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European Eel: Ecology, Threats and Conservation Status

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

The European eel (*Anguilla anguilla*) stock was very abundant in the European waters until approximately over three decades ago when the stock began to decline drastically. Causes of the decline are believed to be a combination of overfishing of the eel in all its continental life stages: Glass eels, yellow eels and silver eels, deterioration of habitat by constructing hydropower plants, drainage of wetlands and pollution as well as climate change and introduced alien species, parasites and diseases. The purpose of this paper is to review the ecology, anti-demographic factors and various conservation efforts geared towards rebuilding the depleted stock.

Keywords: European eel; decline; ecology; anti-demographic; conservation efforts.

1. INTRODUCTION AND BACKGROUND INFORMATION

The European eel*, Anguilla anguilla (*Linnaeus, 1758), is a catadromous, amphi-haline and panmictic teleost species that belongs to the family Anguillidae, Nelson [67], Laffaille et al. [57]. They migrate inshore to the coastal waters, estuaries and streams where they spend a great deal of their time for breeding, feeding and

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developmental purposes, Ringuet et al. [74]. During their growth stages, factors such as, distance from the sea, depth and flow velocity of the streams, rivers, estuaries, etc that they inhabit tend to influence their spatial distribution and population structure, Lobon-Cervia et al. [63], Ibbotsson et al. [39], Laffaille et al. [56], Laffaille et al. [57]. European eel is an important species both ecologically and economically. For instance, in European waters, they account for a significant proportion of the faunal biomass and form an important component of fish communities, Moriarty and Dekker [66], Feunteun et al. [34] and they are essential prey for many predators such as herons and otters. As a result of their migratory pattern, they are essential for organic matter fluxes between marine and continental waters, Ringuet et al. [74]. Additionally, European eels are source of revenue for over 25,000 fishermen that rely on this species for their livelihood in the Europe, Moriarty and Dekker [66]. Over the last three decades, the eel fishery has experienced a drastic decline across its range due to factors such as overfishing, pollution, parasitism, inaccessibility of freshwater habitat, changes in oceanographic conditions, habitat degradation, Laffaille et al. [58], ICES [42] and is measured based on the analysis of catch landing records (ICES, [41], Aprahamian et al. [5], Castonguay et al. [20], Dekker [27], Dekker et al. [29], Kimura et al. [52], Kimura et al. [53]. Fisheries data indicate that the stock is at a historical level; the population is currently reaching only 1% of the 1960 recruitment level and, as a result, it is classified as “critically endangered” under the IUCN (International Union for the Conservation of Nature) Red list, Freyhof & Kottelat, [35]. This prompts and arouses interest and necessitates writing of this article whose objective is to review the ecology, demographic threats and the current management measures in place to restore and rebuild the depleted stock.

2. DISTRIBUTION AND CURRENT DEMOGRAPHIC STATUS

The European eel, which is a highly migratory species, extends across all accessible continental or coastal hydro-systems which are linked with the Baltic and North Seas as well as the English channel, Atlantic and Mediterranean coasts between Iceland and Mauritania (23°N to 70°N) and up to 45°E (Fig. 2), Bevacqua [12], Ringuet et al. [74], Dekker [26]. They are occasionally found entering the White and Barent Seas and have been recorded eastward to Pechura River in northwest Russia UNEP [84]. Since the 1980s, the continental abundance and recruitment (~ 80%) of the European eel have declined drastically throughout its distribution range as shown in (Figs. 2, 3 and 4) Moriarty and Dekker [66], Lobon-Cervia [62], Dekker [26], ICES [40,43] due to over-exploitation by commercial fishers and anglers with an estimated annual catch (of all life stages) of 30,000 tons, Moriarty and Dekker [66]. The main European eel fisheries are found along the coasts of Portugal, Spain, France, Morocco and the Bristol Channel of the United Kingdom Ringuet et al. [74]. Anon [4] reported that the landings dropped significantly to 43.5% over a period of 17 years (1984 to 2000). A few data series that take into account some fishing pressure indices, such as catch per unit effort (CPUE), indicate the same trends. The fisheries are mostly situated in estuaries and mouth of rivers and dams where the natural concentration of eels can be exploited. Capture techniques include both manual and ship based devices including; trawls, stow nets, long lines, shore seines, spears and fyke nets, Ringuet et al. [74]. Ringuet et al. [74] revealed that the optimal time for catching them eels is when they are migrating to the sea because by this time they should have reached maximum size with high fat content and peak condition.

Fig. 1. The European eel (*Anguilla anguilla*) – image from FAO

3. HABITAT, ECOLOGY AND REPRODUCTIVE BIOLOGY

During its continental phase, *Anguilla anguilla*, is found in a wide variety of habitats from small streams to large rivers and lakes and also in estuaries, lagoons and coastal waters. They can tolerate a wide range of temperatures and depths (Fig. 5) ranging from near subtropical to the Arctic Circle (UNEP, 2014). European eels are

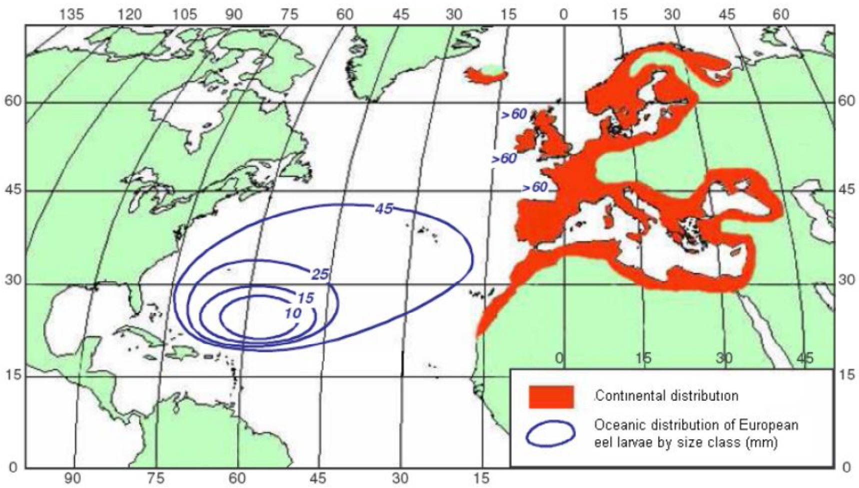

Fig. 2. Distribution area for *A. anguilla*, adapted from Adam [3]

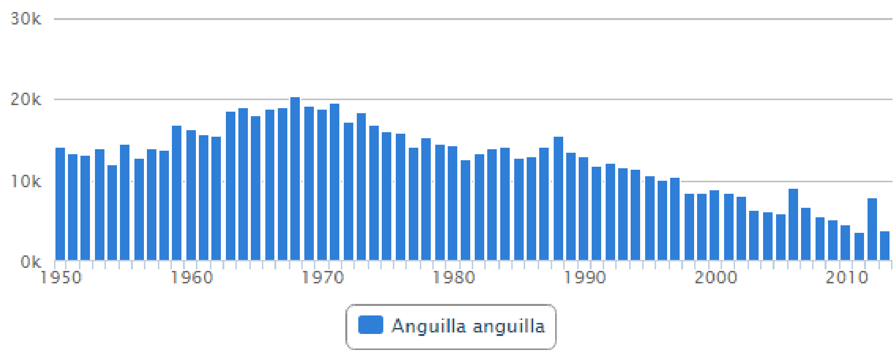

Fig. 3. Global landing statistics for eels since 1950-2013 (in tonnes) (FAO Fish-Stat)

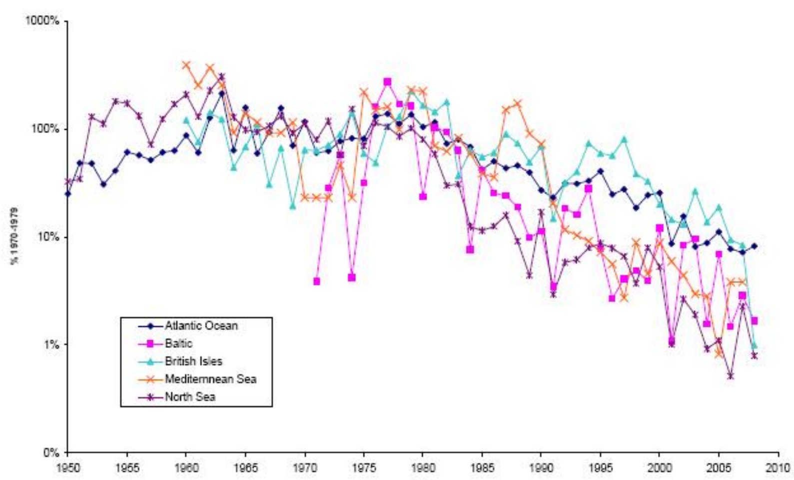

Fig. 4. Recruitment (glass eel and elvers) index per area in logarithmic scale. Each series have been scaled to 1970–1979 average, ICES [43]

tolerant to low oxygen environments and poor water quality and they exhibit several migratory behaviours both during oceanic and continental phases. Although, they are believed to originate from marine ancestors, Inoue et al. [49], their breeding habits are a conservative trait, Arai and Chino [6]. The migratory patterns of European eel's life cycle are the longest and most oceanographically complex of the *anguillid* species, Tsukamoto et al. [83]. The life cycle of European eel can be divided into a continental and an oceanic phase. Although, the eel is widespread on the European continent, they have been reported to spawn in the Sargasso sea (located south east of Bermuda), Aarestrup et al. [2], in the western part of the Atlantic ocean and the newly hatched larvae (*leptocephali*) are carried inland by prevailing ocean currents (Gulf Stream) over a period of a few months, Tsukamoto [82], Lecomte-Finigeri [59], to few years, Scmidt [77], Kettle and Haines [51]. On reaching the continental shelf, *leptocephali* metamorphose into glass eels (unpigmented), which colonise both coastal inland waters of the Atlantic and Mediterranean coasts. In these new environments, they undergo some physiological and behavioural changes such as pigmentation, active swimming and then enter into elver stage (small yellow eel). These young eels feed on plankton and detritus, Tanaka et al. [79], Mochioka [65], and they remain and grow in these coastal environments ranging for 3-8 years for males and 5-20 years for females until they reach maturity (around 400 mm for males and 600mm for females, Bevacqua [12]. At this stage, they develop into silver stage (size range from 30cm-1m in length and 300 g-3 kg in weight), become sexually mature and migrate (which may take 1.5-3years) back to the spawning ground (ocean) to complete their maturation processes, van Ginneken et al. [86, 87], spawn and then die (Fig. 6) Tesch [80]. When fully matured, they exhibit a diel vertical migration by inhabiting the deeper, cooler waters during the day and shallow, warm waters at night, Aarestrup et al. [1]. Mature females are always bigger and longer than the males.

4. ANTHROPOGENIC AND CLIMATIC THREATS AND IMPACTS

There is a growing concern on the fate of the European eel stock, Dekker et al. [28], which has experienced a 99% recruitment drop in the last 3 decades and is presently outside safe biological limits, ICES [42]. The causes of the declining recruitment and population of European eels are still not fully understood, Dekker [27]. Some of the few proposed causal factors are discussed below.

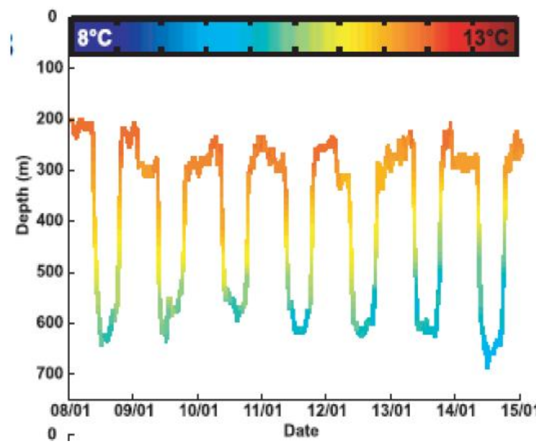

Fig. 5. Depth and temperature data from two satellite tagged European eels exhibiting diel vertical migration, from Aarestrup et al. [1]

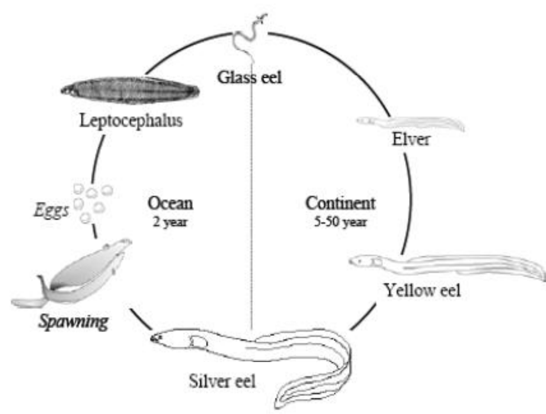

Fig. 6. The life cycle of the European eel Dekker [24]. The names of the major life stages are indicated

4.1 Habitat Destruction and Modification

One of the major threats to European eel population is the construction of barriers and structures such as hydropower-stations (turbines), flood control, dams, navigation weirs, canals, land reclamation, sand mining, embankment, water level management and the abstraction of surface and ground water for both domestic and commercial uses. Across Europe, there are a total of 24,350 hydropower plants and this figure is set to rise in the near future, van der Meer [85]. These barriers and structures tend to inhibit the upstream and downstream migration by preventing the eels from reaching their spawning grounds and result in loss of freshwater habitats and hydro-power turbines, screens, etc lead to sub-lethal injuries and mortality of eels (Fig. 7), ICES [40], Winter et al. [91], Jansen et al. [50], Calles et al. [17], Pedersen et al. [72], Piper et al. [73], Buysse et al. [16]. Several studies have shown that eels are blocked or killed when they migrate through oxygen depleted estuaries due to port activities and dredging, OSPAR [68]. Knights [55] and Robinet and Feunteun [76] found that the deteriorating water quality in aquatic ecosystems in Europe can contribute to eel mortality.

4.2 Overfishing

European eels are subject to fishing pressure at all stages of their life cycle from juvenile to adult and fishing mortality has been recorded very high, Dekker [24] cited in FAO [31]. They have been commercially exploited over the years and landings have declined in many areas and according to ICES [40], the number of European eels that succeed in reaching their spawning ground is very low. For instance, a high level of fishing mortality ranging from 20-25% have been recorded in open estuaries and about 98% in closed estuaries in France, ICES [40]. The exploitation rate on the Ijsselmeer Lake in Holland during the period 1989–1996 was estimated at 85 percent of all males and practically 100 percent of the females, Dekker [24]. At Grandlieu Lake in France the exploitation rate is estimated at 45–50 percent, Adam [3]. In addition, under-reporting, poaching and illegal trade have been found to further deplete the stock throughout the range of the European eel fisheries. Castelnaud et al. [18] reported an estimate of 520 tonnes of landed European eel by 4360 fishermen in France in 1989, out of which 73% were taken by non-professionals estimated to worth US$ 34 million, Rigaud [75].

4.3 Climate Change

Harsh climatic conditions tend to have adverse effect on the recruitment and demography of European eel. Durif et al. [30] showed a negative correlation between periods of high North Atlantic Oscillation (NAO) and recruitment due to larvae (*leptocephali*) drifted into cold water and slowing down their metamorphosis into the next stage (elver stage). It has also been observed that climate change is responsible for fluctuation in productivity and food availability for l*eptocephali* , Miller et al. [64]. Increased sea surface temperature in the Sargasso Sea since 1979 onwards is correlated with a sharp decline primary productivity and therefore likely affects recruitment in European rivers, Bonhommeau et al. [13,14]. Kimura et al. [52] pointed out a decline in catches of European and Japanese glass eels in years when El Niño occurs because any Japanese glass eel swim in unfavourable ocean currents. Temperature change in the region may also shift the spawning location of the species northwards which could, in turn, affect transport of *leptocephali* by ocean currents, Miller et al. [64].

4.4 Pollution

Recently, there is a growing concern and evidence that pollution by chemical contaminants such as DDT, PCBs, herbicides, pesticides, heavy metals, cyanotoxins, have significant influence on the health of the eel. European eels accumulate these contaminants especially in their body fat, tissues and gonads, Belpaire et al. [10], due to their physiological and ecological traits, Belpaire and Goemans [9]. These chemical burdens have detrimental effects on the physiological functions and processes,

Fig. 7. Mortality of European eels passing through hydropower turbines (© Sustainable Eel Group)

these include; impairment of osmoregulation, lipid metabolism, reproduction (gonado-genesis, delayed embryo and larval development), nervous and endocrine systems, Robinet and Feunteun [76], Palstra et al. [69], Geeraerts & Belpair [36]. The aforementioned contaminants are believed to be a crucial element declining the species, Belpaire [8].

4.5 Diseases, Parasites and Predation

Anguilla japonica was imported to Europe from Asia for farming purposes in the 1980s; the nematode found its way into natural watercourses and infected wild populations of the European eel, De Charleroy et al. [23]. European eels are susceptible to various forms of parasitic infections. These include; swim bladder nematode (*Anguillicola crassus*), viruses, fungi and other diseases. This is reflected in general health problems, including debilitation and mass mortality of the species. For instance, *Anguillicola* infections have been shown to damage the swim-bladder and affect the swimming ability and migratory pattern of the infected eel, Brusle [15], Würtz and Taraschewski [92], Palstra et al. [70], as well as negative physiological effects, such as impairment of osmoregulation and lipid metabolism, Gollock et al. [37]. Fazio et al [32] reported that *Anguillicola* infection had a disruptive influence on silvering. In Europe, eel populations are already from 30 to 100% infected with the nematode, ICES [43]. Wahlberg et al. [89] have shown that European eels are preyed upon by cetaceans during their migration and this has been confirmed and reported by Beguer-Pon et al. [7] that adult American and European eels are voraciously consumed by sharks.

5. EXISTING MANAGEMENT MEASURES

European Union has launched a legislative act (Council Regulation No. 1100/2007) establishing measures for the recovery of the stock of European eel. This regulation requires all member states to implement their eel management plans (EMPs), Bernotas et al. [11]. The development of active conservation policies has been recognized as a fundamental task for the maintenance of the European eel stock and the sustainability of a huge number of small-scale fisheries depending on its commercial harvest, Dekker [26]. Some of these Eel Management Plans (EMPs) are discussed below.

5.1 Fishing/Trade Ban

Since the middle of the 1900s, Dekker [25], and during this time, European eels have been consumed in large quantities in Europe, mainly by Spain.

Prior to 2011, the demand for European eels was primarily driven by East Asian countries, in particular Japan and mainland China, UNEP [84]. Substantial quantities are being purchased on the European market at "excessive" prices. In 2010 a ban on export outside the EU was imposed due to concern over the decline in recruitment and stocks of the European eel meaning there is no further legal trade to East Asia. International trade (for the EU: across external EU borders) is only allowed if a so-called Non-Detriment Finding (export will not be detrimental to the survival of that species) has been issued, Helcom [38]. In December 2010, however, the European Union banned all imports and exports of live and processed European eel to and from the EU, as it was not felt they could ensure that trade would not be detrimental to the species, Crook [22]. Authorities have seized several illegal European glass eel shipments destined for East Asian eel farms, Traffic [81]. France is without doubt the leading country with regard to glass eel exploitation. Commercial fishing for eels predominates in most estuaries of the Atlantic coast. Conversely, glass eel fishing is completely prohibited on the Mediterranean and in the Republic of Ireland, Norway and Italy commercial eel fishing or possession of glass eel for sale or consumption is forbidden, Moriarty and Dekker [66]. The ban is reviewed annually.

5.2 Gear Regulation/Restrictions and Licensing

There is strict regulation and restriction of fishing gears used by fishermen to catch eels in France, Portugal, Spain and the Bristol Channel of the United Kingdom. Standardized elver nets with a diameter of 1.2 mm; net size regulations are enforced in some French estuarine fisheries, which include standardized stow nets in River Minh, Moriarty and Dekker [66]. There is prohibition of specific fishing gears such as fyke-nets in a particular fishing area (e.g. Norway and Ireland) and all countries require yellow, silver and glass eel fishermen to take out a license to fish commercially, and some countries or regions add a requirement for compulsory catch returns for each license. In 2013, there were 1086 licensed fishers or companies operating in the

Estonian coastal fisheries alone. One hundred and thirty-eight of them reported eel catches, with only three reporting 50 kg in total, Bernotas et al. [11].

5.3 Restocking

In 2008, prior to the inception of EMPs in 2009, twelve countries proposed the use of stocking in their management plans to enhance eel populations. In 2013, stocking of glass eel was undertaken in 16 Member States, Moriarty and Dekker [66]. Indeed, the associated EU Regulation 1100/2007 requires that a proportion of glass eels/elver (<12 cm total length) caught must be used for restocking, UNEP [84]. Stocking with only commercial yellow eels carries the risk of spreading disease, reduced genetic fitness and skewed sex ratios, while the stocking of wild-caught young yellow eels from clean donor sites may be deleterious if they are subsequently relocated to contaminated recipient sites, Walker et al. [90]. Recent reviews by ICES [44] and Pawson [71] discussed the merits and drawback associated with stocking on the recovery of the European eel because there is a wide knowledge gap regarding growth, development, sex ratio, behaviour and migration of stocked eels before concrete conclusions on the effectiveness of such management plans can be determined, ICES [46]. According to ICES [47], the effects of stocking under EMPs cannot be demonstrated immediately because of the generational lag time but recent Swedish work indicates that stocked eels behave in the same way as natural recruits. However, the practice of stocking coastal lagoons is becoming less common due to environmental quality problems, but successful programs have been reported in Denmark whose eel production is sustained by stocking, Moriarty and Dekker [66]. Over 90% of the wild eel sold for consumption in Estonia comes from freshwater fisheries that rely almost exclusively on stocking, Bernotas et al. [11].

5.4 Habitat Improvement, Escapement Routes and Hydroelectric Turbines

The main objective of the current EU Eel Regulation is "permitting 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", Helcom [38]. The specific measures taken into consideration in habitat improvement comprise a variety of actions that are often somewhat vague in nature, ranging from those broadly relating to increasing habitat connectivity, and water quality improvement and to the adoption of protected areas. Habitat improvement measures generally have wide ranging impacts that affect all eel life stages, ICES [48]. Passes on migration barriers can play a useful role in enhancing migration and recruitment of young eel into certain freshwater catchments. Many of the hydropower mitigation measures are relevant to problems associated with mortalities, fatal or non-fatal injuries, pumping stations and other anthropogenic obstacles impeding riverine eel migrations, which are encountered from either impingement at turbine intake screens or following entrainment and passage through turbines. These measures involve either removal of barriers or installation of appropriate eel pass structures such as eel ladders, by-pass channels or pipes or troughs attached to barriers, provided with suitable climbing material, e.g. geotextiles, brushes or horticultural netting. Long-term post-construction monitoring is essential to ensure that passes are efficiently maintained and managed and to provide information for other schemes, Moriarty and Dekker [66]. Management plans range from commercial fishing measures such as regulating net sizes to removal or reduction of obstacles created by power plants and other anthropogenic sources (Fig. 8), ICES [48]. Their cost-effectiveness is not known yet, Knights [55].

6. DISCUSSION

The European eel stock is severely depleted. According to estimates from the International Council for Exploration of the Seas (ICES), until 2011, the recruitment level of glass eels (the number of baby eel produced each year) was only 1% compared to 1980s. Despite a statistically significant increase in glass eels recruitment since 2011, the abundance of eels at all the stages of their lifecycle remains very low. Managing a fish population and recruitment like that of the European eel poses a serious challenge, and therefore faces some highly variable socio-economic and legislation constraints. Several hypotheses have been formulated for the causal factors responsible for the general decline of eel densities in Europe, Castonguay et al. [19], Moriarty & Dekker [66], Feunteun [33], Dekker [26], Kirk [54]. Several studies of European elver or eel recruitment are available, Legault [60], Dekker [26], Legault et al.

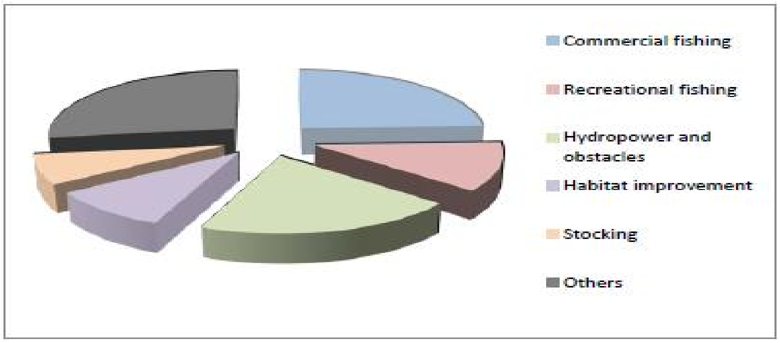

Fig. 8. The proportion of management actions of various categories implemented in EMPs across the EU, ICES [48]

[61], but few have related recruitment trends to population dynamics, Vollestad & Jonsson [88]. Recruitment trends continue to show a decline, posing a serious threat to the future of the species, as well as to its fisheries and aquaculture, Dekker [25]. Loss of habitat, especially that lost above barrages and dams (by disconnecting the available habitat from the stream), seems to be responsible for the decline, or even extinction, of local populations in some places, Chancerel [21], Moriarty & Dekker [66]. At present, migration of eels in many European rivers is impeded by dams, and it is estimated that 33% of habitat within the natural range of species is not accessible for natural or artificial reasons, [66]. Although the situation varies between countries, over 90% of habitat has been lost in Spain, and the eel is expiated in more than 80% of river catchments across Spain, although it remains abundant in a few coastal streams whose waters flow unimpeded into the sea, Lobon-Cervia [62]. Little success of habitat improvement and eel passage has been recorded and in the River Fremur (France) more than 100,000 eels have been caught since the eel passes have been monitored between 1997 and 2003, Legault et al. [61]. Although the presence of eels at Bois Joli before the passes were constructed suggests elvers can bypass the Pont es Omnès and Pont Avet dams, their construction has greatly improved access, and they are indispensable for colonisation of larger-sized eels (>120 mm), Laffaille et al. [58]. During the continental phase of their life cycle, European eels are fished with a variety of fishing gear at all developmental stages. Commercial fishing alone can indeed have a severe impact on the escapement of adult eels from continental waters Dekker [24], and a reduction of fishing disturbance can be attained in the short term if sound fishery policies are enacted, Bevacqua [12].

7. CONCLUSION, RECOMMENDATIONS AND NEED FOR FUTURE RESEARCH

There is an urgent need to develop an international monitoring network on eel quality, recruitment and migration as is widely acknowledged. Essential monitoring should reflect the highly migratory status of the eel while covering the scattered distribution area in continental waters and the wide range of fishing techniques on different life stages throughout the continent. Research co-ordinated between countries will be most cost-effective. There is also a need to install eel passes in all hydraulic structures that disrupt recruitment and decrease habitat availability, and evaluate their effects. There is a need to reduce the anthropogenic impacts until there is clear evidence that the stock is increasing, ICES [45]. Fishermen will be directly affected by the implementation of the EU Regulation, as commercial harvesting is easier to control than other pressures such as pollution, parasitism or habitat disruption. Intensive and collaborative research should be conducted on artificial breeding (aquaculture) of the European eel in captivity to allow a stable production and relieve the population partly from fishing pressure. Above all, it has been raised that the existing national management plans will not be sufficient to protect the species, Svedäng & Gipperth [78], suggesting the need for further actions.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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