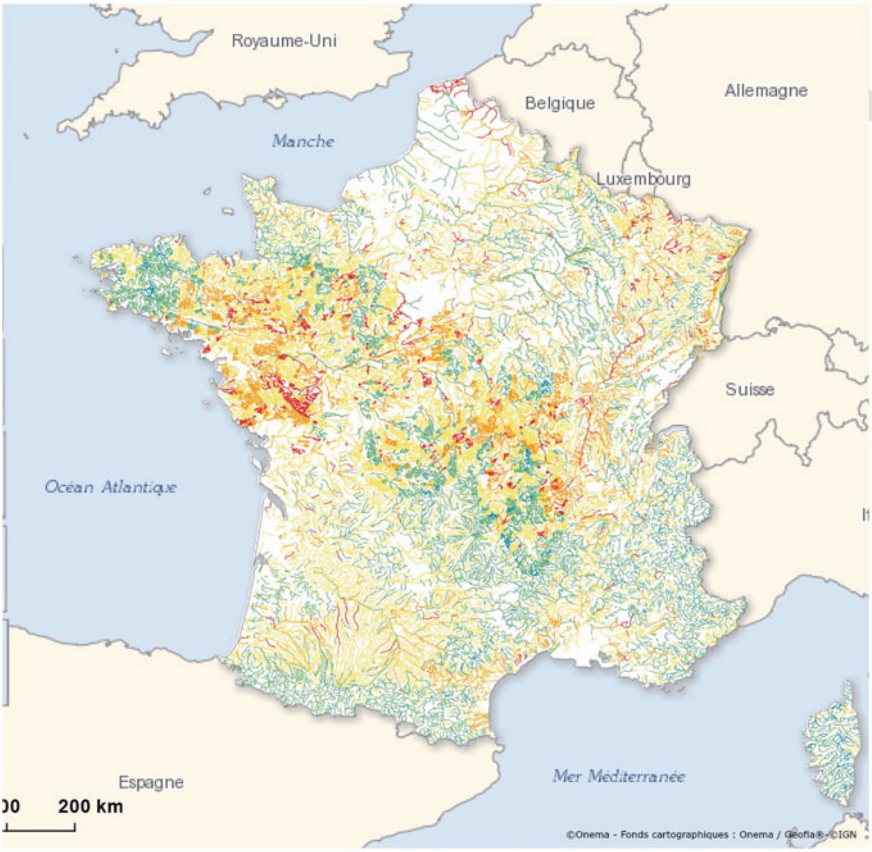


Fig. 8 Map of the priority zones for Eel (from Onema/AFB 2015)

Unfortunately, this is no longer the case for most fish species, of which some of the essential habitats are located in the interface environments between the continent and the ocean (estuaries, lagoons, bays and coastlines), which are subject to many pressures from terrestrial environments and especially for diadromous species such as eel (Gros and Prouzet 2014).

For most commercial marine species, fishing mortality is thought to be the main driver of population dynamics (Gulland 1969; Laurec and Le Guen 1981). Conversely, this is not the case for coastal-dependant species and more particularly for diadromous species that depend on the quality and integrity of littoral, estuarine and riverine habitats and on the quality of the water. Eels have a particularly complex life cycle, and the success of the management of their population is strongly dependent on the restoration of quality of their continental habitat and connectivity that has strongly been impacted at least since the middle of the twentieth century (Feunteun 2002; Adam et al. 2008; Miller et al. 2016; Prouzet 2010).

Table 2 summarizes the history of European eel awareness and management. The first alarm bell on the decline of the eel stock was pulled in 1984 by the French working group on eels, but it took more than 14 years for ICES to state that eels were outside biological limits and that it was necessary to reduce fishing mortality



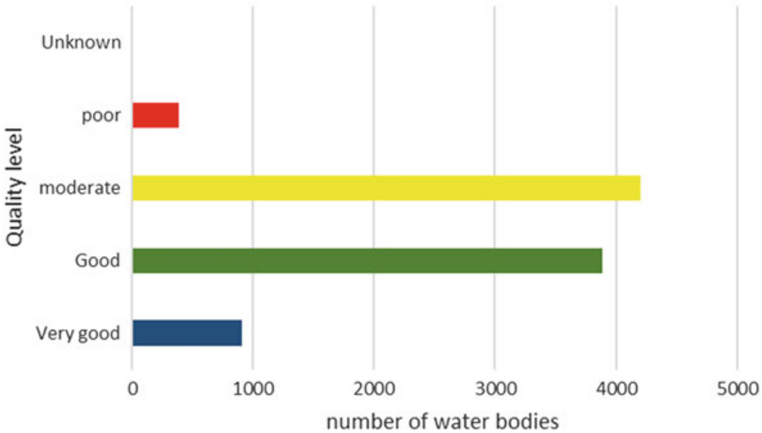


Fig. 9 Ecological status of French waters in 2015 (from Eau France)

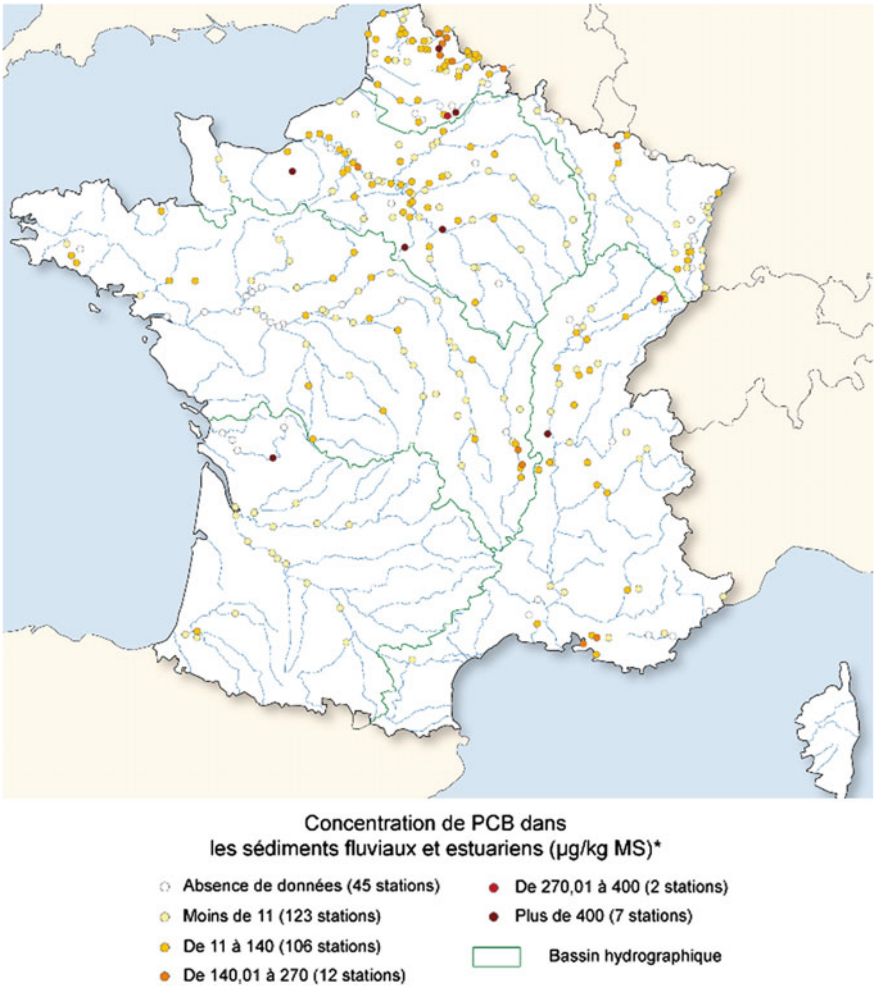


Fig. 10 PCBs concentration in the sediments of estuarian and continental water bodies in µg/kg of dry matter (from Eau France)

to the lowest possible level (EIFAC ICES working group on eels 1998, Silkeborg). A year later, the EIFAC/ICES WGEEL confirmed the decline, but recognized that all anthropogenic mortality sources should be reduced to the lowest possible level implicitly and explicitly admitting that the causes of the decline were multiple and not solely due to overfishing. Since then, a number of studies and two European projects (INDICANG,[3] see Adam et al. 2008, EELIAD,[4]) showed that the hierarchy of the causes still remains controversial. All the stakeholders involved in the exploitation,

[3] http://www.ifremer.fr/indicang/.

[4] https://www.eip-water.eu/projects/eeliad-european-eels-atlantic-assessment-their-decline.

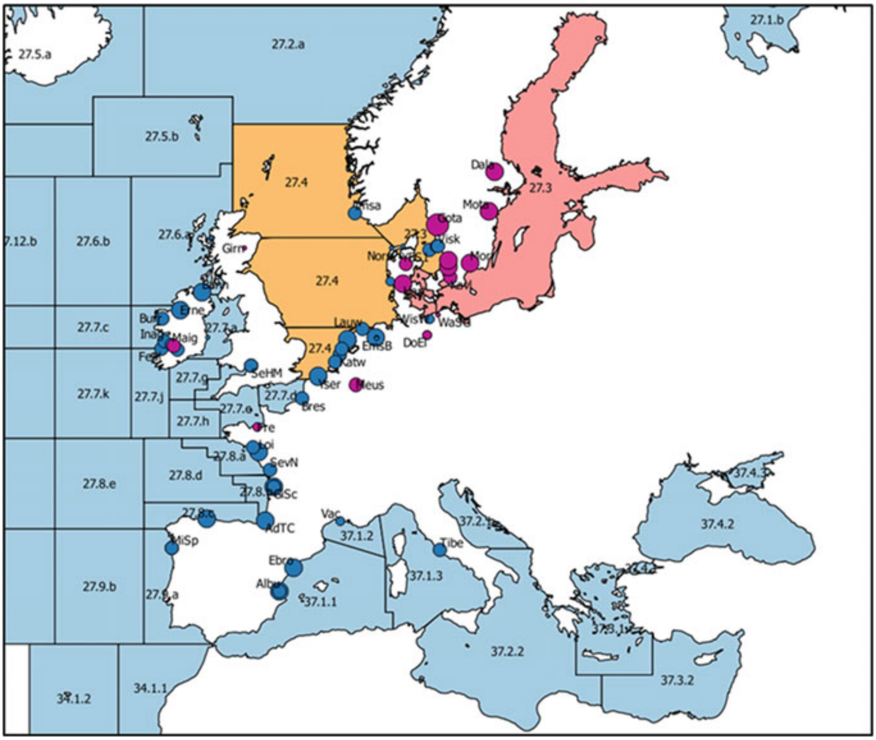


Fig. 11 Geographical locations on all the data used to estimate the trend of the eel recruitment. North Sea corresponds to the areas 27.3 and 27.4. The others areas correspond to "Elsewhere Europe" (from ICES/WGEEL 2018a)

management and studies of eel population agree that the pressures are very diversified: chemical pollution of waters, alien invasive species, loss and degradation of natural wetlands, limitation to the free migration of the fish, fishery exploitation at all the stages of the eel biological cycle. In addition, there are a number of marine pressures, not yet assessed, on the marine phases of the European eel. For example, what are the effects and impacts of:

- Sublethal persistent organic pollutant and metallic contaminations of the eels on their physiology, spawning migration and mortality of eggs and larvae
- Decrease of the productivity in the subtropical gyres on the production of marine snow, the main food of the leptocephali (refs) during their transoceanic migration
- Microplastic on the starvation and mortality of leptocephali when we observe high concentrations of microplastic along the Sargasso Sea and leptocephali migration routes
- Climate change on the migration speed of the leptocephali through the North Atlantic Ocean circulation

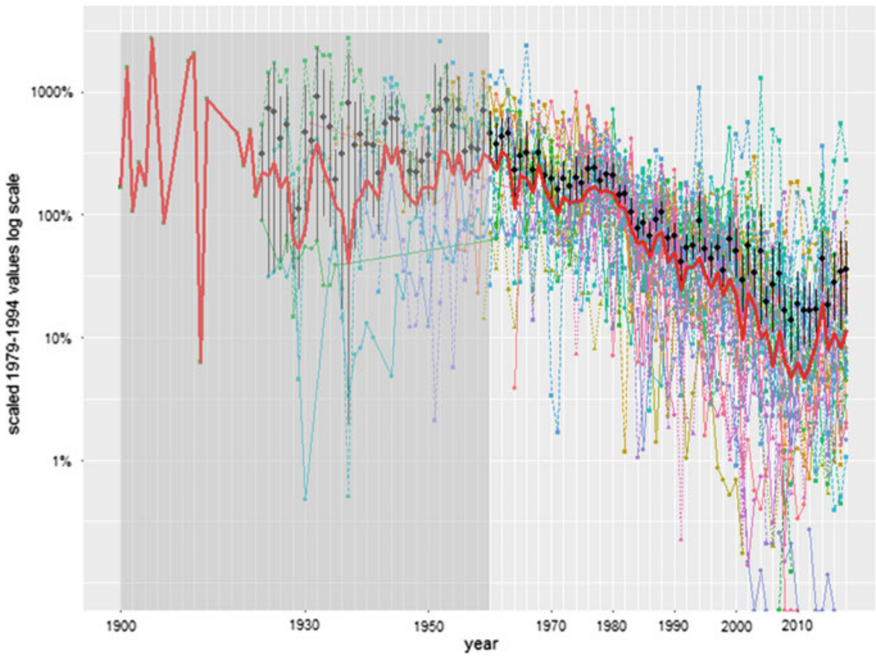


Fig. 12 Times series of glass eel or glass eel + yellow eel (46 time series) and yellow eel (14 time series) recruitment in European rivers. Each time series has been scaled to its 1979–1994 average. Black dots and bars represent the mean values and their bootstrap confidence interval (95%). The red line is the geometric means. (From ICES WGEEL 2018b)

4 Definition and Implementation of the UE Eel Restoration and Management Plan

In order to restore this depleted eel population, UE defined an internationally based eel recovery plan in 2007 (EC 1100/2007[5]), which was progressively implemented by the member states starting from 2010.

Table 2 defines the main benchmarks for the definition and implementation of the UE eel restoration plan and shows the time lag between the first observation of the depleted level of the eel resources and the reaction of the member states.

This time lag is not due to the disinterest of the member states but mainly to the difficulty to implement such an Eel Management Plan at the European scale with different social, economic and environmental contexts (Fig. 6—the eel tree).

This figure gives an idea of the extreme complexity of the management of eels with schematically three geographical groups of fish with different growth characteristics and habitats. The northern group (Baltic sea, North Sea, North of the British Islands and Ireland) with a slow growth, low arrivals of glass eels or elvers and a large part

[5]Council regulation 1100/2007 establishing measures for the recovery of the stock of European eel.

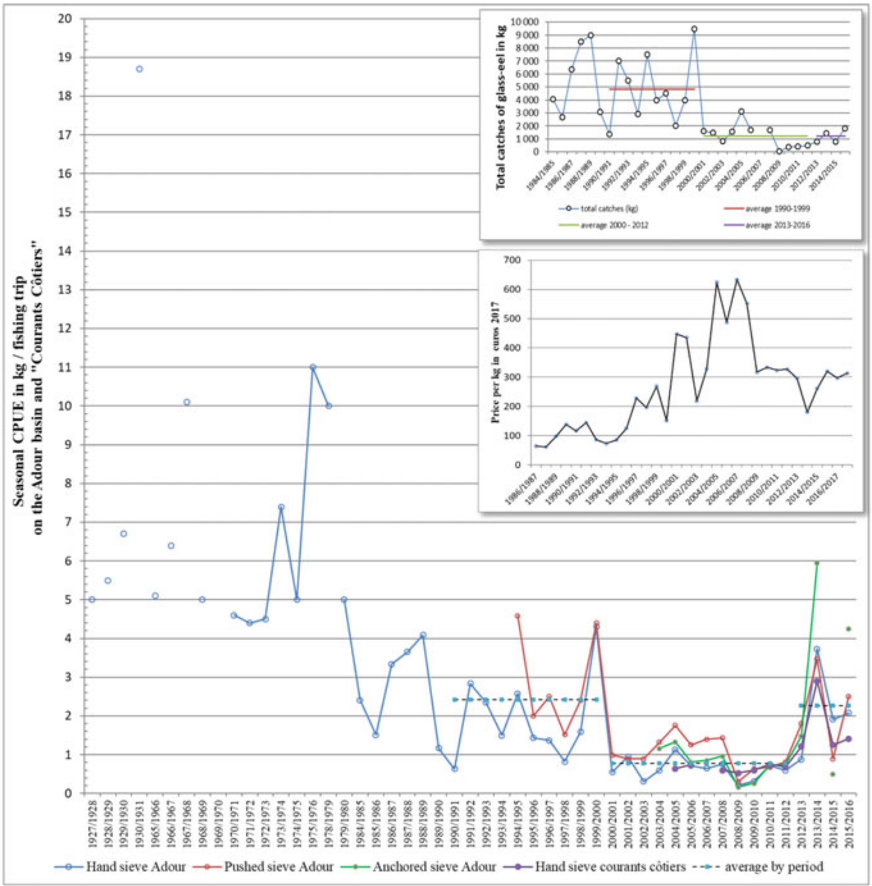


Fig. 13 Time series of marine glass eel catches on the Adour basin expressed in kg per fishing trip in the main graph on the period on the period 1927–2016 and in kg for the whole season in the upper graph on the period 1984–2016 and the mean price per kg of glass eel in the middle graph on the period 1986–2018

of the eel population growing at sea; the southern group (Mediterranean sea, South of the Iberian Peninsula and North Africa) with a high growth rate with a part of the eel population living in transitional waters such as Mediterranean lagoons and a central group (Southern part of the British Islands, Atlantic coast of France and Northern part of the Iberian peninsula) with a wide range of growth rates and a large diversity of habitats mainly in inland and estuarine waters. In addition, the use of the eel resources is different: exploitation of glass eels in the central area (mainly from the South of the British Islands to the North of the Iberian Peninsula) that represented one of the most valuable commercial fishery of the Bay of Biscay before the export ban to Asia in 2010 (Léauté et al. 2002); exploitation of yellow and silver eels in the two others geographic areas with a large development of eel culture in the northern

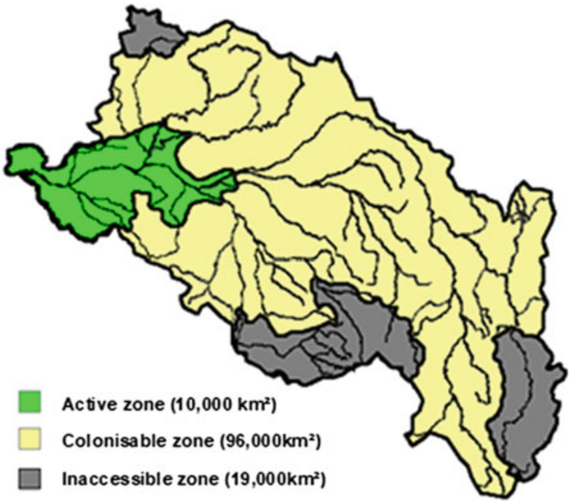


Fig. 14 Active, colonisable and inaccessible zones for eel in the Loire catchment (from Laffaille and Rigaud 2008)

Table 2 Main actions for the implementation of the European eel international regulation

Years	Actions
1984	The French Working Group on Eel declared eels are steeply declining
1998	ICES considered European eel outside "safe biological limits" and advised to reduce fishing mortality to the lowest possible level
1999	ICES recommended to reduce all the anthropogenic mortalities to the lowest possible level
2007	UE defined an Eel regulation plan (1100/2007) for the recovery of the European eel
2008	European eel is included in the IUCN red list (critically endangered)
2009	CITES listed the European eel at the Annex 2 (threatened species with a necessary control of its international trade)
2010	Definition and implementation of a UE Eel Management Plan
2011	Ban of the eel export outside Europe
2012	First assessment of the national Eel Management Plans
2014	First assessment by ICES of the national Eel Management Plans
2018	French assessment of the Eel Management Plan

area completely dependent on the glass eels catches (availability and price) landed in the central area.

As a consequence of the drastic depletion of the eel population, the Scientific Review Group (SRG) of the EU CITES management authorities concludes in December 2010: "It was not possible for the SRG to consider that the capture or the collection of European eel specimen in the wild or their export will not have a harmful effect on the conservation status of the species".

Thus from 2010, the eel export ban outside Europe (and of course Asia) is the background of the national Eel Management Plan that has to include:

- A reduction of commercial and recreational fishing activities.
- Restocking measures.
- Improvement of river habitats and of free movement of migrating fish (including measures to reduce the mortality linked to the hydro-electric power turbines).
- Transportation of silver eels from inland waters.
- Control of the predators.
- Aquaculture for restocking purposes.
- And other measures for the achievement of the target defined by the EU for the European eel resource: 40% of the pristine biomass.

In addition, the EU Member States that allow the fishing of glass eels (less than 12 cm in length) have an obligation to reserve 60% of their glass eel catches for the restocking of European waters.[6]

Article 4(2) of the Eel regulation establishes that a member state that has not submitted an eel regulation plan is forced by default to implement a fifty per cent reduction in their eel fisheries.

According to Article 9(1) of the Eel Regulation, each member state have to report every 3 years on progress in the implementation of their Eel Management Plans (EMPs).

5 What Has Been Done to Achieve the Target: In France

The objective defined by the EU for the eel resource is a long-term target if we consider the slow turn-over of that population between 5 and 30 y for a first spawning (Aoyama and Miller 2003). The objective of the EU EMP is defined in Article 2(4): "the objective of each Eel Management Plan shall be to reduce anthropogenic mortalities to permit with high probability the escapement to the sea of at least 40% of the silver eel biomass relative to the best estimate of escapement that would have existed if no anthropogenic influences had impacted the stock". This kind of pristine biomass (B_0) is very difficult to define accurately for most of the EU member states and the way of defining it differs among countries (ICES 2018a, b).

The 2018 French eel management report describes the actions that have been deployed to restore the eel population (Anon. 2018). However, these 168 pages mainly focus on fishery-dependant actions as restrictions and control of fishing effort and restocking. A significant effort has been paid to restore river continuity. Finally, this report implicitly acknowledges that little has been done to reduce sublethal contamination of eels by metallic and organic pollutants, and other anthropogenic impacts on water and ecosystem quality.

[6] Article 7(1) of the Eel regulation, by 31 July 2012 60% of the national total catches.

5.1 A Reduction of the Fishing Pressure in Line with the EU Eel Management Plan

For France, since the beginning of the implementation of the Eel Management Plan, a reduction of the fishing pressure on all the Eel biological stages occurred:

- 51% decrease of the number of glass eel licences for the professional marine fishers and 71% decrease for the professional inland fishers (Table 3)
- 28% decrease of the number of yellow and silver eel licenses for the professional marine fishers and 25% decrease for the professional inland fishers (Table 4).

The number of fishing enterprises in the Mediterranean Sea also declined from by 33% between 2009 and 2018.

- A quota is also defined annually by a commitee formed by scientists, managers, and fishermen. Then, the annual quota is shared according to a key of dispatching in the different eel management units and between marine and inland groups of fishers (Table 5).

The consumption quota (human consumption) was largely exceeded during the fishing seasons 2012–2013 and 2013–2014, the first two years when 60% of the total quota was reserved for restocking purposes. The restocking quota is never reached, direct result of a slack European restocking market (see Fig. 5).

- A precise record of the glass eel catches is made according to a very strict framework. For the professional marine fishers, according to the regulation (CE) 1224/2009, the masters of fishing vessels have to declare their catches in a logbook as soon as the first one hundred grams of glass eels have been caught. The logbook must be completed when the glass eels are landed. These catches have to be declared to FranceAgrimer[7] directly by the fisher within the 24 h following the landing. For the inland fishers, the reporting requirement is analogous, but the logbook has to be sent to the French Biodiversity Agency.
- The fishing of glass eel (eels < 12 cm) is not allowed for the amateur fishery. Presently, there exists no scheme of prior administrative authorization to regulate the fishing activity in the French maritime area. The implementation of a licence regime is not made as there is no quota defined for yellow eel. For the recreational fishery in continental waters, there exists, since 2010, a decree defining the administrative conditions to deliver a fishing authorization for yellow eel fishing in freshwater with eel pots and lines. From 2011 to 2017, à 82% decrease of the numbers of amateur fishers has been recorded (from 5224 in 2011 to 931 in 2017, Anon. 2018). For the rod fishery in inshore waters, no authorization scheme has been defined and no obligatory catch reporting system. So as in most of the European waters (ICES 2018a), it is very difficult to know with accuracy the amount of yellow eel caught by the recreational fishery.

[7] French Office for farm and fishery products.

Table 3 Evolution of the number of glass eel licenses on the period 2006–2018 in France

	2006	2010	2011	2012	2013	2014	2015	2016	2017	2018	Trend 2006–2018 (%)
Marine fishers	853	643	573	500	475	457	413	420	437	417	−51
Inland fishers	371	180	158	147	145	129	126	112	109	109	−71
Total	1224	823	733	647	620	586	539	532	546	526	−57

Table 4 Evolution of the number of the yellow and silver eel licences on the period 2009–2018 in France (Mediterranean area non-included)

		2009	2012	2013	2014	2015	2016	2017	2018	Trend 2009–2018 (%)
Yellow eel	Marine fishers	309	236	224	248	222	228	229	216	−30
	Inland fishers	169	169	172	146	143	134	135	128	−24
	Total	478	405	396	394	365	362	364	344	−28
Silver eel	Inland fishers	44	34	34	34	33	34	34	33	−25

Table 5 French glass eel quota (in kg) on the period 2010–2018 shared between consumption and restocking

Fishing seasons	Consumption quota (kg)	Restocking quota (kg)	Total quota (kg)	Use level of the consumption quota (%)	Use level of the restocking quota (%)
2010–2011	26,800	17,866	44,666	109	31
2011–2012	20,349	16,649	36,998	105	75
2012–2013	17,000	17,000	34,000	140	45
2013–2014	17,000	25,500	42,500	145	63
2014–2015	30,000	45,000	75,000	81	26
2015–2016	22,290	34,485	56,775	94	74
2016–2017	25,780	38,970	64,750	91	51
2017–2018	25,940	38,914	64,854	94	78
Mean	23,145	29,298	52,443		

5.2 Restocking

The objective of the French Eel Management Plan planned to keep 5–10% of the yearly catches of glass eels to restocking on the French catchments of the Bay of Biscay and the coasts of the Channel (Tréguier et al. 2015). A total of 21,800 kg (approx. 77 million) of glass eels have been restocked between 2011 and 2018 in 74 operations (Fig. 7). Restocking is funded by a national grant following a protocol that gives clear recommendations on the selection of restocking sites and density that can be applied. The efficiency of this measure is still been assessed by a national monitoring programme, but and no strong conclusions are yet available (Tréguier et al. 2015; Anon. 2018).

5.3 A Slow but Significant Restoration of the River Continuity

Figure 8 shows the location of the priority zones for the eel restoration defined in the French Eel Management Plan in 2010.

The priority zone for Eel is a river or a part of a river where priority is given to eliminating obstacles that prevent the free migration of eels. In 2018, 9564 obstacles have been counted on the areas colonized (or potentially colonized) by eel, 2950 of which are in the priority zones for eel.

By 1 January 2018, 1882 (19.6%) of obstacles, 515 (17.5%) of which in the priority zones have been aligned with the environmental policy. So, a considerable amount of work still remains to increase the Eel available habitat. Restoration of the river continuity is one of the main critical factors to recover the eel resource and increase the potential eel habitat. In Spain, according to Clavero and Hermoso (2015), the amount of eel habitat lost since the nineteenth century surpasses 82% and explains in that country the collapse of the species the range of which is currently restricted to a coastal fringe (see Fig. 3 of the communication of Clavero and Hermoso 2015).

6 What Has not Been Targeted by the Management Plan

6.1 Eel Habitat Restoration

The Water Framework Directive (2000/60/CE) has set the objective to achieve good ecological status for all waters in the European Union by 2015 (unless exception in 2021 or 2027).

In France, as in many European countries this objective is far from being achieved (Fig. 9).

The joint analysis of Figs. 8 and 9 shows that eels are mainly concentrated in areas where the ecological status of the water bodies is very often moderate (yellow colour) or poor (red colour). It is a major impediment to the achievement of the European Eel restoration programme.

According to the European Environment Agency (EEA 2012), "more than half the surface of the water bodies in Europe are reported to be in less than good ecological status or potential, and will need mitigation and/or restoration measures to meet the WFD objective". In addition, the EEA observed that river bodies and transitional waters have the worse ecological status compared to water bodies in lakes and coastal waters. The EEA concludes that "the worst area in Europe concerning ecological status and pressures in freshwater are in central and north-western Europe, while for coastal and transitional waters, the Baltic Sea and Greater North Sea regions are the worst" (EAA 2012).

6.2 Limiting Contamination by Organic and Metallic Pollutants

The effects of contamination by pesticides have been suspected and proven to be one of the major causes of the eel species declines worldwide (Robinet and Feunteun 2002; Feunteun 2002). The difficulty is to fix sublethal thresholds to target management options. Given that eels are semelparous and that they spawn in remote oceanic habitats, it is practically impossible to measure reaction norms and contamination thresholds beyond which transoceanic breeding migration, breeders survival, and larval survival are compromised (Robinet and Feunteun 2002).

According the European Environment Agency (EEA), "the chemical quality of water bodies has improved significantly in the last 30 years but the situation as regards the priority substances introduced by the Water Framework Directive (WFD) is not clear" (EEA 2012). In addition, that Agency observed "Monitoring is clearly insufficient and inadequate in many Member States (MS), where not all priority substances are monitored and the number of water bodies being monitored is limited".

In its last report (EEA 2012), the Agency reports the poor chemical status of the transitional water of 6 MS: Netherlands, Sweden, Belgium Flanders, Germany and France, water bodies of an extreme importance for the future of the eel resources.

Pesticides are the predominant cause of poor chemical status in Luxembourg, France, Belgium, Czech Republic, Germany, Spain, Hungary, Italy, Netherlands and Romania.

Heavy metals are identified as problematic by 21 MS and 15 MS highlight cadmium as a cause of poor status.

TBT (tributyltin), powerful biocide, now banning in Europe, remains found at high levels in the aquatic ecosystems. It is a particular issue in Belgium, France and UK.

In France (Fig. 10), as in many European countries (ICES 2018a), polychlorinated biphenyls (PCBs) have a great impact on the quality of the environment (Tchilian 2010). Between 1930 and 1980, about one million metric tons were produced worldwide. PCBs are mixtures of chlorinated biphenyl congeners and cause a wide range of toxics effects across species from mammal to fish (Monosson 1999). They are known to affect the hypothalamic-pituitary-gonadal-liver (HPGL) axis at almost every point (Thomas 1990). The liver serves as reservoir for PCBs as for many lipophilic chemicals, and many of these contaminants are incorporated into the vitellogenin and are taken up by the developing oocyte. It is an important way of exposure for developing embryos or larva (Monosson 1999).

In 2006, UE defined a maximum acceptable concentration of PCBs in products for human consumption.

In 2008, a French action plan was set up and took into account new health standards such as 12 pg/g fresh weight for eels.[8] That level is often exceeded in several eel populations living in the vicinity of industrial and urban areas as shown in Fig. 10: Northern and Eastern France in industrial areas, Paris Basin, Rhône river downstream Lyon. In some European countries, the sale of eels from some areas is forbidden (ICES 2018a). It is the case in France for eels caught in some rivers or part of the catchments impacted by urban and industrial activities. Through biological magnification, PCBs as chemicals or heavy metals concentrations increase with each trophic level of food chain. Eel, after a given size, is a carnivorous species and accumulates high level of contaminants, especially in its fat content. Some biological investigations have shown that pollutant accumulation is related to head dimorphism in eel (De Meyer et al. 2018). These authors found that broad-headed eels contained higher concentrations of mercury and several lipophilic organic pollutants, compared to narrow-headed ones, irrespective of their fat content: with increasing head width the trophic position of the individual increased.

[8]Picogram equals 10^{-12} g.

6.3 Marine Stages and Habitats

It is well accepted that global change has provoked severe oceanic regime shifts that have deeply changed the food web structure, temperature, currents and other parameters of the epipelagic intertropical marine habitats where the eel larvae live. In turn, this has very likely impeded larval growth, transport to continental habitats and survival (i.e. Miller et al. 2016 for a summary). This is completely outside the objectives of the management plans because the actions are way outside the control of regional or national staff in charge of eel management. Indeed, all the global changes issues are to be dealt with at the international level. To that end, eels could and should be considered as ambassador species for the Conference of the Parties (COP) on climate change.

7 What Happened 10 Years After the Implementation of the Eel Management Plan?

7.1 Trends in Glass Eel Recruitment: The Syndrome of the Broken Thermometer

Glass eel recruitment series are estimated from a mixture of observations from fishery-dependant and independent surveys focusing on different stages: glass eels, elvers, young yellow eels in estuary, lakes or rivers (Fig. 11).

The two separate areas: "North Sea" and "Elsewhere Europe" correspond to two geographical groups of eels (see Fig. 6): the Northern group on one hand and the Central and Southern groups on the other hand characterized by different types of eel habitats and irrigated by different branches of the North Atlantic Current: Azores Current in the South; the main branch of the north Atlantic drift in the central part of the eel colonization area and the northern part of the North Atlantic drift for the Northern group. Moreover, the time series that are used are highly variable, fishery dependant or not. The fishery-dependant series may either report total catches or CPUE, which provide a very different view of the trends, especially when under a quota and price controlled by CITES regulations (see § 2, Figs. 4 and 5). This certainly impacts the robustness and the meaning of the time series since the eel management has been implemented in 2010 and may lead to the impossibility to detect clearly short-term variability. This is the syndrome of the broken thermometer.

Figure 12 shows the extreme variabilities of time series allowing however to emphasize a declining trend of the recruitment at least since the seventies. But the question is: can we detect, from the implementation of the European Eel Management Plan, a significant increase of the glass eel recruitment at least in the central part of the colonization area that receives the main arrivals of glass eel?

As mentioned previously, the trend of total catches, especially after the implementation of the European Eel Management Plan,[9] makes it difficult to detect a potential increase of the glass eel recruitment (see Fig. 3 for example), hence the need to take into account the variation of the fishing effort and use some relative index as the catch per unit of effort. The example taken into account is the glass eel fishery of the Adour river where a long time series of marine glass eels catches is recorded by Ifremer and IMA (Institut des Milieux Aquatiques). The catches are splitted according to the fishing gear used: pushed sieve since 1995, anchored sieve since 2003 and hand-sieve since 1970. The trend of the hand-sieve time series is, as previously mentioned (see § 2), less influenced by the different regulation regimes and economical contexts before and after the implementation of the EU Eel Management Plan.

When comparing CPUE and total catches in a same river, the steepness or even the significance of the decline is not the same as shown in Fig. 13.

The total catches reported on the Adour river since the eighties do not allowed to detect an increase of the glass eel landings after 2013 (3 years after the beginning of the decrease of the fishing pressure on yellow and silver eel in Europe). The average catches on the period 2013–2016 is similar to the average in the previous period (2000–2012) and much lower than the average in the period 1990–1999. This is not the case for the CPUE (main graph Fig. 13): the average CPUE in the period 2013–2016 is similar to the average observed in the period 1990–1999 and much higher than that observed in the period 2000–2012. This difference between total catches and CPUE is explained mainly by the fact that the total catches in France are limited by quota since 2010 in each Eel Management Unit (EMU) (see § 5.1).

In this context, Bornarel et al. (2018) considered four different types of time series to estimate absolute recruitment variations using GEREM model (Drouineau et al. 2016) and following an upscaling design from rivers, to regions and finally Europe. As expected, their model showed a decline of the recruitment since the 1980s until 2009, with a significant variation among regions. The steepness of the decline decreased globally from northern to southern latitudes. However, this study did not discuss the effect of the Eel Management Plan on the significance of the fishery-dependant series since 2009. The authors however concluded that there is a need for additional data to properly characterize the glass eel recruitment trends.

7.2 Trends in Colonization of River Catchments

As mentioned by Adam et al. (2008), the estimation of the eel biomass in a whole catchment (especially a large one) is presently nearly impossible to achieve. To address this objective, a modelling approach has been developed to predict the abundance of eels according to information derived from the national freshwater fish

[9] Decrease of the fishing effort, limitation of catches, constraint of the eel market, …

survey (RCS[10] et RSA[11]) (Briand et al. 2018). This model has been applied to Ireland (de Eyto et al. 2016). It is also used to assess the abundance of silver eel potential per catchment unit and confronted to "real data" that are available from eel index rivers in France (Anon. 2018). However, the limitations of this model are numerous because the data set is mainly based on electrofishing and skews the results to shallow waters and does not properly take account of deep waters (large rivers, lakes) and to saline habitats (lagoons and estuaries).

Therefore, as quoted by Laffaille and Rigaud (2008): "Hence, observing the occurrence of the species or of some size groups can be useful at least in a first stage to visualize the current state of the resource and the way in which the situation is tending to evolve". The absence of eels from an eel suitable area or the absence of young eel stages from the lower part of the estuary or a lower part of a river is sufficiently explicit of the depletion of the eel resources. Seeing the reappearance of eels in the upper part of the rivers or the increase of the active zone (Fig. 14) characterized by the presence of individuals <15 cm[12] or between 15 and 30 cm[13] is a positive signal for the restoration of that species in a given catchment.

For example, on the Loire catchment, Canal et al. (2013) observed an increase of the eel abundance in the lower part of the Loire axis, increase mainly due to the important number of young eels inferior to 15 cm in size. The consequence is an increase of the presence probabilities of eels smaller than 30 cm at the tidal limit[14] in the Loire axis and an increase of the distance between the $D_{0.5}$ limit[15] and the tidal limit in 2013 compared to 2010. This shift of the $D_{0.5}$ limit upstream is confirmed in 2016 (Dufour 2016). Fig. 15 shows the evolution trend of $D_{0.5}$ limit for small yellow eels (size inferior to 30 cm) in the Loire axis.

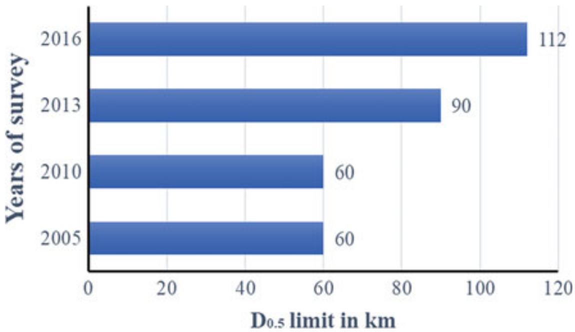


Fig. 15 Evolution trend of the $D_{0.5}$ limit for the young yellow eels on the period 2005–2016 in the Loire axis (from LOGRAMI data http://www.migrateurs-loire.fr/front-de-colonisation-de-languille/)

[10]RCS: Réseau de contrôle et de surveillance de l'état écologique des eaux.

[11]RSA: Réseau spécifique anguille.

[12]This size is a size limit for the young individuals newly recruited that begin the process of the catchment colonization.

[13]That size category corresponds to older individuals aged 2–5.

[14]Tidal limit: the maximum upstream location at which a tidal variation of water level is observed.

[15]$D_{0.5}$ limit: which corresponds to the distance from the tidal limit where the probability of observing eels less than 30 cm is equal to 0.5. It is a colonisation and accessibility index.

It is an encouraging sign and a positive result obtained after the reduction of the fishing effort on silver eel in Europe and consistent with the increase in glass eel CPUE reported by the marine fishers and observed in the Adour river (see Fig. 13).

8 Conclusion

The implementation of the UE Eel Management Plan in 2010 and the Member States operational measures derived from that plan show that important efforts have been made, since 2010, to control and decrease the fishing pressure on all the stages of the Eel biological cycle. However, further substantial efforts are required to improve the quality of eel habitats, the free migration of individuals towards and from some of their potential habitats. In many countries, the loss of surface becomes irreversible and the remaining surface is just a small part of the pristine eel habitat (ICES 2018a, b) making difficult, if not impossible, the achievement of the long-term objective of the UE management plan: 40% of the pristine biomass.

There exists also, due to a change of the fishing regulation regime: export ban to Asia, adoption of quotas associated with a slack market for glass eel restocking, a real difficulty to estimate the variation of the recruitment after 2010 compared to that of the previous period and consequently the impacts of fishing regulation from 2013. The significance of the total catches is not the same before and after the implementation of the UE Eel Management Plan. Even, the CPUE time series after 2010 have to be interpreted carefully and taking into account the gear used. So, a need to reinvent surveys and to deeply re-examine significance of the series to unravel effects of the change of fishing habits from those of the recruitment variability and recovery.

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