EEL: AN ENDANGERED SPECIES DUE TO HIGH CONCENTRATIONS OF PCBs AND OTHER ORGANOHALOGENS

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Introduction

Since the 1980s, the European eel (*Anguilla anguilla*) stock is in steep decline. Several suggestions have been made on the reasons of this decline: extensive fisheries, glass eel fisheries, climate change, pollution, endocrine disruption, insufficient energy for migration, oceanic changes, plastic litter at spawning areas, diseases and others[1]. Recruitment of other eel populations, American eel (*Anguilla rostrata*) and Japanese eel (*Anguilla japonica*) have also decreased over more or less the same period[2-4]. Eel is a somewhat mysterious fish. Different from all other fish species very little is known about its reproduction. Spawning of European and American is supposed to take place at significant depths in the Sargasso Sea but until know nobody has been able to watch that process. Only for the Japanese eel, the spawning location has been identified exactly: in the northern Pacific, near the salinity front. Japanese eel spawn during new moon periods throughout the spawning season, at depths of 150-200m[5]. It is unclear if reproductive failure, if taking place, is due to fewer eels reaching the Sargasso Sea due to low fat contents and related energy reserves or due to effects of chemicals on the reproduction itself. Spawning of Japanese eel takes place in the Pacific. Two large and independent data sets from Belgium and The Netherlands showed an average one-third decrease in fat contents of yellow eels over the past 15 years: from 20 to 12% in the period 1994-2006 in Flanders, and from 21 to 13% in the period 1985-2004 in The Netherlands[1]. High concentrations of polychlorinated biphenyls (PCBs) and other organohalogen compounds such as DDT, hexachlorocyclohexanes (HCHs), dieldrin, brominated diphenyl ethers (PBDEs) and hexabromocyclododecane (HBCD) have been reported in European, Japanese and American eel[6-8]. The high lipid contents of eel facilitate storage of PCBs and related compounds up to high levels in the body fat of the fish. When silvering, prior to leaving to spawn in the ocean, the fat content builds up to over 30%. Lipid reserves are essential to cover energetic requirements of migration.

The decrease in fat contents in Duch and Belgian eel was initially explained as the possible cause of the reduced migration and spawning success[1]. However, one important factor, the sex of the eels was not measured. Female eels have much lower fat contents than male eels. The sex of the eel only develops several months after arrival in Europe. Female eels occur mainly at locations with a less dense eel population, often marine locations such as the Wadden Sea[9]. New data on sex ratios of eels have now been made available. These data show significant changes in sex ratios with more female eels occurring in the rivers Rhine and Meuse, which explains the lower fat contents found in the pooled samples from the monitoring programs in The Netherlands and Belgium. What emerges from this observation is that the high PCB concentrations in the 1970s and 1980s have indeed had a dramatic impact on the eel stocks. What seemed a 'delayed' effect of these chemicals on the eel populations is now more easily explained.

Materials and methods

Pooled samples of 25 eels from ca. 25 locations in The Netherlands were analyzed every year. The eels were mainly caught by electro-fishing. The program has now lasted for more than thirty years and has delivered unique information with regard to temporal trends and spatial differences in PCB concentrations in the delta of the rivers Rhine and Meuse and other Dutch freshwaters. Details of analysis have been reported before[6,9]. The fat contents were reported separately[1]. Body fat of eel consists of >99% triglycerides. An extractable lipid determination based on a Soxhlet extraction with n-pentane/dichloromethane (1:1, v/v) was, therefore, sufficient to quantitatively extract all lipids. The entire program, including the determination of the sex ratios was carried out at the Netherlands Institute for Fisheries Research (RIVO), IJmuiden, The Netherlands. More recent information on sex ratios was made available by the Dutch Ministry of Agriculture, Fisheries and Nature Management[10].

Results and discussion

The sum of the seven PCB congeners in eel from the rivers Rhine and Meuse varied from 10-30 mg/kg lipid weight (lw) in the first decade of the program to 5-10 mg/kg lw during the last decade. This corresponds with ca. 2-6 mg/kg wet weight (ww) and 0.7-1.5 mg/kg ww, respectively. PCB patterns were different between the rivers Rhine and Meuse, with more higher chlorinated congeners in the River Meuse, but also changed over time, with e.g. lower percentages of lower chlorinated congeners in river Rhine eel later in the program[5]. These two rivers are among the sites with the highest PCB contamination in the world. At most locations, temporal trends now show slowly decreasing PCB concentrations. Eels from the rivers Rhine and Meuse still exceed present European maximum residue limits for dioxin-like PCBs[11]. The data from this monitoring program predict that it will not be until 2200 before PCB levels in Dutch eel will decrease below detection limits (ca. 0.03 µg/kg lw). Apart from PCBs, relatively high concentrations of organochlorine pesticides (OCPs), PBDEs and HBCD have been found in eels from these rivers. Dioxins have also been analysed and were reported to exceed European tolerance levels. Interestingly, the tolerance limits for PCBs and dioxins have decreased almost in parallel with the PCB and dioxin levels in eel. Initially, a Dutch congener-specific tolerance limit was set for eel consumption: 200 µg/kg ww for PCB52, 400 µg/kg for the congeners 101 and 118, 500 µg/kg for 28, 138 and 153, and 600 µg/kg for PCB 180. Exceeding one of these would label the eel as unsuitable for consumption. The current PCB concentrations in eel are below these limits. However, new insights, in particular developed after the Belgian dioxin crisis, have led to new European tolerance levels for dioxins and dioxin-like PCBs[10]. The new limit, 12 pg/g ww for eel is exceeded by all eel samples from the Rhine and Meuse.

A clear and significant decrease in the fat content of eel from both The Netherlands and Belgium, from 1 down to 13% (average values) was reported by Belpaire et a1.[1] Due to the lack of information of sex ratios it was suggested that the decreasing fat contents had negatively influenced the numbers of silver eel that could successfully migrate to the Sargasso Sea and spawn. However, the new sex ratio data show that there has been a significant shift in this ratio[10]. Whereas mainly male eels were found in these rivers, nowadays the majority of eels is female (Table 1). Female eels have a preference for selecting locations for their stay in Europe with less densely eel populations. Female eels are also much leaner than male eels, although they grow to greater lengths. The change in sex ratio to the favor of female eels should, therefore, be seen as *a consequence* of the decreasing eel stock.

Table 1. Sex ratios of eel in from The Netherlands in 1984 and 2009.

	1984 Rhine, Meuse delta (N=25)	2009 Rhine, Meuse delta (N=ca. 90)	1984 Wadden Sea (N=25)	1984, Fluessen, Friesland (N=25)
Female %	4	71	96	28
Male %	96	29	4	72

This new insight helps to explain the relation between the high PCB levels in the 1970s and 1980s and the decrease of the eel stock. The highest PCB concentrations were found when the monitoring program started, around 1975-1978. It is unlikely that the PCB levels have been much higher before, as the PCBs were only discovered in the environment in 1966. A conservative estimate of the peak in PCB levels in The Netherlands would, therefore, be around 1975, maybe back to 1970. It takes ca. 10-15 years for eel to mature. That means that from ca. 1980 onwards, most silver eels migrating from The Netherlands have shown seriously elevated PCB levels. If this would have led to a lower number of glass eels returning to Europe – and this is confirmed by the decreasing numbers of returning glass eels starting in 1977[12] – the eel population in the Rhine and Meuse should have gradually decreased since then. This again would have led to more female eels compared to male eels and, consequently, lower fat contents in pooled samples from those locations. The first signs of decreasing fat contents in eel were seen in the period 1987-1991[1]. This sequence of high PCB levels, lower numbers of returning glass eels, and change in sex ratios in favor of female eels with lower fat contents, fits much better in time than a possible direct decrease of lipid contents due to interaction with contaminants or their hydroxylated metabolites. Hydroxylated metabolites would mimic the well-known slimming tool 2,4-dinitrophenol, leading at the end to a lethal process. This explanation was, however, hampered by the long time-span between the peak in PCB levels and the decrease of the fat contents ca. 15-20 years later.

A comparison of fat contents in pooled eel samples from different locations suggests that the detrimental effects on the eel stock have been larger at locations with a cocktail of high contaminant concentrations. Figure 1 shows that the fat content of the eel from the Twentekanaal, and to some extent that in eel from the river Roer, decrease faster than those in eel from other locations. Characteristic for the Twentekanaal is the high load of HCHs due to a historic deposit of lindane[5]. This led to high concentrations of all HCH isomers (sum HCH > 5 mg/kg lw) in eel from that location on top of a PCB contamination. The river Roer was characterized by an even higher level of PCBs than in the rivers Rhine and Meuse, caused by hydraulic fluid leakages in a German mining area. The PCB pattern showed much lower chlorinated congeners (28 and 52). On top of that tetrachlorobenzyltoluenes (Ugilec) and relatively high levels of PBDEs were found.

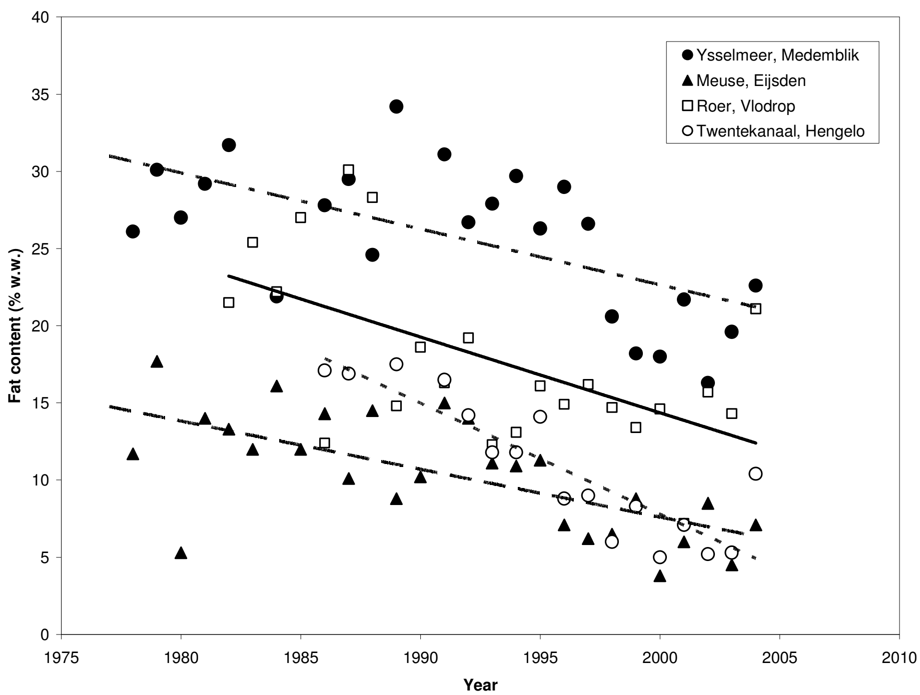

Fig. 1. Temporal trends in fat contents in eel from The Netherlands. Regression curves: IJsselmeer y=-721.24 ln(x)+5504, R^2=0.38; Twentekanaal: y=-1435.4 ln(x)+10918, R^2=0.78; Roer: y=-979.6(x)+7460, R^2=0.34; Meuse: y=-619.14ln(x)+4713, R^2=0.43 (Reprinted from Ecol. Freshw. Fish. 18 (2009): 197-214).

Given the decreasing eel stocks in North America and Japan, occurring at the same time as those in Europe, given the high PCB and other organohalogen concentrations in eel in Europe, North America and Japan, given the decrease of the cod stocks in the North Sea, in which extremely high PCB levels were and are being found in their livers which contain ca. 50% of lipids[13], it seems likely that PCBs and other organohalogen contaminants such as HCHs are related to the decrease of fish populations with high fat contents in their body or in their liver such as eel and cod. Of course, other processes may also play a role. Direct effects of PCB metabolites on the lipid contents should not be excluded. The change in sex ratios caused by a diminishing stock, may in itself have further consequences for the spawning success. However, given the current knowledge, little doubt remains on a relationship between the eel stock decrease and high levels of PCBs and related contaminants. We can only hope that due to the ban of PCBs decreasing PCBs levels may help to restore the eel stocks again. However, the PCB trends in the Rhine and Meuse develop very slowly. Ca. 200 years will be needed before PCBs will have disappeared. Other solutions are not easily found. Catching larger amounts of eel in those rivers and let them grow at a different place until silvering may lead to a better quality silver eel and a better recruitment, but moving them from their original location into other waters may imply other risks. To save the eel for future generations further research into this matter seems a wise thing to do. From their experience, local eel fisherman may be of great help in such studies. Authorities should seek funding from industry, such as in case of the Sandoz incident[14], to support such research. On top of that, authorities, industry and environmental scientists should be extremely aware of new emerging chemicals. Chlorinated paraffins, produced in extremely high amounts in China could easily be e next generation of contaminants causing other species to become extinct.

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