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Monitoring selected indicators of ecological change in the Elbe River since the fall of the Iron Curtain

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Summary

The sudden, large-scale cessation of industrial and agricultural practices following the collapse of the communist regimes in the former Czechoslovakia and East Germany, coupled with a set of programmes aimed at reducing industrial and municipal pollutant loads, provided an unique opportunity to observe changes in a severely polluted river, the Elbe. Several sets of data for the post-communist Elbe reflect water quality and ecological health, including surface water pollutants, accumulation in mussels and several species of fish, and diversity of fish species. The ecological health of the Elbe has indeed benefited, and greatly, from post-communist change. The loads of most pollutants in the Elbe surface water have declined significantly over the last decade. Contaminant loading in fish tissue is also declining. Finally, the diversity of fish species in the Elbe is increasing, with a majority of the returning species being native fishes, characteristic of the pre-World War Two Elbe. Nonetheless, several pollutants remain a concern, including nitrate, suspended sediments, mercury, cadmium, hexachlorobenzene, two DDT metabolites, and three HCH isomers. The reasons for these problems include relicts from the communist era and current activities in the Elbe watershed. Further, the invasion of the river by exotic species, while not yet a concern, does remain a threat.

Keywords: Elbe River, water quality, pollutant loads, fish diversity, river pollution, German reunification

Introduction

Since World War Two, many major rivers, such as the Thames (UK), the Rhine (Germany/Netherlands), the Hudson (USA), and the Elbe (Czech Republic/Germany), have suffered extreme levels of pollution. The first three recovered significantly during the 1980s and 1990s due to legislation aimed at pollution control and clean water in those countries (Gurtner-Zimmerman 1998; Power *et al.* 1999; Sanudo-Wilhelmy & Gill 1999). The Elbe, on the other hand, remained one of Europe's most polluted rivers until the early 1990s. Since that time, it, too, has experienced an improvement in river quality and health. However, this change was not brought about through legislation, rather it resulted from the political and economic upheaval that occurred in Eastern Europe in the late 1980s and from subsequent events. The goal of this paper is to examine the changes of the last decade and how they relate to human activities in the watershed.

In 1989, the water of the Elbe was comparable to the severely polluted Rhine of the early 1970s (Ruchay 2000). For decades, it had been the recipient of untreated or insufficiently treated wastewater from urban centres, industry and agriculture in East Germany and the former Czechoslovakia. During that period, the Elbe's catchment contained 82% of the East German populace, over half of the East German industrial production, and the entire western Czechoslovakian industrial region (Naumann 1992). Major industrial point sources included pulp and paper, chemical, and pharmaceutical facilities, which were located all along the Elbe, as well as its tributaries, such as the Saale and Mulde Rivers. For example, the chemical complex at Bitterfeld on the tributary Mulde was a major source of mercury for the Elbe (Simon 1990). In addition, it released 200 000 m^3 of untreated industrial sewage into the Elbe daily. Many East German and Czech cities also lacked proper sewage treatment facilities. The city of Dresden released all of its sewage into the Elbe untreated, after its wastewater treatment plant was severely damaged in a flood in 1987. All of these inputs had drastic impacts on the water quality and biota of the Elbe.

The political changes of the late 1980s ushered in a number of significant changes for the Elbe's watershed and the Elbe itself. Since 1990, the population of former East Germany has shrunk by 800 000 (Emcke *et al.* 1999). The industrial and agricultural complexes of the former communist state have collapsed; remaining industries and farms or those that have started since the early 1990s generally implement modern pollution control technologies (Anon. 2000). Recognizing the need to improve the treatment of wastewater

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flowing into the Elbe, the International Commission for the Protection of the Elbe (IKSE) initiated a series of programmes in the early 1990s (IKSE 1992). These programmes targeted industrial sources considered to be the major polluters, such as the chemical, pharmaceutical, paper-pulp, and leather and leather-processing industries. Further, 181 sewage treatment plants were constructed during the 1990s (139 in Germany and 42 in the Czech Republic), each having a capacity to handle wastewater from 20 000 inhabitants (IKSE 2000).

Despite the improvements, the Elbe still faces challenges. Legacies from the communist era, such as landfills, toxic waste dumps and sludge deposits remain. These sites pose potentially serious threats to both ground and surface waters, including the Elbe. The most seriously polluted sites are in the areas of Bitterfeld-Wolfen, Magdeburg-Rothensee, BUNA industrial chemical complex and VEB-Leuna-Werke, the largest industrial chemical plant of the former East Germany (Simon 1990). Major cleanup efforts are being directed at these sites. As in the rest of Germany, non-point sources, such as agriculture, also contribute significant levels of nitrogen and phosphorus to the Elbe (Brockmann & Wilken 1996).

This paper explores the pollutant load of Elbe since the late 1980s, investigating how the collapse of the region's political and economic systems has influenced water quality and the river's ecology. We employ data from traditional water quality sampling, as well as from biomonitoring programmes, which examine the presence of species and the contaminant levels accumulated in indicator species. Such programmes have recently gained recognition in river systems as a means to supplement traditional monitoring programmes using chemical and physical parameters (Gaumert 1995). Resulting data provide insight into pollutants whose ambient levels may not be immediately toxic, but, through the processes of bioaccumulation and biomagnification, possess the potential of disrupting the ecological system, as well as rendering fish and other organisms unfit for human consumption. Finally, we analyse changes in the structure of the fish species assemblages in the Elbe. Sitting at the top of the aquatic food chain, fish represent important indicators of the health of the entire system. We expand here upon analysis from a previous paper (Adams *et al.* 1996), which summarized a number of issues associated with the ecological status of the Elbe River for the first five years after the political changes. We use statistical analysis to detect trends in the water quality data and incorporate new data on pollutant accumulation in mussel and fish species, as well as data on changes in the fish species assemblages. Finally, this paper provides an English language summary of work that has been done on the Elbe, but has hitherto only been available in German.

Methods

Study area: the Elbe

After the Danube and the Rhine, the Elbe is the third largest river of Central Europe, based on both length and area of catchment (Marcinek 1975; IKSE 1992). The Elbe flows 1091 km from its source in the Giant Mountains in the Czech Republic through central and northern Germany before emptying into the North Sea (Fig. 1) with an average discharge of 862 $m^3 s^{-1}$ (ARGE-ELBE [Arbeitsgemeinschaft für die Reinhaltung der Elbe] 1999). Along the way, its catchment drains some of north and central Europe's major

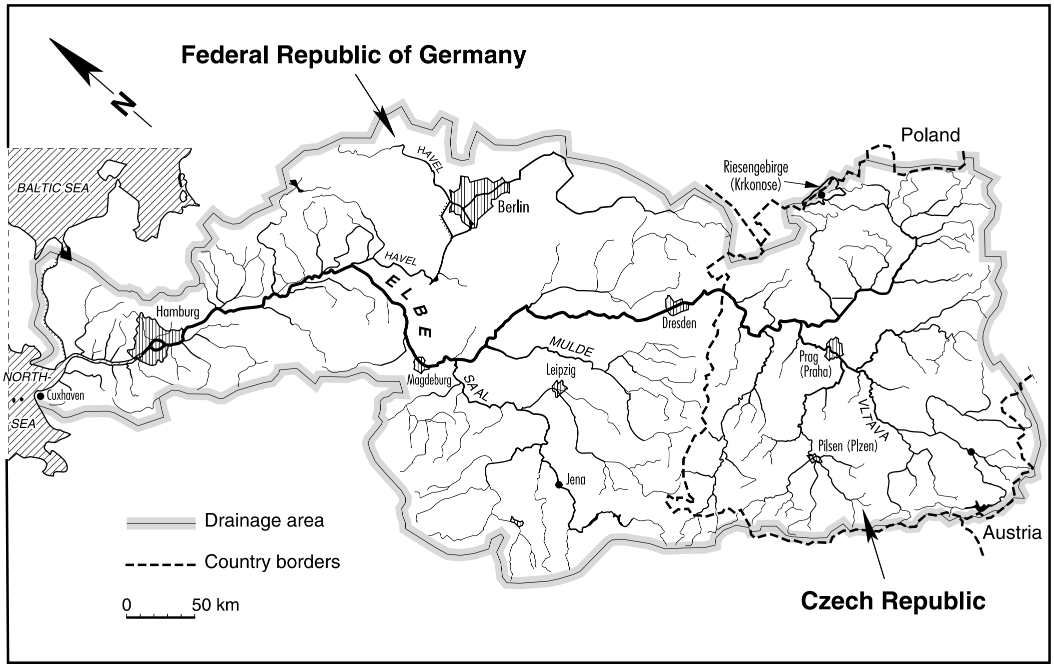

Figure 1 Map of the catchment of the Elbe River. Source: ARGE-ELBE.

cities, including Prague, Dresden, Berlin and Hamburg. Despite having been a heavily polluted river, the Elbe stands out among central European rivers for its natural structures. Although the upper catchment of the Elbe possesses a long series of dams and reservoirs, the Elbe is free flowing for 600 km, from the Czech-German border until the dam at Geesthacht. These 600 km have been mostly spared the devastating ecological impacts of river engineering works common on other major European rivers, such as the Rhine and the Danube. The Elbe has not been channelized, and only a few meanders have been straightened. Its flow is only partially regulated through a system of wing dams and levees. Although it has lost a majority of its floodplains, those that remain experience annual floods and support wetland and floodplain forest habitats that have been internationally recognized and are unique within central Europe.

Water quality data

The annual water quality data we report in Table 1 represent averaged values from weekly samples taken at Schnackenburg (474.5 km downstream from the German/Czech Republic border) by the Arbeitsgemeinschaft für die Reinhaltung der Elbe (ARGE-ELBE). Located on the former border between East and West Germany, the station at Schnackenburg is uniquely situated to evaluate the water quality impacts of the political and economic upheaval of the late 1980s. This station captures approximately 85% of the Elbe's watershed and has been collecting water quality data since the mid-1980s. The variables we have chosen to analyse here have either been listed as priority pollutants (USA) or been proposed as priority pollutants (European Union) (Agency For Toxic Substances And Disease Registry 1999*a*; European Union 2001). Additionally, we analyse several forms of nitrogen and phosphorus, due to the role they play in the eutrophication of surface waters, and suspended sediments, which affect water clarity and transport phosphorus and organic pollutants (Novotny & Olem 1994). The data for mercury and cadmium were collected by ARGE-ELBE, but at Finkenwerder, a station that lies 155 km downstream from the monitoring station at Schnackenburg.

To analyse trends in the water quality data, we used linear regression of pollutant load on time, as recommended by Hirsch *et al.* (1991), the slope providing a measure of the direction and magnitude of any trends with time. For annual data, the time variable was simply the year. For data collected at multiple points during the year (Hg and Cd), we include an additional variable to account for the time of year when the data were collected (week or month). We also include a discharge variable in the regression, as water quality data often varies with discharge (Hirsch *et al.* 1991). Where data were skewed, we log-transformed them before performing regressions. We determined the statistical significance of each calculated trend with the t statistic and related p value for the estimated slope. For this analysis, we set our level of significance (α) at 0.05.

Mussels data

The data on pollutant accumulation in zebra mussels (*Dreissena polymorpha*) were also collected by ARGE-ELBE. The mussels were taken from a control source, the Gartower Lake (Germany), and left at seven locations in the Elbe for two months. Gartower Lake was studied in the late 1980s and determined to be a suitable control for mussel studies (ARGE-ELBE 1991). ARGE-ELBE uses this data to classify pollutant levels of the river stretches associated with the seven sampling sites. The classification system, based on work by Krieg and Gaumert (1998), possesses seven levels, ranging from class I (not polluted/slightly polluted) to class IV (excessively polluted). In this analysis, we employ 1998 data to complement the data from the other water quality media we examine.

Fish pollutant data

The Staatliches Veterinäruntersuchungsamt (VUA) für Fische und Fischwaren (the State Veterinary Research Institute for Fish and Fish Products) in Cuxhaven supplied data on contaminants in bream (*Abramis brama*) and eel (*Anguilla anguilla*), which derive from the sampling programme at Lauenburg (570 km downstream from the German/Czech Republic border) from 1979 to 1999. We used linear regression to test for trends over time in the bream and eel data from VUA. We followed the same assumptions and steps as outlined for the water chemistry data. One difference is that we did not require a discharge variable in the regression. We compare these results to similar fish studies undertaken by ARGE-ELBE (1996, 2000) in 1994 and 1999, which examined pollutant levels in pike–perch (*Stizostedion lucioperca*), as well as bream and eel.

Fish species data

We compare the number of fish species found in the Elbe between the time of German reunification and at the end of the 1990s. ARGE-ELBE (1995) surveyed the number of fish species found in the Elbe for period 1991–1993, coinciding approximately with the time of political reunification in Germany. ARGE-ELBE completed additional fish surveys in June 1999, creating a long-term data set extending from 1990 to 1999. This data set includes the intensive data collection from the surveys conducted in 1991–1993. We further use data from the 19th century as a historical reference point for species typically found in the Elbe (Gaumert 2001).

Table 1 Annual discharge and pollutant load of the Elbe 1985–1999. Source: ARGE-ELBE. BOD$_{21}$ = biological oxygen demand 21 days after discharge. * Single samples.

Variable	*Unit*	*Year*														
		1985	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*	*1994*	*1995*	*1996*	*1997*	*1998*	*1999*
Discharge (Neu Darchau, ab 1997 Wittenberge)	m^{3}s^{-1}	558	716	1130	874	520	447	384	515	510	860	908	669	592	605	640
BOD$_{21}$*	t O$_2$ yr^{-1}	–	570 000	620 000	590 000	430 000	310 000	210 000	220 000	220 000	240 000	230 000	190 000	190 000	190 000	220 000
Chloride	t Cl$^-$ yr^{-1}	3 700 000	4 400 000	5 400 000	4 800 000	3 500 000	3 300 000	2 700 000	2 400 000	2 400 000	3 200 000	2 700 000	2 600 000	2 600 000	2 500 000	2 600 000
Ammonia	t N yr^{-1}	54 000	49 000	53 000	42 000	32 000	23 000	11 000	7700	6900	6800	6900	9400	4000	3100	3100
Nitrate	t N yr^{-1}	54 000	97 000	180 000	140 000	75 000	69 000	58 000	88 000	81 000	150 000	140 000	100 000	92 000	89 000	98 000
Total nitrogen	t N yr^{-1}	140 000	190 000	280 000	230 000	140 000	110 000	82 000	110 000	100 000	180 000	170 000	130 000	110 000	110 000	120 000
Phosphate	t P yr^{-1}	3400	3500	4100	2800	2200	2300	1500	1600	<1500	1500	1200	1800	970	950	820
Total phosphorus	t P yr^{-1}	12 000	10 000	15 000	12 000	9100	9100	4200	4100	6400	5400	5200	5200	3900	4500	4000
Suspended solids	t yr^{-1}	460 000	670 000	1 100 000	770 000	480 000	440 000	320 000	350 000	370 000	480 000	670 000	450 000	520 000	480 000	520 000
Mercury	t yr^{-1}	28	23	26	16	12	6.5	6.9	4.2	1.9	4.7	3.2	1.7	1.4	1.6	1.4
Cadmium	t yr^{-1}	13	13	16	9.7	6.4	6.0	4.9	5.3	5.0	6.0	5.5	5.6	5.6	5.1	6.5
Lead	t yr^{-1}	110	120	130	180	110	73	70	76	75	52	96	100	100	73	57
Copper	t yr^{-1}	260	380	760	880	240	180	150	150	110	100	140	110	120	96	85
Zinc	t yr^{-1}	1900	2400	4000	4000	2400	1700	1300	1500	1100	2600	1600	1200	1200	860	890
Chromium	t yr^{-1}	150	260	560	510	190	170	110	130	81	110	51	49	64	33	24
Nickel	t yr^{-1}	190	270	420	210	200	150	110	130	93	150	140	110	99	67	74
Iron	t yr^{-1}	20 000	30 000	35 000	28 000	20 000	16 000	12 000	18 000	12 000	15 000	18 000	16 000	17 000	13 000	9 100
Manganese	t yr^{-1}									2400	4500	3000	2500	2600	2000	2200
Arsenic	t yr^{-1}	99	110	110	74	52	44	36	65	67	120	83	67	63	52	49
Chloroform	kg yr^{-1}	14 000	24 000	22 000	21 000	13 000	8700	5300	2000	860*	430*	1200*	1100*	1600*	3600*	2100*
Trichloroethylene	kg yr^{-1}	40 000	31 000	28 000	9600	7300	3400	1200	1900	1100*	1800*	1500*	1200*	870*	260*	320*
Tetrachloroethylene	kg yr^{-1}	13 000	22 000	20 000	7700	8300	3000	1500	1600	790*	1200*	3900*	1900*	960*	460*	540*
α-HCH	kg yr^{-1}	200	230	250	140	140	170	83	110	150	130	250	190	180	480	<81
β-HCH	kg yr^{-1}	86	56	130	94	88	48	55	100	110	140	390	150	100	280	<100
γ-HCH (Lindane)	kg yr^{-1}	570	670	970	560	490	270	180	320	440	520	670	380	420	660	250
1.2.4-Trichlorobenzene	kg yr^{-1}	2600	610	2200	950	570	260	320	50	50	<80	<14	<160	<19	<11	<12*
Hexachlorobenzene	kg yr^{-1}	110	130	190	140	150	180	40	50	90	110	180	120	180	230	<100
p.p′-DDT	kg yr^{-1}	–	–	<35	<28	<15	<14	110	<15	18	<80	260	<20	<19	<95	2.4
p.p′-DDE	kg yr^{-1}	–	–	<35	<28	<15	<14	<12	<15	<15	<80	<28	<20	<75	<95	8.7
p.p′-DDD	kg yr^{-1}	–	–	57	40	30	38	<12	<15	29	<80	<99	<20	<75	<19	13
AOX	kg yr^{-1}	2 600 000	3 000 000	3 600 000	2 400 000	1 600 000	990 000	890 000	760 000	760 000	1 100 000	1 100 000	720 000	1 100 000	830 000	500 000

Results

Water quality data

Our analyses revealed significant negative trends over time in the loads of most of the analysed pollutants (Table 2). Only one pollutant demonstrated a significant positive trend over time, β-HCH. Eight others did not yield any statistically significant trends; these included nutrients, heavy metals, and organic compounds.

Mussels data

Table 3 lists the chemicals and related river stretches that are at or above the classification level III (heavily polluted) based on the mussel tissue samples. The 1998 study (Krieg & Gaumert 1998) identified cadmium in the Mulde and copper at Schmilka (Czech–German border) to be heavy metals of concern, placing them both in class III (heavily polluted).

Table 2 Temporal trends observed in regression analysis of water quality data.

Significant negative trend	*Significant positive trend*	*Trend not significant*
Total nitrogen	β-HCH	Nitrate
Ammonium		Suspended sediment
Total phosphorus		Arsenic
Ortho-phosphate		Cadmium (sediment)
Mercury (dissolved)		α-HCH
Mercury (sediment)		γ-HCH
Cadmium (dissolved)		Hexachlorobenzene (HCB)
Copper		
Zinc		
Chromium		
Nickel		
Lead		
Chloroform		
Trichloroethylene		
Tetrachloroethylene		
AOX		
1,2,4 Trichlorobenzene		

Table 3 Pollutants of concern from mussel studies in the Elbe in 1998.

River stretch	*Pollutant classes*	
	III (heavily polluted)	*III–IV (very heavily polluted)*
Obristvi	β-HCH	α-HCH
Schmilka	Cu, β-HCH, HCB, OCS	α-HCH
Domitzsch	HCB, OCS	
Dessau (Mulde)	Cd, α-HCH	β-HCH, DDE, DDD
Madgeburg	α-HCH, β-HCH, DDE, DDD, HCB, OCS	
Schnackenburg	α-HCH, β-HCH, HCB, OCS	
Blankenese	α-HCH, β-HCH, OCS	

Chlorinated hydrocarbons levels in the Elbe and Mulde were also a problem at all sites. Of the organic pollutants tested, α- and β-HCH were the most prevalent, occurring at all but the Domitzch stretch. DDT metabolites, DDD and DDE, were also a concern, particularly in the Mulde River (Dessau), which merited a class III–IV designation (very heavily-polluted). The DDD and DDE contamination continues downstream to Magdeburg, which rated a class III designation for both compounds.

Fish contaminant data

All of the analysed pollutants in the VUA fish surveys demonstrated negative trends over time in bream; however, the trends for α-HCH, DDE, and DDD were not statistically significant (Table 4). All pollutants demonstrated statistically significant decreasing trends over time in eel (Table 4). Eel showed a much stronger trend than bream. Our comparison of the results of ARGE-ELBE studies from 1994 and 1999 (ARGE-ELBE 1996, 2000) demonstrates how the number of pollutants of concern across species has decreased over that time (Table 5). The 1994 study (ARGE-ELBE 1996) identified mercury in the eel, bream, and pike–perch; HCB-contamination in bream and eel; and total DDT content in eel as the most serious concerns. The number of serious concerns in the 1999 study identified only HCB in the muscle tissue of eel and mercury-levels in pike–perch, particularly individuals over 50 cm in length.

Table 4 Temporal trends observed in regression analysis of bream and eel tissue.

Fish species	*Significant negative trend*	*Significant positive trend*	*Result not significant*
Bream	Hg HCB γ-HCH OCS PCB 153	None	α-HCH DDE DDD
Eel	Hg HCB α-HCH γ-HCH OCS PCB 153 DDE DDD	None	None

Table 5 Pollutants of concern in ARGE-ELBE fish surveys. B = bream, E = eel and P = pike–perch.

Pollutant	*1994 study*	*1999 study*
Hg	B, E, P	P
HCB	B, E	E
Total DDT	E	none

Fish species data

The ARGE-ELBE surveys demonstrate a marked increase in both freshwater and euryhaline species within the last decade, as well as since the end of the 19th century (Table 6). The number of marine species has also increased in the last decade (Table 6); historical data for marine species in the 19th century were not available. We break down the changes in the number fish species into specific regions of the Elbe, and demonstrate that each region has seen increases since the early 1990s (Table 7). The region with the greatest increase was the German Upper Elbe with an increase of 22 species. Two regions tied for the smallest increase, the Czech Upper Elbe and the Elbe stretch in the city of Hamburg, both with an increase of four species. We examine the particular species that make up the increases seen in the species assemblage in the German Upper Elbe in the 1990s (Table 8); most of these are rheophilic species that are native to this region of the Elbe. The remaining species are euryhalic and include both native and exotics.

Table 6 Number of fish species found in the Elbe. (* Not comparable to other totals.)

Type of species set	*End of the 19th century*	*Intensive 1991–1993 survey*	*1990–1999 long-term data*
Marine	not measured	31	34
Euryhaline	12	11	16
Freshwater	37	37	43
Total	49*	79	94

Table 7 Increases in fish species in the Elbe in the 1990s.

Elbe section	*Change in number of fish species*
Upper Elbe-Czech section	+4
Upper Elbe-German section	+22
Middle Elbe	+16
Upper tidal Elbe	+10
Hamburg Elbe	+4
Lower Elbe	+7
Brackish zone	+7

Table 8 Newly-recorded species in the German Upper Elbe at the end of the 1990s.

Rheophilic species	*Euryhaline species*
Barbel (*Barbus barbus*)	Allis shad (*Alosa alosa*)
Brown trout (*Salmo trutta fario*)	Salmon (*Salmo salar*)
Grayling (*Thymallus thymallus*)	Rainbow trout (*Salmo gairdneri*)
Common dace (*Leuciscus leuciscus*)	Broad whitefish (*Coregonus lavaretus nasus*)
Nase (*Chondrostoma nasus*)	Common whitefish (*Coregonus lavaretus lavaretus*)
Whitefin gudgeon (*Gobio albipinnatus*)	
Baltic vimba (*Vimba vimba*)	
Stone loach (*Barbatula barbatula*)	
Burbot (*Lota lota*)	
Bullhead (*Cottus gobio*)	
Brook trout (*Salvelinus fontinalis*)	

Discussion

Water quality analyses

Given the large-scale closures in the industrial and agricultural sectors of the former East Germany and Czechoslovakia in the late 1980s and the subsequent efforts to clean up wastewater effluents, the expectation of substantial decreases in pollutant loads entering receiving bodies of water, such as the Elbe, is not unwarranted. Our results support this notion in many cases. However, our analyses revealed that several cases exist where either no significant trend was discernible or the trend is actually increasing with time. These cases represent situations that are either interesting from a scientific perspective, or that identify water quality issues that are still of concern. We base the following discussion upon these cases.

Nitrate

Nitrogen, along with phosphorus, is typically a limiting nutrient in many water bodies (Smith 1998). Modern agricultural practices are often responsible for increased levels of nitrogen compounds, such as ammonia and nitrates (Horne & Goldman 1994). Thus, the collapse of the large-scale agricultural systems of East Germany and subsequent restructuring of the Eastern German agricultural economy provides one explanation for the decreases observed in ammonia and total nitrogen. In contrast, the trend for nitrate was positive, albeit not statistically significant. There was a sharp increase in nitrate levels in the years immediately following German reunification (Fig. 2). This

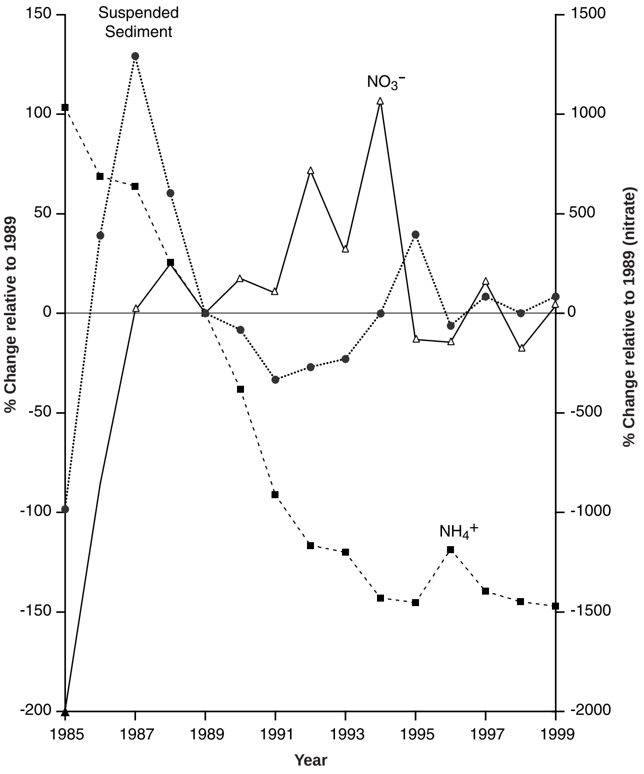

Figure 2 Trends relative to 1989 in nitrogen and suspended sediments (left-hand side: ammonium and suspended sediments; right-hand side: nitrate) in the Elbe, 1985–1999.

increase does not contradict the trends in other nitrogen forms. On the contrary, nitrification, a bacterial-driven process that converts ammonia to nitrate, would have been extremely low prior to political reunification. Nitrifying bacteria require sufficient levels of oxygen and slightly basic pH levels; conditions that did not exist prior to the early 1990s (Novotny & Olem 1994). Further, the high levels of toxic pollution would have also impeded the bacteria. With the decrease in BOD (biological oxygen demand) and COD (chemical oxygen demand) in the Elbe waters, an increase in the pH of the Elbe, and the sharp reduction in most toxic pollutants, the nitrifying bacteria were able to convert ammonium to nitrate, contributing to the decrease in the levels of ammonia and increase in the levels of nitrate, as observed.

Suspended sediment

Suspended sediment can be a cause for concern because it impacts water clarity and often transports pollutants such as phosphorus and pesticides that adsorb onto the sediment particles (Novotny & Olem 1994). Novotny and Olem (1994) identify non-point sources, such as runoff from agriculture fields and construction sites, as responsible for levels of suspended sediment that exceed typical ambient values. Due to the decrease in active cropland following the political changes in East Germany (Wilson & Klages 2001), we would have expected to see a decrease in sediment load. A similar decrease occurred in Czechoslovakian agriculture; however, the dams on the Czech section of the Elbe would have acted as sediment traps, and sediment from upstream of the dams would not affect the sediment load of the river below the dams (Poff *et al.* 1997). However, we discerned no overall time trend in suspended sediment levels (Fig. 2). This might be explained, in part, by the increase in building and road construction that has occurred since German reunification (Anon. 2000), which may have offset decreases from the agricultural sector.

Heavy metals

At least six heavy metals were major contributors to the water quality problems of the Elbe in the late 1980s. That has decreased to three: mercury, cadmium and arsenic. Organic forms of mercury readily accumulate in muscle tissue and function as neurotoxins (Agency For Toxic Substances And Disease Registry 1999*c*). Mercury is one of the pollutants that through bioaccumulation and magnification can create problems for the higher end of the food chain. The significant negative trends present for mercury levels in surface water and sediments (Fig. 3*a*, *b*) correspond to decreasing mercury

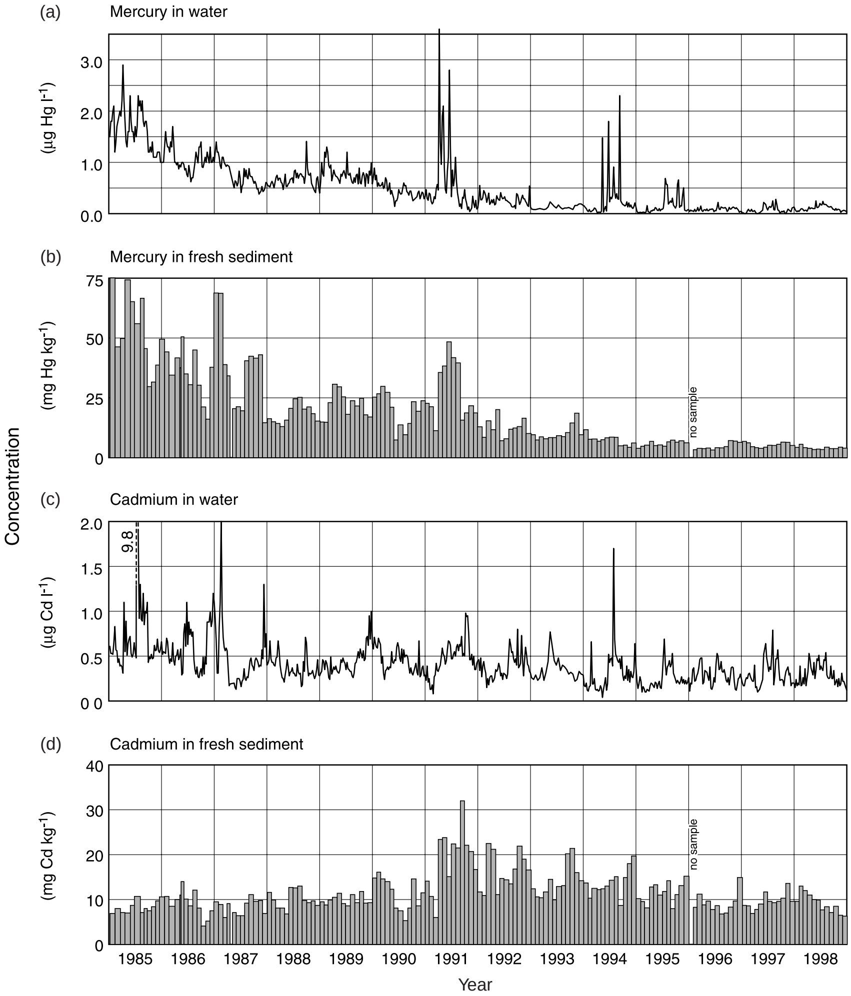

Figure 3 (*a*) Dissolved Hg in water, (*b*) Hg in sediment, (*c*) dissolved Cd in water, and (*d*) Cd in sediments in the Elbe 1985–1999. Source: ARGE-ELBE.

concerns among fish species over time. However, mercury levels in tissue remain a concern for the longer-lived pike–perch, particularly in larger specimens. At present, the consumption of such fish is not permitted.

The lack of a significant trend in cadmium levels in the sediment versus in the water column relates, in part at least, to the large variability seen in the samples (Fig. 3*c*, *d*). Between 1985 and the spring of 1991, cadmium varied around 10 mg kg^{-1} dry weight (< 20 μm fraction). Then, over a short period, the concentration almost doubled. By 1998, the level had decreased again to a level similar to that in the 1980s. One possible explanation is that the increase in 1991 corresponded to an increase in pH and a reduction in salt content in the Elbe, both of which would impact the complexation of cadmium. The sudden decrease in the level of toxic pollution in the Elbe immediately following the collapse of East Germany coincided with an increase in primary productivity, which, in turn, elevated the pH to 9.2, a level not previously observed (ARGE-ELBE 1984–1989, 1993–1999). This coincided with a reduction in chloride load of about 30% over two years. Since the solubility of cadmium decreases significantly as pH increases, cadmium would have been sequestered in a bound form (Stumm & Morgan 1996). Decreasing salt content affects cadmium similarly (Förstner 1980).

The fact that cadmium is remaining near the level seen in the 1980s is cause for concern and is echoed by the results from the mussel study. The high level of cadmium in the Mulde River has been constant for many years (Müller 1996). The source of the pollution is attributed to closed mines in the upper part of the Mulde catchment. As such, the prognosis for an improvement in the cadmium levels in the near future is poor, unless significant effort is focused in this area.

Arsenic levels experienced a sudden increase in the mid-1990s; the reasons for this are unclear. However, since that increase, arsenic levels appear to be decreasing (Fig. 4). Several more years of observation will be needed to confirm this trend.

HCH isomers

Organochlorines are often used as pesticides, with gamma-HCH more commonly referred to as lindane. These chemicals are less persistent in water, although they do accumulate in fatty tissues and have toxic effects in living systems (Agency For Toxic Substances And Disease Registry 1999*b*). The positive trend in the organochlorine, β-HCH, and the lack of significant trends in two other isomers, α-HCH and γ-HCH (lindane), is not surprising given that HCH-production continues in the Elbe watershed (Fig. 5). Some of the pollution may also stem from old stores of these chemicals. The findings of the mussel study help pinpoint possible sources of the HCH contamination, with high levels in both the Czech Elbe and the Mulde watershed. In part, the class III–IV (very heavily polluted) designation for the Mulde relates to the chemical industry complexes at Bitterfeld and Wolfen in this sub-catchment during the communist era.

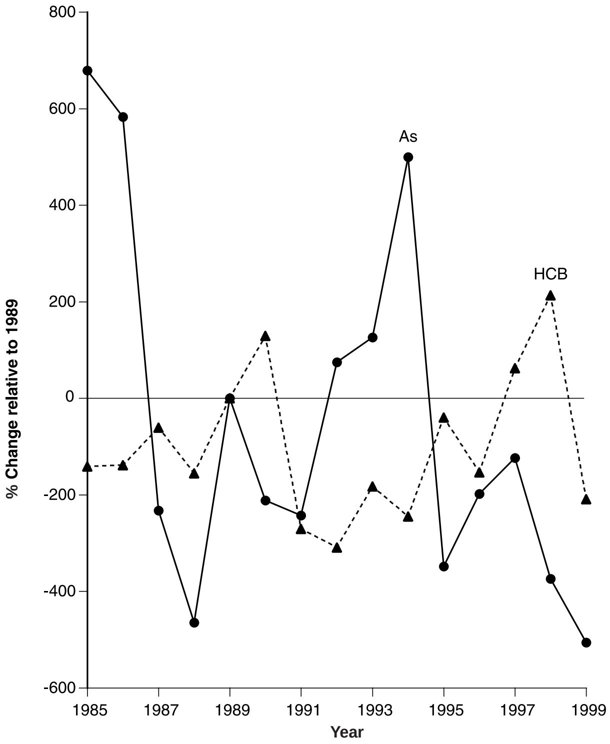

Figure 4 Trends relative to 1989 in As and HCB in the Elbe, 1985–1999. Source: ARGE-ELBE.

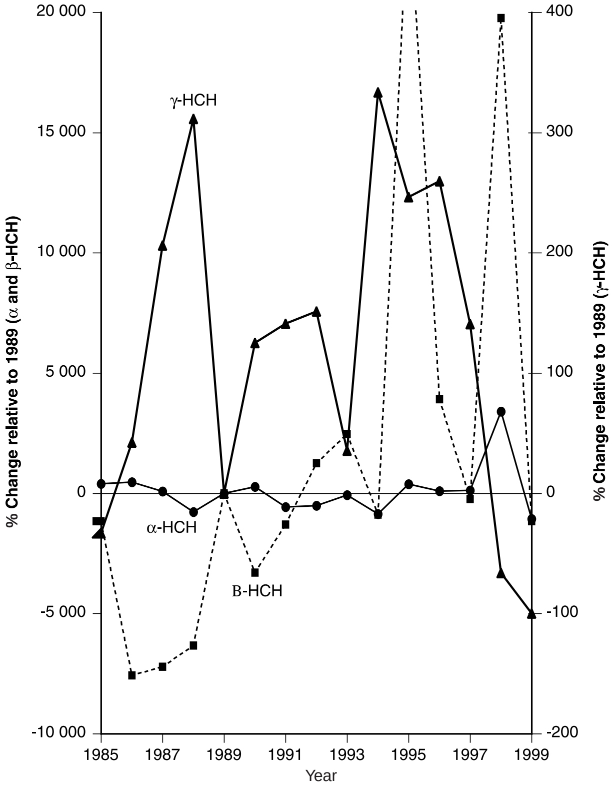

Figure 5 Trends relative to 1989 in HCH isomers (left-hand side: α-HCH and β-HCH; right-hand side: γ-HCH) in the Elbe, 1985–1999. Source: ARGE-ELBE.

Leachate from landfills and surface runoff from precipitation will continue to be a source of pollutants for not only the Mulde, but also the Elbe in the near future. Due to the toxic nature of these substances, it would be wise to concentrate efforts on reducing current sources of HCH-isomers. The lack of a significant decline in bream would seem to underscore this point.

Hexachlorobenzene

Hexachlorobenzene (HCB) also can be used in certain industries and as a pesticide. It is very persistent in the environment and accumulates in plant and animal tissues (Agency For Toxic Substances And Disease Registry 1997). The course of HCB levels over the period of our analysis is particularly striking. Until the time of German reunification, the annual load remained relatively constant. Immediately following the political changes, a significant reduction was observed, particularly from 1991 to 1993 (Fig. 4). Subsequently, the load has increased, rising to a record peak of 230 kg yr^{-1} in 1998 (Table 1). This increase is associated with the presence of a very significant HCB industrial source located in the Czech Republic immediately upstream from the German-Czech border. The plant is sited on the Bilna, a tributary river to the Elbe. Pollution concerns are not solely relicts of the former communist societies, as the suspended sediment data indicated; they can occur just as easily under the new systems. However, current efforts by the German federal government, the German state of Saxony, and the city of Hamburg have helped reduce these loads. The bream and eel studies have shown that HCB levels have decreased significantly, and that HCB is no longer the dominant pollutant. Despite decreases, the results from the eel studies reveal levels too high to allow human consumption of this species.

DDE and DDD

DDT and its metabolites, DDE and DDD, are very persistent in soils and accumulate in fatty tissues, leading to, among others, reproductive and nervous system problems (Agency For Toxic Substances And Disease Registry 1995). Results from the mussel studies indicate that the Mulde catchment remains a major source of these chemicals, whose contamination continues downstream in the Magdeburg region. Although DDT has been banned in Germany for some time, old sources, such as landfills, still exist.

In contrast to the decreasing trends in eel, the lack of significant trends in DDE and DDD levels in bream relate to the respective life histories of those species (Figs. 6 and 7). Bream remain in localized areas throughout their life (Lühmann & Mann 1962). Thus, those that live in a contaminated environment will accumulate high levels of any fat-soluble contaminants. Eel, on the other hand, range over a much larger area and spend part of their life cycle at sea (Muus & Dahlström 1974). Thus, the accumulation of contaminants in their tissues represents an average of a much larger area. On a positive note, total DDT content in eel is no longer cause for serious concern according the 1999 ARGE-ELBE fish surveys.

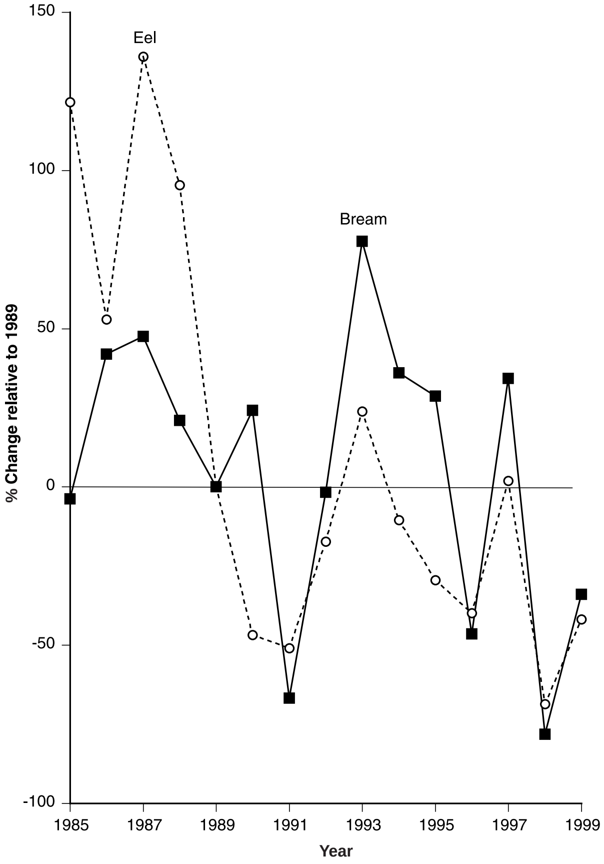

Figure 6 Trends relative to 1989 in accumulation of DDD in bream and eel the Elbe, 1985–1999. Source: State Veterinary Research Institute for Fish and Fish Products, Cuxhaven, Germany.

Fish species diversity

Overall, the increase in diversity of fish species since German reunification is a positive sign. With decreasing pollutant loads, and resulting decreases in BOD and COD, the environment of the Elbe has become more attractive and hospitable to many different forms of life. Since fish occupy the top of the aquatic food chain, a diverse assemblage of fish species indicates that the fish's prey and forage are also diverse. The increase in species diversity also reflects habitat improvements, such as the installation of fish ladders at the dam at Geesthacht. The importance of river structure is also seen in the difference in the increases observed between the Czech and German Upper Elbe. The German Upper Elbe saw the greatest overall increase, whereas the Czech segment saw the lowest. A probable explanation for this occurrence is the presence of dams on the Czech part of the river. Dams function as effective barriers to the movement of species (World Commission on Dams 2000), and can thus impact both recolonization of natives, as well as invasion by exotics. Thus,

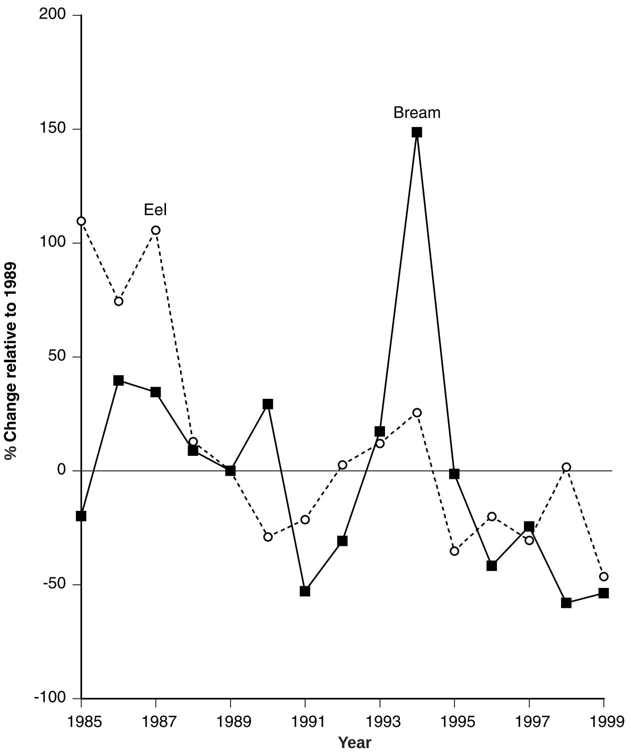

Figure 7 Trends relative to 1989 in accumulation of DDE in bream and eel the Elbe, 1985–1999. Source: State Veterinary Research Institute for Fish and Fish Products, Cuxhaven, Germany.

dams have probably prevented some species from returning the Czech Elbe, as well as some exotic species from invading. We discuss the issue of exotic species in a later section.

The type of species (re)colonizing the system also provides important insights into the direction of the recovery. We focus our attention on the species additions in the German Upper Elbe, as an example of the changes that are occurring throughout the Elbe. As the German Upper Elbe belongs to the barbel-region of the Elbe, the situation described here applies to all the barbel-regions of the Elbe. The fish surveys immediately following German reunification showed that the fish species assemblage of the Upper Elbe was primarily dominated by generalist species that possess non-specific characteristics and are limited in their function as indicator species. Most notably absent was the barbel (*Barbus barbus*), the characteristic species of most of the Upper Elbe. In contrast, the latest surveys show a dramatic return of rheophilic species, including the barbel. Rheophilic species serve as indicators for this region of the Elbe; their absence at the beginning of the decade and return now speak a great deal to the improving ecological condition of the Elbe. An increase has also been recorded for euryhaline species. Except for the salmon, which was the subject of an intensive reintroduction project, all of the other euryhaline species have returned on their own.

The Middle Elbe, which belongs to the bream region, has a similar story. The rheophilic species have also increased, though not to the same magnitude as in the Upper Elbe. This, however, follows expectations, as the rate of flow in the Middle Elbe is much slower and it is less suitable to rheophilic species.

Other factors have also contributed to the increase observed in species diversity. For instance, improved data collection technology was available for the later fish census work conducted toward the end of the 1990–1999 surveys. Thus, it is possible that some species that were not recorded were, nonetheless, previously present. Secondly, the numbers also reflect invasion by exotic, non-native species, an issue to which we now turn our discussion.

Evaluating the situation of exotic fish species in the Elbe is complex. Gaumert (2001) attributes this both to the long history and tradition of introducing foreign fish species into European waters and to the varying definitions of ‘exotic fish species’. Further, based on data from ARGE-ELBE, about 20% of the non-marine fish-species in the whole river can be identified as being exotics and have become established in the river. Overall, the exotics generally play a minor role based on their dominance (as measured by relative numbers of individuals) and by biomass (relative to total Elbe fish biomass), which both measure less than 1%. In individual cases, they can play a more significant role. There are only occasional circumstances in which the exotics significantly compete for resource with native species. Given the Elbe’s status as an international shipping route, it can be expected that exotic species will likely continue to be introduced. Such exotics could alter the fish communities in the river.

In conclusion, much progress has been made in restoring the Elbe, since the massive political changes in former East Germany and Czechoslovakia at the end of the 1980s. Whether or not this progress can be maintained remains to be seen. Certainly, the physical template is in place, as the Elbe retains many natural structures and habitats. Further, as we have demonstrated, the water quality has improved greatly, much to the benefit of the river’s biota. Moreover, the desire to protect the river extends beyond simply improving its water quality. This is evident in the growing number of protected areas along the Elbe. Simon (1999) reports that the area placed under protection along the Elbe has increased dramatically in the last 10 years, so that a total of 702 km of the Elbe now possesses some type of protection.

Despite the positive changes, our analysis identifies pollutants that remain problematic. Not all of them are simply relicts of the past; some stem from current activity in the Elbe’s watershed, such as industrial production and construction. Another threat to the Elbe is the invasion by exotic species. All of these problems could be aggravated by proposed alterations to the Elbe’s channel. Further, they all can affect the entire system. Therefore, they require the kind of approach Naumann (1992) suggested; a regional approach encompassing the whole of the Elbe catchment. IKSE has been a solid step towards co-ordinating the varying and diverse interests throughout the Elbe catchment. Continued integrated planning, through co-operation amongst political institutions, industry, agriculture, and the public will be necessary, if the Elbe is to continue its amazing recovery.

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