KEYNOTE SPEAKER

THE EEL IN A POLLUTED WORLD – SURVIVAL OF THE FATTEST

Claude Belpaire and Caroline Geeraerts
Research Institute for Nature and Forest (INBO), Ministry of the Flemish Government,
Duboislaan 14, B-1560 Groenendaal-Hoeilaart, Belgium
claude.belpaire@inbo.be

Abstract
European eel (*Anguilla anguilla* (L.)) stocks are in decline in most of their geographical distribution and their status is considered below safe biological limits. The quality of potential spawners might be an essential element in the decline of the species since pollution by bioaccumulating chemical substances may have a large impact on the migration and reproduction success of the eel. This paper gives a brief overview of work conducted in Flanders (Belgium) to assess the status, trends and impact of noxious substances in the European eel.

Keywords: European eel, *Anguilla*, ecotoxicology, bioaccumulation, POPs

Introduction

The European eel is endangered. *Anguilla anguilla* (L.) is a widespread, panmictic and catadromous fish, widely distributed over Europe, with an important economic value for fisheries. The population is waning, as shown through recruitment monitoring in European rivers. Its stock is in decline for more than 30 years now.

In 2001 ICES considered the status of the stock as outside safe biological limits and concluded that current fisheries is not sustainable. Two years later eel scientists from 18 countries assembled at the International Eel Symposium 2003 organized in conjunction with the 2003 American Fisheries Society Annual Meeting in Québec unanimously raised an urgent alarm and asked for immediate action to save the declining eel resources (Québec Declaration of Concern).

Very recently, Europe added this fish species on the CITES and the Red List (World Conservation Union) and is now planning a stricter control on its trade. In September 2007 the Council of the European Union established a framework and measures for the recovery and sustainable use of the stock of European eel (EC 2007). Member states of the European Commission have proposed national eel management plans aiming a recovery of the eel stock. Brussels hopes to restore the stock focusing on maximal protection of potential spawners : the migratory silver eel, leaving continental waters, for their journey to their spawning place in the Sargasso Sea.

Life cycle
The European eel is a marine fish with a complex life cycle (Figure 1). Reproduction takes place in the Sargasso Sea (central North Atlantic Ocean) at some 5000 to 8000 km from the European continent. After hatching, the larvae (*leptocephali*) grow and drift with oceanic currents towards Europe. At the edge of the continental shelf the leptocephali metamorphose into *glass eel*. Depending on the latitude these glass eel enter European estuaries during winter or early spring. They pigment and either swim up the rivers in search for a suitable habitat to grow up or grow up in the coastal zone. This growing phase as *yellow eels* takes 3 to 20 years, dependent on gender (on average 5.9 years for males and 8.7 years for females) and local environmental variables (Vøllestad 1992). There is a marked sexual dimorphism with respect to size. Males have a mean length of 32-46 cm, whereas female mean size at maturity varies between 45 and 86 cm (Vøllestad 1992). Among fishes eels present extremely high lipid contents (Tesch 2003). These energy stores are essential for fulfilling their journey back to the spawning area. At the end of their growing phase, eels go through some morphological and physiological changes and become *silver eels*. In fall or early winter these silver eels leave continental waters to start their journey to the Sargasso Sea.

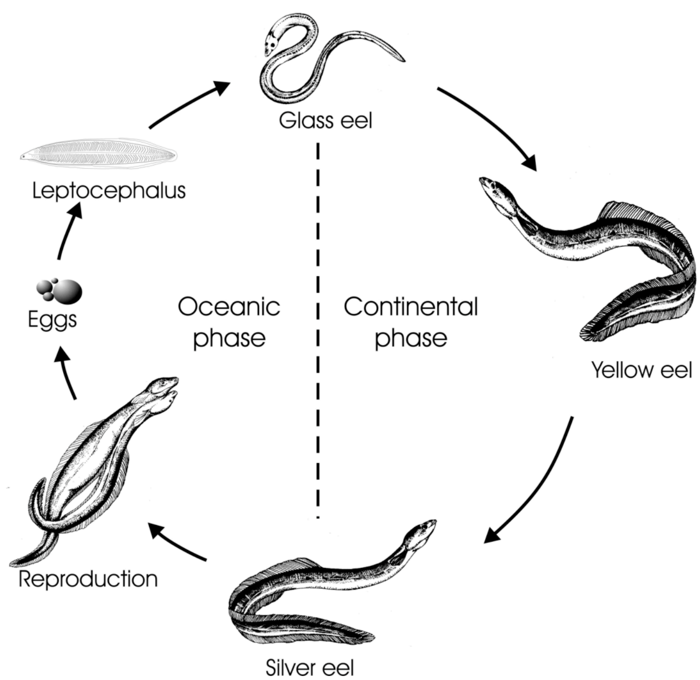

Figure 1. The life cycle of the European eel with indication of major life stages (from Belpaire 2008).

Why are the stocks declining?

The stock started to decline at the beginning of the 1980s. Monitoring series of the recruitment of glass eel ascending European rivers and estuaries have now dropped to *ca.* 1 % of the quantities observed during the 1970s and before. As an example Figure 2 represents the glass eel recruitment series for the River IJzer in Belgium. But also fisheries yields of both yellow and silver eels have declined considerably in most European countries.

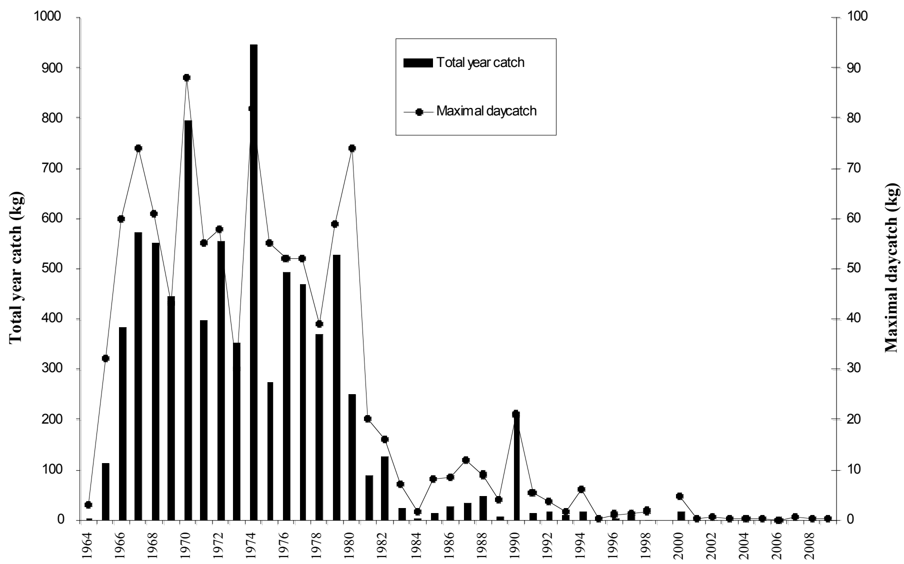

Figure 2. Trend in glass eel recruitment between 1964 and 2009 at the mouth of River IJzer, Belgium (Belpaire *et al.* 2009) The total year catches and the maximum daycatch per season are presented. Data Provincial Fisheries Commission West-Vlaanderen.

The reasons for this abrupt decline have not been firmly established. The international scientific community searches frenetically for evidence explaining the decrease of the stocks. Many potential causes have been suggested: climate change and oceanic variability (e.g. changes in currents, decrease in productivity) influencing (the migration of) the leptocephali; destruction of habitats in freshwater; physical obstruction of the migration by dams, sluices, pumps and hydropower; overfishing of glass eel, yellow eel and silver eel; infestations by introduced pathogens (parasites such as the swimbladder nematode *Anguillicoloides crassus*, and viruses such as EVEX) and predation.

Recently, benefiting from new scientific evidence, pollution received increasing attention as possible cause for the eel decline.

Eels as environmental indicators

Eels are fat, long-lived, benthic carnivores, and spawn only once during their lives. They are prone to bioaccumulation of especially lipophilic compounds. Yellow eels are highly sedentary. Their pollution load is thus expected to be indicative of the contaminant pressure of the site where they live. In this stage, within their on-growing habitat, movements (foraging behaviour or other) seem to be very limited, hence eels reflect the contamination present in this particular site. Consequently, we used the eel as a chemical bioindicator to identify and monitor noxious chemical compounds in the environment, especially lipophilic contaminants such as polychlorinated biphenyls (PCBs), organochlorine pesticides (OCPs) and brominated flame retardants (BFRs), but also heavy metals. An Eel Pollution Monitoring Network was set up over Flanders, an area of the northern part of Belgium (surface 13500 km^2) and more than 3000 eels from more than 350 locations were analysed between 1994 and 2009. In brief, most substances are omnipresent all over Flanders, but there is considerable variation between river basins, dependent on land use. Contaminant analysis in eel is able to pinpoint specific pollution sources, such as some volatile organic compounds in very specific locations, very high BFR levels in eels from areas with intensive textile industry, or high levels of the pesticide lindane in some rivers under agricultural pressure. We could demonstrate that banned chemicals like DDT are still in use in some places. Within the study period, trend analysis indicated significant reductions in PCBs and many OCPs. Also for some heavy metals (lead, arsenic, nickel and chromium), concentrations decreased in the eel, but this was not the case for cadmium and mercury (Maes *et al*. 2008; Belpaire 2008).

Self-caught eels are much esteemed by fishermen, but considering the eel's high contaminant body burden, consumption constitutes a potential risk for human health. Several measures have been taken in Flanders, such as a temporary catch and release obligation for eels caught between 2002 and 2006, and the legal enforcement of a maximum concentration for PCBs in fish and fisheries products. On ca 75 % of the sites, PCB levels in eel exceed however this legal upper limit (Figure 3). The intake of PCBs through consumption of eel by recreational fishermen was compared with the intake of a background population through a probabilistic approach. Anglers consuming their self caught eels on a regular basis may multiply their daily PCB intake by a factor 200. PCB intake through fishermen seems to be at a level of high concern, and body burden in fishermen in Flanders might reach levels of toxicological relevance (Roosens *et al*. 2008; Bilau *et al*. 2007).

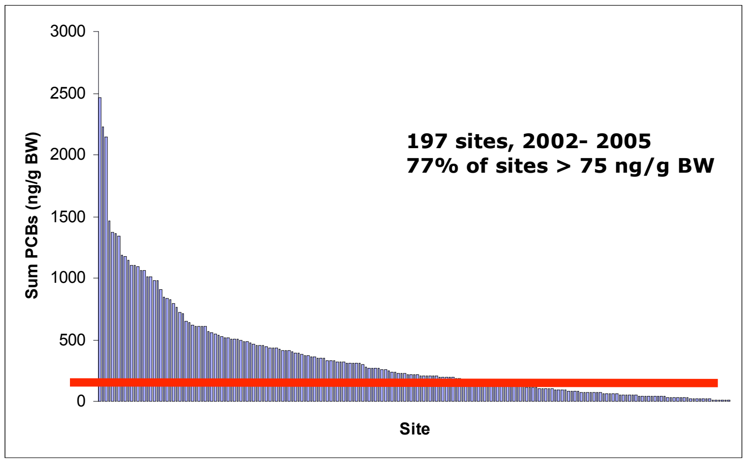

Figure 3. Mean PCB concentrations (ng/g body weight) in eels from Flanders (197 stations, 2002-2005). The legal food safety limit in Belgium is 75 ng/g body weight (red line).

Effects of pollution on the eel

Body burdens of contaminants in eels are in general a tenfold of the levels measured in other species. The increasing evidence of the negative impact of toxic substances on the eel has initiated a growing awareness in scientific community that pollution is a key factor in the decline of the eel stock. Pollution and contamination by hazardous substances is affecting the eel in various ways. A recent review (Geeraerts and Belpaire 2009) described the effects of different groups of contaminants on the European eel. A variety of contaminants have been found to affect the eel and these contaminants may cause disturbance of the immune system, the reproduction system, the nervous system and the endocrine system and effects were reported on several levels of biological organization, from subcellular, organ, individual up to even population level. On the yellow eel, considerable work has been done in Flanders.

Maes *et al.* (2005) described the effects of pollutants on the genome of yellow eels with variable metal load. We analysed the relationship between heavy metal bioaccumulation, fitness (condition) and genetic variability. A significant negative correlation between heavy metal pollution load and condition was observed, suggesting an impact of pollution on the health of yellow eels. In general, a reduced genetic variability was observed in strongly polluted eels, as well as a negative correlation between level of bioaccumulation and allozymatic multi-locus heterozygosity.

Van Campenhout *et al*. (2008) studied the effect of metal exposure on the accumulation and cytosolic speciation of metals in livers of European eel by measuring metallothionein (MT) induction. This research was carried out in four sampling sites in Flanders showing different degrees of heavy metal contamination (Cd, Cu, Ni, Pb and Zn). It was concluded that the metals, rather than other stress factors, are the major factor determining MT induction. There is other evidence that under field conditions liver functions may be damaged by contaminants. The effects of perfluorooctane sulfonic acids (PFOS) in Flemish eels were studied by Hoff *et al*. (2005), indicating that PFOS induces liver damage.

Although endocrine disruption seems a widely distributed phenomenon among freshwater fishes, no indications were found for estrogenic effects to occur in natural freshwater yellow eel populations in Flanders. The plasma VTG content of yellow eels was very low, despite a very high internal load of endocrine disrupters. It is assumed that endocrine disrupting effects of pollutants related with reproduction, will only become apparent during the maturing silver eel stage (Versonnen *et al.* 2004).

Recently, a significant decrease of the muscle lipid contents of yellow eels in Belgium and The Netherlands have been described (Belpaire *et al*. 2009). The magnitude of this decrease was considerable: from 20.0 to 12.3% over a 13-year period since 1994 in Belgium and from 20.6 to 13.1% in the Netherlands (Figure 4). Statistical modelling on an extensive dataset of contaminants from the Eel Pollution Monitoring Network (Geeraerts *et al.* 2007) demonstrated that some specific compounds (the higher chlorinated PCBs, and DDTs) have a negative impact on lipid content. Establishing sufficient lipid energy is essential in the life cycle of the eel. The silvering process, the subsequent downstream and transoceanic reproductive migration, as well as gonad maturation, can only take place if a sufficient quantity of energy is stored as lipids. Our observations of lowered fat levels now question the ability of these eels to start silvering and to achieve their spawning migration. Both, the reduction of the lipid energy as a consequence of (specific) contaminants, and the mobilization of high loads of reprotoxic chemicals during migration (Pierron *et al.* 2008; Palstra *et al*. 2006), seem to be key elements decreasing the probability of a successful migration and normal reproduction.

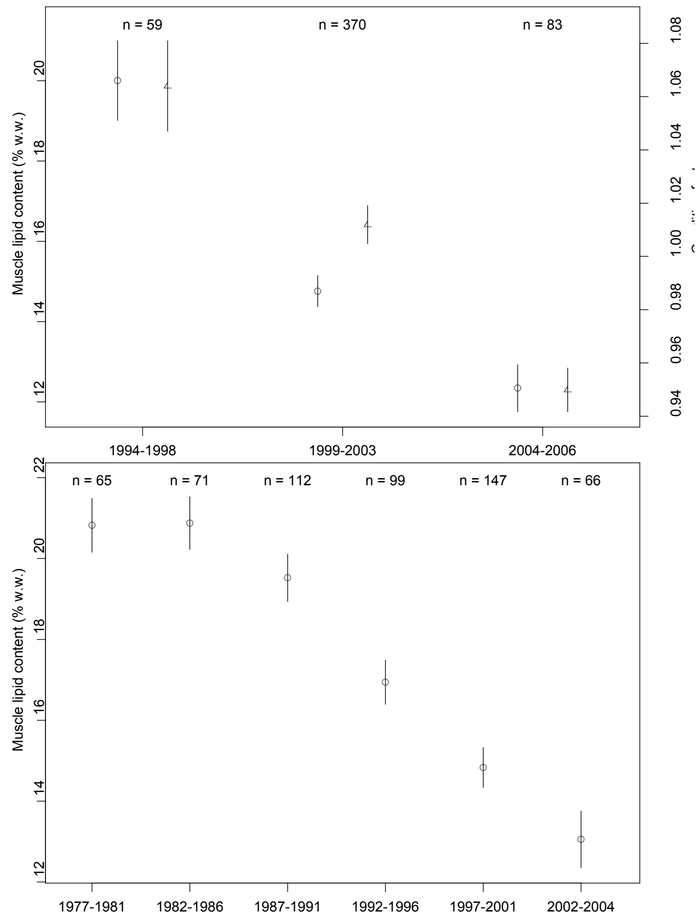

Figure 4. Decreasing fat contents (○) and condition factor (Δ) (means, bars indicating standard errors) in yellow eels in Belgium (above) between 1994 and 2006 and in The Netherlands (below) between 1977 and 2004. Secondary Y-axis is the relative condition factor (only available for Belgium). The number of sites is indicated. From Belpaire *et al.* (2009).

Conclusion

As described above many pressures have been suggested or demonstrated to negatively impact the eel stock. Maybe these pressures acted in a synergetic way, resulting in the collapse of the stock. It has been suggested that the most likely cause of the collapse in recruitment is an insufficient quantity of spawners leaving continental waters (Dekker, 2004), but considering the impact of hazardous substances, we may conclude that not only the quantity, but also the quality of the potential spawners, is a major reason of concern. Contaminant pressure in continental waters seems to represent a major threat for the European eel stock and will limit the possibilities of restoration of the stock. Hence, we believe that within the (inter)national eel restoration plans, measures to decrease contaminant pressure are an essential issue.

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