Eels : contaminant cocktails pinpointing environmental contamination.

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Abstract

Recently some scientific evidence has indicated that insufficient quality of the silver eels leaving the continental waters for migrating to the spawning areas might be a key factor explaining the overall decline of the stock. High contaminant accumulation in the eel and poor physiological condition might be responsible for failure of migration and/or impairment of successful reproduction. During a 12-year study on a relatively small area within the river basins of Ijzer, Scheldt and Meuse (ca 13 500 km²) 2 613 eels were harvested covering a dense monitoring network of 357 stations. Eels sampled were analysed for a series of ca 100 chemicals. These include PCBs, organochlorine pesticides, heavy metals, brominated flame retardants, volatile organic pollutants (VOCs), endocrine disruptors, dioxins, perfluorooctane sulfonic acids (PFOSs), metallothionines and polycyclic aromatic compounds. This series represents only a very small fraction (less then 0.5 %) of the more then 30 000 chemicals currently marketed and used in Europe. Two major conclusions can be drawn. The indicator value of eel as a tool for monitoring environmental contamination, both for local matters and for international issues (evaluating the chemical status for the Water Framework Directive) is evident. Considering the variation in contaminant profile and intensity it is highly probable that the degree and potential of reproduction for eels leaving our system will vary a lot dependent on the level of pollution in the habitat where the eels grew up.

Keywords: European eel, *Anguilla anguilla*, Flanders, bioaccumulation, pollution, spawner quality, Water Framework Directive

Introduction

Recently some scientific evidence has indicated that insufficient quality of the silver eels leaving the continental waters for migrating to the spawning areas might be a key factor explaining the overall decline of the stock. High contaminant accumulation in the eel and poor physiological condition might be responsible for failure of migration and/or impairment of successful reproduction. It was recommended by the EIFAC/ICES Working Group on Eels (WG Eel, 2006) and by the Scientific, Technical and Economic Committee for Fisheries (STECF, 2006) that the

WFD should use eel (*Anguilla anguilla* L.)as a sentinel species for monitoring the chemical status of surface waters with respect to hazardous substances.

During a 12-years study on a relatively small area within the river basins of Ijzer, Scheldt and Meuse (ca 13 500 km²) 2 613 eels were harvested covering a dense monitoring network of 357 stations. Eels sampled were analysed for a series of ca 100 chemicals. These include PCBs, organochlorine pesticides, heavy metals, brominated flame retardants, volatile organic pollutants (VOCs), endocrine disruptors, dioxins, perfluorooctane sulfonic acids (PFOSs), metallothionines and polycyclic aromatic compounds and were reported in various papers (Goemans *et al*., 2003, Roose *et al.*, 2003, Goemans & Belpaire, 2004, Morris *et al*., 2004, van Campenhout, 2004, Versonnen *et al*., 2004, Hoff *et al*., 2005, Maes *et al*., 2005).

A small number of specific substances were selected to discuss in this paper, in order to document the use of eel for pollutant monitoring for environmental issues and local management. On a broader scale the use of this monitoring strategy in the context of the Water Framework Directive is discussed.

Body burdens of selected chemicals in eels

Volatile organic compounds in eel

Volatile organic compounds (VOCs) are atmospheric contaminants that are frequently determined in air, drinking water, fresh water, effluents and soils. Many of these compounds are substances of concern, some of them are on the list of priority substances proposed by the WFD (CEC, 2006). A series of 52 VOCs was analysed in eels from 20 sites and were reported by Roose et al (2003). The most prominent VOCs were the BTEX and a number of chlorinated compounds such as chloroform and tetrachloroethene.

<u>1, 2-dichlorobenzene (or o-dichlorobenzene)</u>

This VOC with a low water solubility (118 mg/L at 25°C) is an intermediate for making agricultural chemicals, primarily herbicides. Other present and past uses include: solvent for waxes, gums, resins, wood preservatives, paints; insecticide for termites and borers; in making dyes; as a coolant, deodorizer, degreaser.

On the basis of its volatility and the dispersive nature of its uses, it is expected that 1,2-dichlorobenzene is released to the environment, primarily in liquid effluents and atmospheric emissions from production and other facilities. But possibly also as a result from the dehalogenation of more highly chlorinated chlorobenzenes (Bosma *et al.*, 1988) and in emissions from incineration of organic matter containing chlorine (Young and Voorhees, 1989). 1,2-Dichlorobenzene has been reported from a survey of effluents of 10 Canadian textile mills conducted in 1985-86; concentrations were reported to range up to 95.5 mg/L (Environment Canada, 1989).

Analysis of this chemical in eels from 20 locations collected between 1996 and 1998 showed a diverse pattern (Figure 1, after data presented in Roose *et al*., 2003). On 10 sites (50%) levels were below the detection limit. However eels from two sites showed high levels of dichlorobenzene (Oude Leie at Wevelgem 85 ng/g wet weight and Leie at Menen 49 ng/g wet weight). Few studies have been presented concerning the presence of 1,2-dichlorobenzene in fish. Based on studies conducted in the Great Lakes in the early 1980s, the concentration of 1,2-dichlorobenzene in lake trout (*Salvelinus namaycush*) and rainbow trout (*Oncorhynchus mykiss*) ranged between 0.3 and 1 ng/g wet weight respectively (Oliver and Nicol, 1982; Oliver and Niimi, 1983; Fox *et al.*, 1983).

Both sites with the reported high levels of dichlorobenzene were situated on or in the vicinity of the River Leie. Each of the stations is in the neighbourhood of important industrial companies. One company is located at Wevelgem and is active in the textile finishing industry. These activities comprise pre-treatment, dyeing and finishing treatment with diverse chemicals. The company is one of the largest dischargers (2 990 m³ /day) directly in the river. Another company is situated at Menen. It is a large manufactory producing pigments used especially by the paints, ink and plastics industries. It is discharging 3 348 m³ water/day (Anon., 2003).

A network is in place for monitoring some VOCs in water on a selection of ca 40 sites measured monthly. From Figure 2 and Table 1 it is obvious that this compound is difficult to detect in water. In water 95% of the measurements are under the detection limit, compared to 50 % for analysis in eel tissue.

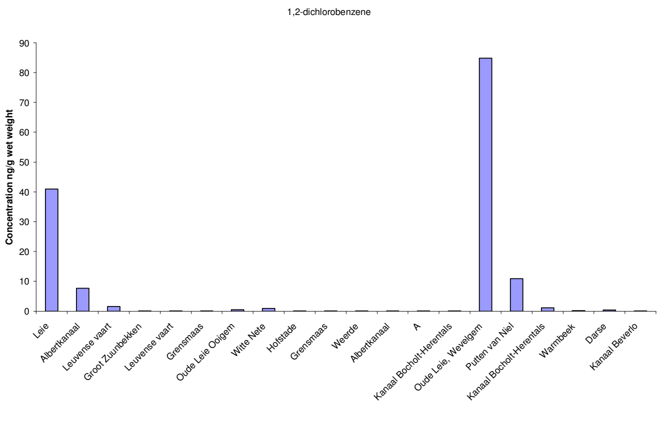

Figure 1. Concentrations of 1,2-dichlorobenzene in eels collected on 20 sites in Flanders (1996-1998). Data from Roose *et al*. (2003).

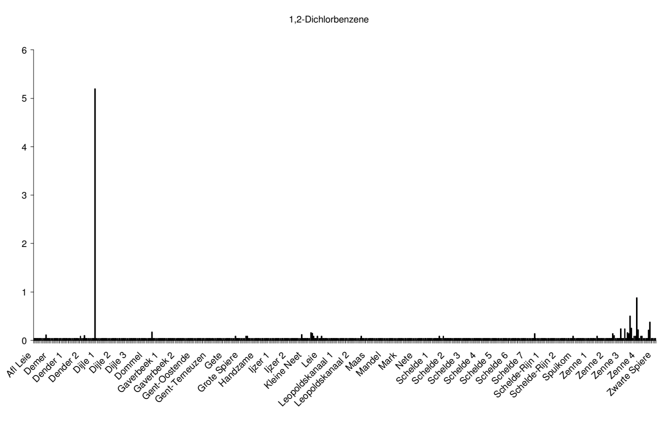

Figure 2. Concentrations of 1,2-dichlorobenzene in water collected monthly on ca 40 sites in Flanders (2005). Concentrations under the detection limit were set on the detection limit. Data from the Flemish Environmental Company.

Nothing is known about the ecotoxicological effect of 1,2-dichlorobenzene on eel. Impairment of reproduction was identified as the most sensitive toxicity end-point reported for aquatic organisms. Ahmad *et al.* (1984) reported the 96-h LC_{50} in rainbow trout (*Oncorhynchus mykiss*) to be 1.61 mg/L. Black *et al.* (1982) studied the susceptibility of the embryo-larval stages of fish to 1,2-dichlorobenzene. The organisms were exposed from 20 to 30 minutes following fertilization of the egg to 4 days after hatching of the larva. LC_{50} s were 3.01 mg/L for the rainbow trout (*Oncorhynchus mykiss*), following total exposure times of 27 days, respectively.

Table 1 Concentration of 5 VOCs as measured in water and in eels. Data from the Flemish Environmental Company and Roose et al. (2003) respectively. Values in water are expressed in µg/L, in eels in ng/g wet weight.

Substance	Water (470 measurements, 2005)			Eel (20 sites, 1996-1998)		
	Min - Max	Mean	% < D.L.	Min - Max	Mean	% < D.L.
1, 2-dichlorobenzene	0.044- 5.2	0.06	95.5	0.02-84.8	7.5	50
Benzene	0.007-2.68	0.06	83,4	1.2-18.9	5.7	0
Toluene	0.03-15	0.28	86.4	1.0-72.6	19.0	0
o-Xylene	0.05-1.6	0.07	94.9	0.6-39.7	7.1	0
Ethylbenzene	0.043-2.2	0.06	94.9	1.2-35.6	14.9	0

1,2-Dibromo-3-chloropropane

1,2-dibromo-3-chloropropane was used as a pesticide (registered by US EPA as a soil fumigant to control nematodes during growth of crops). The US EPA banned all uses of 1,2-dibromo-3-chloropropane in 1985. 1,2-Dibromo-3-chloropropane is now used only as an intermediate in organic synthesis and for research purposes (ATSDR 1992). 1,2-Dibromo-3-chloropropane breaks down slowly in the air. Most of the 1,2-dibromo-3-chloropropane that is released to the air disappears within several months. Most of this chemical that enters surface water evaporates into the air within several days or a week.

From 20 sites eels were analysed, but 80% was under the detection limit (Fig 3), but staggering high levels were found in eels from two canals (Leuvense vaart 265 ng/g and Albertkanaal 706 ng/g). Both are important canals situated in the centre of Belgium. These data are indicating pollution sources of this chemical in those areas, however the origin of the presence of this chemical in these high amounts is still unclear.

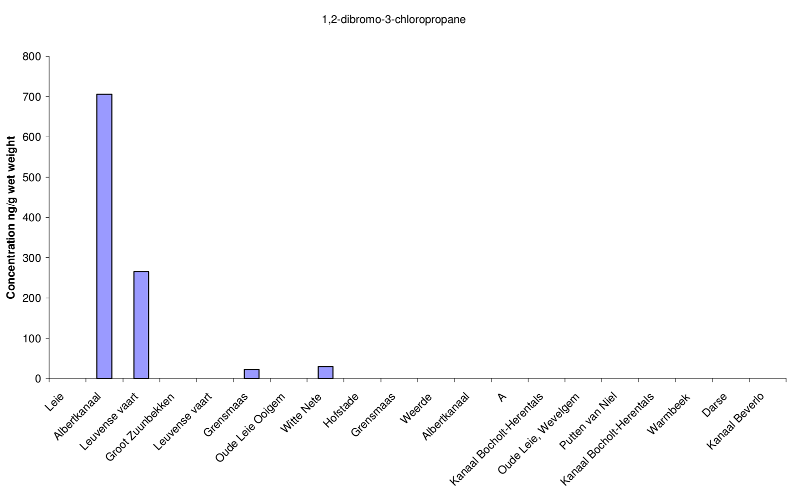

Figure 3. Concentrations of 1,2-dibromo-3-chloropropane in eels collected on 20 sites in Flanders (1996-1998). Data from Roose *et al*. (2003).

Following ATSDR (1992), 1,2-dibromo-3-chloropropane does not stick to the soil at the bottom of rivers, lakes, or ponds, and fish was not expected to build up large amounts of this chemical in their bodies. Our results nevertheless suggest that in some cases bioaccumulation of this chemical in fish may occur.

There are no ecotoxicological studies of the effect of this chemical on eel. Studies of workers in chemical factories that produced 1,2-dibromo-3-chloropropane showed that its main harmful effect is on male reproductive organs, lower production of sperm, and lower ability to reproduce.

BTEX compounds

Benzene, toluene, ethylbenzene and the xylenes (BTEX) are important industrial compounds amongst the VOCs. Moreover, BTEX compounds are important additives to unleaded gasoline and are present in crude oil. Benzene is on the list of priority substances proposed by the WFD (CEC, 2006). Industrial processes are the main sources of benzene in the environment. Benzene levels in the air can be elevated by emissions from burning coal and oil, benzene waste and storage operations, motor vehicle exhaust, and evaporation from gasoline service stations. Industrial discharge, disposal of products containing benzene, and gasoline leaks from underground storage tanks release benzene into water and soil (ATSDR, 2005).

In figure 4 the body burdens of benzene, toluene, ethylbenzene and m-xylene are presented. It is striking that all compounds are detectable on every site (N=20). The distribution of BTEX over Flanders is thus much more widespread than most of other chemicals. The variability of the data is somewhat less than for the other chemicals. Furthermore the BTEX compounds were found to correlate extremely well with each other, with correlation coefficients between 0.77 and 0.98 (Roose *et al*, 2003). This is indicating that contamination by BTEX is of a rather diffuse nature which supports the conclusion that the use of fossil fuel in, e.g. traffic, is the major source of BTEX. BTEX are common constituents of diesel oil and many petrochemical products, and are emitted in the exhaust gases of combustion engines (Howard 1989, 1990, Crookes *et al.,*1993).

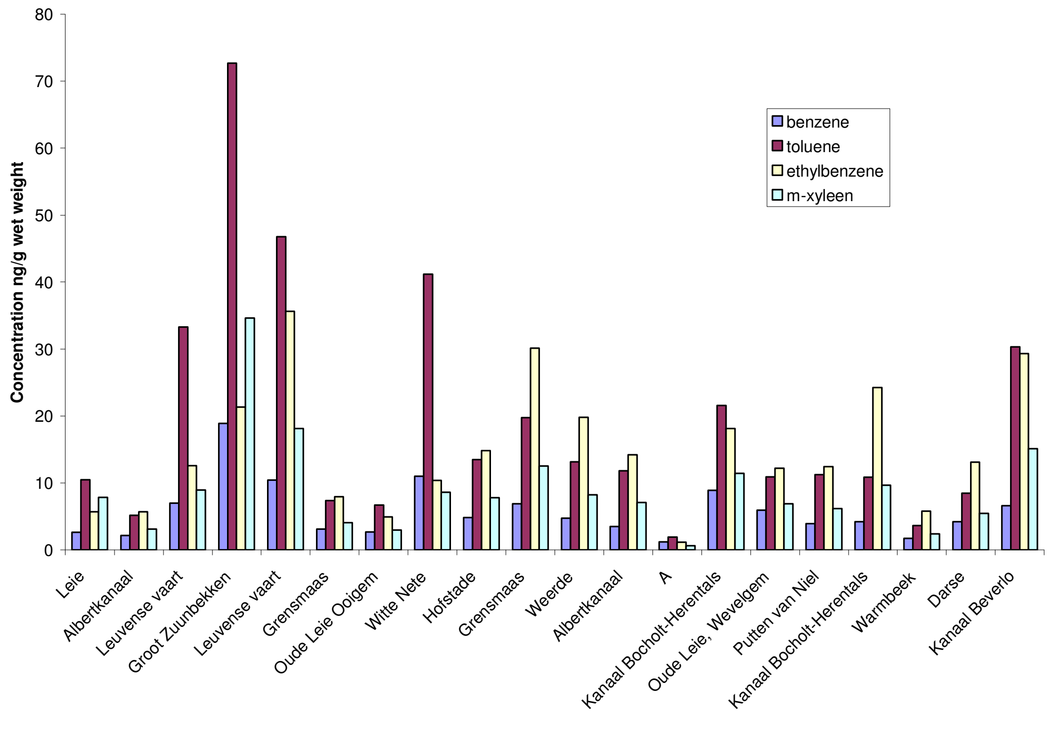

Figure 4. Concentrations of BTEX compounds in eels collected on 20 sites in Flanders (1996-1998). Data from Roose *et al*. (2003).

The high concentrations observed at the Groot-Zuunbekken station can possibly be explained by the fact that this is a pond in a densely populated and industrialized area just south west of Brussels. Another source might be a large chemical industry located at Drogenbos (at 9 km of this sampling site), producing plastics in primary forms and emitting directly 0,46 tons/year of BTEX (EPER, the European Pollutant Emission Register). In distinct contrast, eels from rural locations, such as the A (at Poppel) or the Warmbeek (at Achel), have a significantly lower body burden.

Once again, comparison of the BTEX data in eel versus the levels found in water (see table 1), gave evidence that a monitoring strategy for these compounds should preferably be based on biota instead of water.

Brominated flame retardants

Brominated flame retardants or BFRs are chemicals used to inhibit or impede flammability in combustible products. Several groups of BFRs exist, e.g. Hexabromocyclododecane (HBCD) and Polybrominated diphenylethers (PBDEs), which have different applications. HBCD is mainly used to flame retard extruded and expanded polystyrene used for thermal insulations, but also in upholstery textiles. PBDEs are known in three commercially produced mixtures Penta-BDE, Octa-BDE and Deca-BDE. Penta-BDE is used primarily in foam products such as seat cushions and other household upholstered furniture as well as in rigid insulation. Octa-BDE is used in high-impact plastic products, e.g. computers. Deca-BDE is used in plastics, such as wire and cable insulation, adhesives, textile and other coatings. Typical end products include housing for television sets, computers, stereos and other electronics. Deca-BDE is also used as a fabric treatment and coating on carpets and draperies. Deca-BDE is not used on clothing.

BFRs are of major concern as the occurrence of these chemicals in all compartments of our environment is increasing. Generally spoken the toxic activity of these compounds are similar to PCBs. PBDEs are on the list of priority substances proposed by the WFD (CEC, 2006).

Figure 5 is illustrating the presence of PBDEs and HBCD in yellow eels from 18 sites in Flanders. Both groups of chemicals were detected in all samples, indicating the widespread distribution of these chemicals (even in remote areas). But obviously, the analysis of the eel tissues has pointed towards important local pollution with HBCD (Hexabromocyclododecane) and PBDEs (Polybrominated diphenylethers) on some locations along rivers Leie and Scheldt. Especially eels from the site Oudenaarde along the river Scheldt show extreme high body burdens of PBDEs and HBCD, respectively 31 639 and 33 000 ng/g lipid weight. These data are the highest records worldwide.

The primary industry in Oudenaarde is textile production, with several companies involved in coatings, dyes, auxiliaries and services for the textile industry.

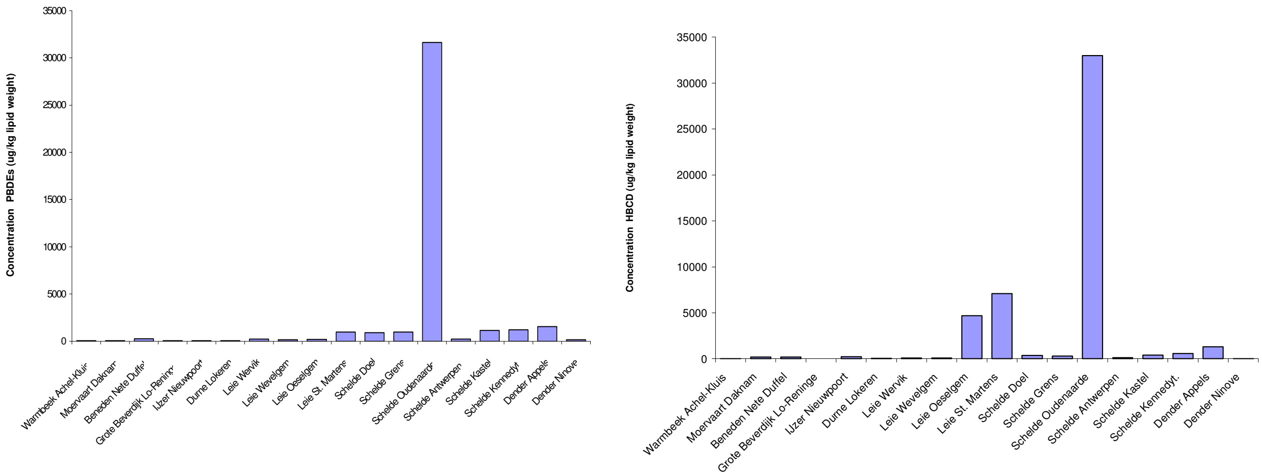

Figure 5. Concentrations of PBDEs and HBCD in eels collected on 18 sites in Flanders (2001). Data expressed in ng/g lipid weight, after data from Morris *et al*. (2004).

PCBs, organochlorine pesticides and heavy metals

A series of ca 30 chemicals are analysed routinely. We selected lindane and cadmium to illustrate the distribution pattern of these contaminants. Both are on the list of priority substances proposed by the WFD (CEC, 2006). Fig. 6 shows that very high lindane levels in eel may occur, as high as 9255 ng/g lipid weight, to our knowledge the highest recorded concentration in Europe. Lindane is an organochlorine insecticide, used on many crops including sugar beet and oil seed rape. Since lindane is a persistent organic pollutant known to be carcinogenic and acts as an endocrine disrupting chemical it has been banned in a lot of countries for many years. In Belgium lindane was banned only very recently (June 2002).

The pattern of distribution of this chemical in eels could clearly be put in relation with agricultural activities, the highest values shown in Fig. 6 are confined to certain geographical areas, all situated in the subcatchments of rivers Ijzer, Demer and Dijle, where intensive sugar beet culture occurs.

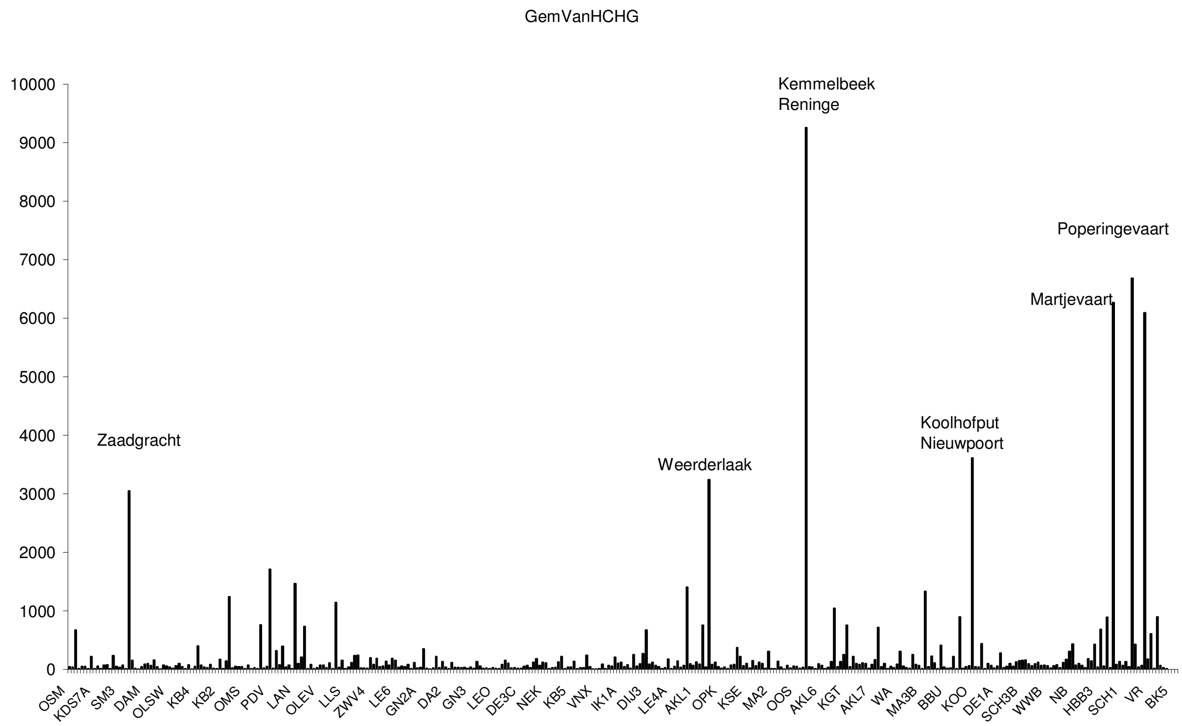

Figure 6. Concentrations of lindane in eels collected on 357 sites in Flanders (1994-2005). Data expressed in ng/g lipid weight, after data from the INBO Eel Pollutant Monitoring Database.

Fig 7 shows cadmium levels in eels from 333 sites. The data clearly show local cadmium pollutions. The sources for these may be various, from historical polluted sediments to still active industrial spills. Some of these values are above international health consumption limits.

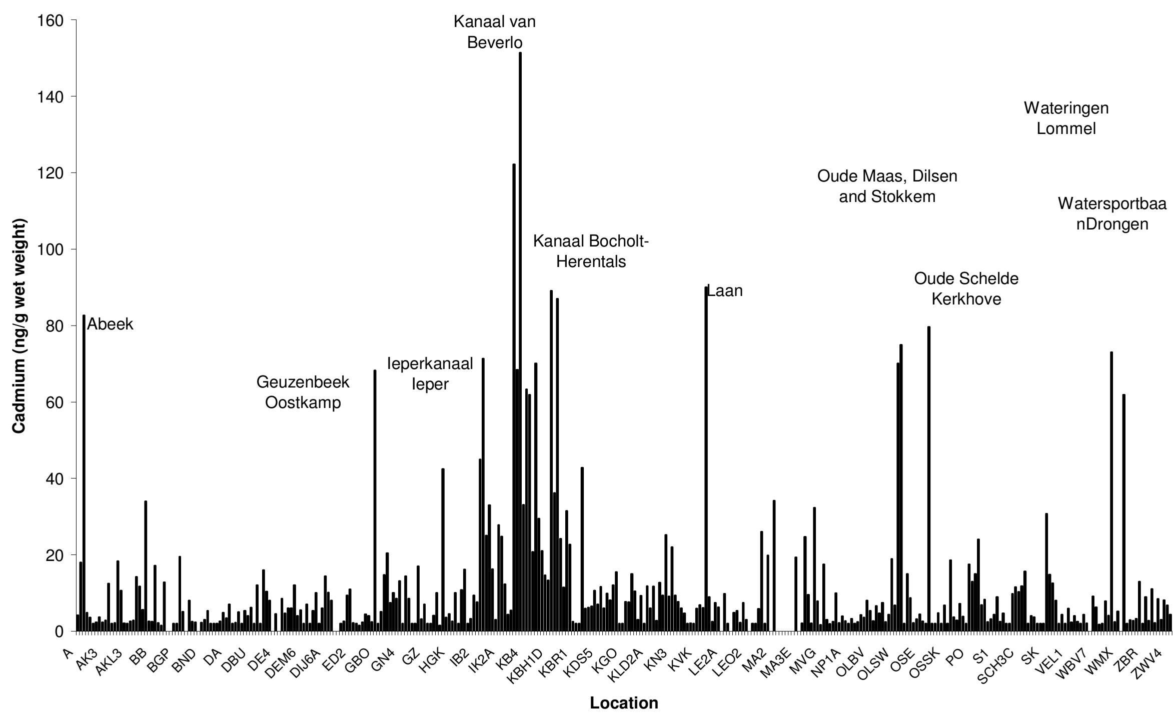

Figure 7. Concentrations of cadmium in eels collected on 333 sites in Flanders (1994-2005). Data expressed in ng/g wet weight, after data from the INBO Eel Pollutant Monitoring Database.

Eel pollutants monitoring and the Water Framework Directive

The time schedule of the Water Framework Directive aims to implement environmental and ecological monitoring (by 2006), to set up a programme of measures (by 2009) and to achieve the good ecological status (by 2015). Within this Directive special emphasis is given in monitoring ecological quality and chemical status of our waters. It is assumed that the WFD should have a positive impact on eel escapement and spawner quality (e.g. with respect to the presence of contaminants). Under the implementation of the Water Framework Directive specific extensions should be implemented for eel as an indicator for river connectivity and ecological and chemical status. It was recommended by the EIFAC/ICES Working Group on Eels (2006) and by the Scientific, Technical and Economic Committee for Fisheries (plenary meeting, April 2006) that the WFD should use eel as a sentinel species for monitoring the chemical status of surface waters with respect to hazardous substances, because of several ecological and physiological traits of this species. Using these specific traits of the eel as a 'target' organism would most probably help in a more direct way to achieve a better status for the target species itself.

However, at the time being no specific reference is made to the use of eels for monitoring the chemical status of our waters. The monitoring guidance document states only that (besides monitoring in water) also some fish species (as well as mussels) can be used in monitoring harmful organic substances and heavy metals because they have a high bioaccumulation capacity (WFD – CIS, 2003).

In the latest proposal (CEC, 2006) for a Directive on environmental quality standards in the field of water policy in amending the WFD (2000/60/EC) emphasis is still given for measuring concentrations of hazardous substances in the water column. According to this proposal there seems to be enough extensive and reliable information on concentrations of priority substances available from measuring in water to provide a sufficient basis to ensure comprehensive protection and effective pollution control. However, CEC (2006) states that Member States shall ensure, on the basis of monitoring of water status carried out in accordance with the WFD, that concentrations of substances listed in Parts A and B of Annex I do not increase in sediment and biota. It is recognised that sediment and biota remain important matrices for monitoring of certain substances by Member States in order to assess long term impacts of anthropogenic activity and trends and the Member States should ensure that existing levels of contamination in biota and sediments will not increase.

Furthermore CEC (2006) demands to establish 'Environmental quality standards' (EQS) for priority substances and selected other pollutants. The EQS are differentiated for inland surface waters (rivers and lakes) and other surface waters (transitional, coastal and territorial waters). Two types of EQS are set, annual average concentrations and maximum allowable concentrations, one for protection against long-term and chronic effects, the other for short-term, direct and acute ecotoxic effects, respectively.

However, as regards to some specific substances (hexachlorobenzene, hexachlorobutadien and methyl-mercury), it is not possible to ensure protection against indirect effects and secondary poisoning by mere EQS for surface water on Community level. Therefore in these cases, EQS for biota should be set up. The directive proposes limit concentrations of hexachlorobenzene, hexachlorobutadiene and methyl-mercury which may not be exceeded in prey tissue of fish, molluscs, crustaceans and other biota (see below).

In order to allow Member States flexibility depending on their monitoring strategy they should be able either to monitor those EQS and check compliance with them in biota, or convert them into EQS for surface water. CEC (2006) is also stating that it is for Member States to set up EQS for sediment or biota where it is necessary and appropriate to complement the EQS set up on Community level. Moreover, as sediment and biota remain important matrices for monitoring of certain substances by Member States in order to assess long term impacts of anthropogenic activity and trends the Member States should ensure that existing levels of contamination in biota and sediments will not increase.

Although CEC (2006) is still concentrating on analysis of those substances in the water column there is certainly a growing consciousness that also other aquatic compartments (sediments and biota) should be monitored and this for various reasons. The need for a harmonised approach to monitor the presence of hazardous substances through aquatic biota is becoming more and more evident. A good bio indicator needs to show a high bioaccumulation capacity (see above). However it is clear that to be adequate potential biomonitor-organisms need more conditions to be fulfilled. We discuss some of these requirements within Table 2.

Table 2: Requirements of an adequate bio indicator for the monitoring of hazardous substances in the aquatic environment.

Prerequisites		**Eel**
A high bioaccumulation capacity	Ecological traits, habitat, trophic status, … are important aspects of a species determining its bioaccumulation capacity.	Eels are benthic fish, carnivorous in their feeding behaviour predating on insect larvae, worms, Crustaceans, snails, mussels and fish, in particular small bottom dwelling species, resulting in high bioaccumulation of toxic residues.
Bioavailability	Choosing a bio indicator from the top of the food chain enables to obtain information on the degree of bioavailability of chemicals.	Eels are carnivorous predators (see above).
Capable to bioaccumulate the range of chemicals needed.	Many studies on the potential of indicator organisms have been restricted to a quite narrow range of chemicals.	Eel has been demonstrated to be a good indicator species for a whole variety of chemical compounds, including PCBs, organochlorine pesticides, heavy metals, brominated flame retardants, volatile organic pollutants (VOCs), endocrine disruptors, dioxins, perfluorooctane sulfonic acids (PFOSs), metallothionines and polycyclic aromatic compounds. However the yellow eel is not suited to indicate the degree of endocrine disruption by vitellogenin measurements.
Common procedure in place in different countries	Member states use diverse organisms as bioindicators: microbial assemblages, molluscs, algae, other fish species (trout, gudgeon, …), fish parasites, invertebrates, aquatic macrophytes, water birds, … There is definitely a need for harmonisation, looking for a common approach and strategy for tracking chemicals in aquatic biota.	Eels have been used in Europe in The Netherlands, France, Sweden, U.K., Spain, Italy, Germany and Belgium (Walloon region and Flanders). A more widespread study over Europe has been presented by Greenpeace using the eel as bioindicator for the presence of brominated flame retardants and PCBs from rivers and lakes in 10 European countries
No seasonal changes	No or minimal seasonal changes through metabolic activities within year cycles, linked with reproduction or seasonal environmental variation.	Due to absence of annual reproduction cycles, there are no reproduction linked seasonal metabolic variations.
Moving behaviour	Sentinel species should be fairly resident	Yellow eels show explicit homing

	to allow fingerprinting the local pollution load.	behaviour and foraging movements are mostly restricted to a few hundred meters. The fingerprint value of the species has been demonstrated. Due to the migration activities in the silver eel stage, the bioindicator value of the eel is restricted to the yellow eel phase.
Occurrence	The species should be widespread and should occur in a wide range of aquatic habitats. In the context of the WFD an overall European distribution is recommended.	Eels are widespread and can be found in almost all aquatic habitats. They occur in fresh, brackish and coastal waters in almost all of Europe (even Northern Scandinavia and from the Azores to the Eastern Mediterranean region) as well as in northern Africa. In Flanders the species is the third most widespread fish species.
Size	The size of the organism must be large enough to permit adequate analysis.	The targeted length size of 40 cm means a weight of ca 100 g, which is large enough to distribute eel tissue for the various analytic procedures and laboratories linked to the various contaminants.
Standardisation	Standardisation on length and/or age is recommended.	Standardising through the choice of an eel length class for monitoring is around 40 cm. Bias due to growth heterogeneity may occur.
Analytic advantages	Besides size, physiological traits like high lipid content will facilitate analysis of (mostly lipophylic) substances.	Eel show extreme high lipid values. But heterogeneity in lipid content between individuals and sites can occur.
Long living	Sufficient long life to be capable to accumulate hazardous substances.	The eel spends between 5 to 18 years in inland and coastal waters.
Robust species	It is of course essential that also in (highly) polluted waters, contaminants can be monitored through the sentinel species; therefore the species should be fairly resistant to environmental degradation.	Eel is quite resistant to degradation of water quality and endures low levels of oxygen and high eutrophication levels.

The WFD proposes under CEC (2006) 33 substances or groups of substances on the list of priority substances including selected existing chemicals, plant protection products, biocides, metals and other groups like Polyaromatic Hydrocarbons (PAH) that are mainly incineration by-products and Polybrominated Biphenylethers (PBDE) that are used as flame retardants. Another 8 pollutants are not on the priority list but fall under the scope of older directives. The complete list of these chemicals is mentioned under Table 3. From various published and non published data from body burdens in eels from Flanders collected between 1994 and 2005, we compiled the available knowledge with respect to these WFD chemicals. Table 3 lists where available minimum and maximum concentrations, as well as the means. All data are expressed in ng/g wet weight. The percentage of the sites where values are under the detection limit (D.L.) is indicated.

Table 3 : WFD substances mentioned under CEC (2006) and available data from measurements in Flemish eels. All data are expressed in ng/g wet weight. [1]: Priority substances . [2] :Other pollutants, which fall under the scope of Directive 86/280/EEC and which are included in List I of the Annex to Directive 76/464/EEC, are not in the priority substances list. Environmental quality standards for these substances are included in the Commissions proposal to maintain the regulation of the substances at Community level. [3]: The data present the Sum of 10 BDEs.

[4]: alpha Hexachlorocyclohexane [5]: Cd. [6]: Pb. [7]: Hg. [8]:Nickel. [9]:Sum of p,p'-DDD, p,p'-DDT, p,p'-DDE. [10]: after data from Roose *et al*., 2003. [11]: INBO Eel Pollutant Monitoring Database, [12]: after data from Morris *et al*., 2004.

Substance		In eel in Flanders Min – Max (Mean)	%<D.L.	N sites	Year	Ref.
Alachlor	1					
Anthracene	1					
Atrazine	1					
Benzene	1	1.2-18.9 (5.7)	0	20	1996-98	10
Brominated diphenylethers	1	6.9-5284.4 (369.1)[3]	0	18	2001	12
Cadmium and its compounds	1	D.L.-151.4 (11.7)[4]	19	357	1994-2005	11
C_{10-13}-chloroalkanes	1					
Chlorfenvinphos	1					
Chlorpyrifos	1					
1,2-Dichloroethane	1	D.L.-4.9 (1,2)	55	20	1996-98	10
Dichloromethane	1					
Di(2-ethylhexyl)phthalate (DEHP)	1					
Diuron	1					
Endosulfan	1					
(alpha-endosulfan)	1					
Fluoranthene	1					
Hexachlorobenzene	1	D.L.-61.6 (5.7)	<1	357	1994-2005	11
Hexachlorobutadiene	1	D.L.-12.2 (1.8)	50	20	1996-98	10
Alfa-Hexachlorocyclohexane	1	D.L.-13.7 (0.8)[5]	13	357	1994-2005	11
(gamma-isomer, Lindane)	1	0.1-2076.4 (46.9)	0	357	1994-2005	11
Isoproturon	1					
Lead and its compounds	1	D.L.-1744.2 (56.6)[6]	3	357	1994-2005	11
Mercury and its compounds	1	10-535.4 (113.5)[7]	0	355	1994-2005	11
Naphthalene	1	1.5-63 (5.8)	20	20	1996-98	10
Nickel and its compounds	1	D.L.-2944.7 (186.2)[8]	16	297	1994-2005	11
Nonylphenols	1					
(4-(para)-nonylphenol)	1					
Octylphenols	1					
(para-tert-octylphenol)	1					
Pentachlorobenzene	1					
Pentachlorophenol	1					
Polyaromatic hydrocarbons	1	Data available				
Simazine	1					
Tributyltin compounds	1					
(Tributyltin-cation)	1					
Trichlorobenzenes	1					
(1,2,4-Trichlorobenzene)	1	D.L.-30.9 (6.0)	15	20	1996-98	10
Trichloromethane (Chloroform)	1	D.L.-96.0 (13.4)	25	20	1996-98	10
Trifluralin	1					
DDT total	2	6.6-1102.7 (90.2)[9]	0	357	1994-2005	11
para-para-DDT	2	D.L.-62.6 (2.9)	38	357	1994-2005	11
Aldrin	2	D.L.-11.4 (1.3)	33	96	1994-2005	11
Dieldrin	2	D.L.-237.6 (19.1)	15	357	1994-2005	11
Endrin	2	D.L.-29.1 (1.1)	80	346	1994-2005	11
Isodrin	2					
Carbontetrachloride	2					
Tetrachloroethylene	2	D.L.-88.9 (13.4)	50	20	1996-98	10
Trichloroethylene	2	D.L.-30.3 (2.0)	95	20	1996-98	10

As can be seen from the table, data are available for more than half of the substances. Looking at the % of sites with concentrations above the detection limit, and to the range of the measurements of these substances in eels it may be concluded that at least in some sites some of those substances show extremely high body burdens in eel (see e.g. maximum values for lindane, total DDT, lead, cadmium, mercury, brominated diphenylethers, …) indicating the value and need for a consequent follow up of these substances in aquatic biota.

CEC (2006) stated that Member States have to ensure that the following concentrations of hexachlorobenzene, hexachlorobutadiene and methyl-mercury are not to be exceeded in tissue (wet weight) of fish, molluscs, crustaceans and other biota: 10 µg/kg for hexachlorobenzene, 55 µg/kg for hexachlorobutadiene and 20 µg/kg for methyl-mercury. As can be seen from Table 3 hexachlorobutadiene is present in eels from 50 % of the sites but is always lower than the 10 ng/g wet weight. However, for hexachlorobenzene 14 % of the sites (total 357 sites) the standard is exceeded. The situation is even more serious for mercury : on 99 % of the sites (total 355 sites) the 20 ng/g wet weight is exceeded.

Conclusions

From the various examples it is clear that usage of eels as sentinel species may clearly pinpoint sources of pollution. Due to various ecological and physiological traits of the species, the European eel in its yellow phase turns out to be a perfect sentinel species for a variety of chemical substances. The indicator value of eel as a tool for monitoring environmental contamination, both for local matters and for international issues (evaluating the chemical status for the Water Framework Directive) is evident. Within the requirements of the Water Framework Directive eel can be the model to use when monitoring in aquatic biota. Results show that at least for some substances, monitoring in water is insufficient and does not guaranty sufficient protection of the aquatic environment. Efforts have to be made to elaborate and optimize techniques for analysis of more chemicals in eel. There is a by far insufficient knowledge about the effects of these chemical on eel, but considering the levels of some chemicals measured in some sites, it is more than likely that these toxic substances have detrimental effects on the reproduction success of the species. Considering the variation in contaminant profile and intensity it is highly likely that the degree and potential of reproduction for eels leaving our system will vary a lot dependent on the level of pollution in the habitat where the eels grew up.

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