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ORIGINAL ARTICLE

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# Long-term investigation of the degree of exposure of German peregrine falcons (*Falco peregrinus*) to damaging chemicals from the environment

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**Abstract** The contamination of German peregrine falcons (*Falco peregrinus*) with organochlorine (CHC) biocides and mercury (Hg) was investigated over the years 1955–2002. A total of 960 unhatched eggs from eastern Germany, Baden-Württemberg (BW) and North Rhine-Westphalia/Rhineland Palatinate (NRW/RP) were analysed for the biocides DDE, HCB, PCB, etc., and for shell index and shell thickness. Hg analyses from 367 samples (unhatched eggs, moulted and nestling feathers, tissue samples) complete the investigation. The results confirm that the collapse of the German peregrine populations is correlated with the application of the insecticide DDT. The mean DDE values in BW over the years 1970–1976 were above the relevant threshold values of 70–100 μg/g (all concentrations refer to the dry sample mass), with single analyses showing values above 100 μg/g until as late as 1987. The mean contamination levels in the 1960s can be retrospectively assumed to have lain above 200 μg/g. With the help of thorough conservation measures it was possible after a fall in numbers of about 80% to stabilise the remnant population in BW . Following the West German DDT ban in 1972 and the resulting decline in environmental CHC contamination, this core population was able to recover from about 1980 onwards and has since increased tenfold. The shell index improved steadily from 1.48 (1970–1971) to a normal value of 1.80–1.88 (2000–2002). Hg contamination in western Germany stayed under toxic threshold values over the period 1969–1991. The significantly more intense application of DDT in eastern Germany, continuing until 1989, led to the extinction of the peregrine falcon, of both the cliff- and tree-nesting populations. This phenomenon is described with respect to DDE analysis data and shell thickness/index studies, complemented by observations of breeding biology. In addition, the employment in the GDR of methyl/phenyl Hg as seed treatments had dramatic local toxic effects on embryo survival and shell thickness. Hg burdens reached very high levels in feathers (147 μg/g) and eggs (65 μg/g). The combination of DDT and Hg was responsible for the species' extinction in this region. The current peregrine falcon population of eastern Germany even now shows biocide contaminant burdens up to 3 times higher than in samples from western German falcons. Shell index and shell thickness had, however, normalised to a large extent by 2002. The tree-nesting habit of the peregrines formerly breeding in the forested lowlands of Central and Eastern Europe, a tradition which had been passed on by imprinting, has been completely eradicated as a result of the effects of the environmental contamination. In NRW/RP unhatched eggs over the period 1989–2002 show uncritical DDE contamination levels in the region of 4–20 μg/g with normal shell index values. PCB analyses from all three regions confirm the highest levels of contamination from industrial centres with no clear trend so far. HCB burdens peaked at a maximum of 80 μg/g and have been stable at $<1$ μg/g since 1983. Population parameters did not improve in BW until 1976, after DDE and HCB contamination levels had started to decrease as a result of the bans on use. In East Germany and NRW/RP, the documented recolonisation and increases in breeding success parameters were only possible after the DDE levels (and in East Germany additionally the Hg levels) had fallen to below toxic threshold levels.

**Keywords** *Falco peregrinus* · DDT · PCB · Mercury · Recovery

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## Introduction

In many countries and regions of the northern hemisphere the population levels of peregrine falcon (*Falco peregrinus*) decreased dramatically during the period 1950–1975, with local extinctions occuring over large areas. Other species at the top of the food chain were also affected. As insectivorous birds began to decrease in numbers (Carson 1962), an intensive hunt for the causes began.

Fairly quickly, certain newly developed pesticides came under suspicion. The discovery of this connection is closely linked with the name of Derek Ratcliffe (1958, 1967, 1970, 1980). Ratcliffe recognised that certain chlorinated hydrocarbon (CHC) pesticides, such as DDT, lindane, aldrin and heptachloroepoxide, negatively affected the fertility and mortality of some birds of prey. He was able to produce direct and indirect evidence, for example pesticide residues in eggs and thin-shelled eggs, respectively. This connection, originally formulated as a working hypothesis, is now proven scientific fact (summaries in: Hickey 1969; Cade et al. 1988; Meyburg and Chancellor 1994). Apart from the above-named CHC-pesticides, heavy metals and polychlorinated biphenyls (PCBs) are also implicated in the species' decline.

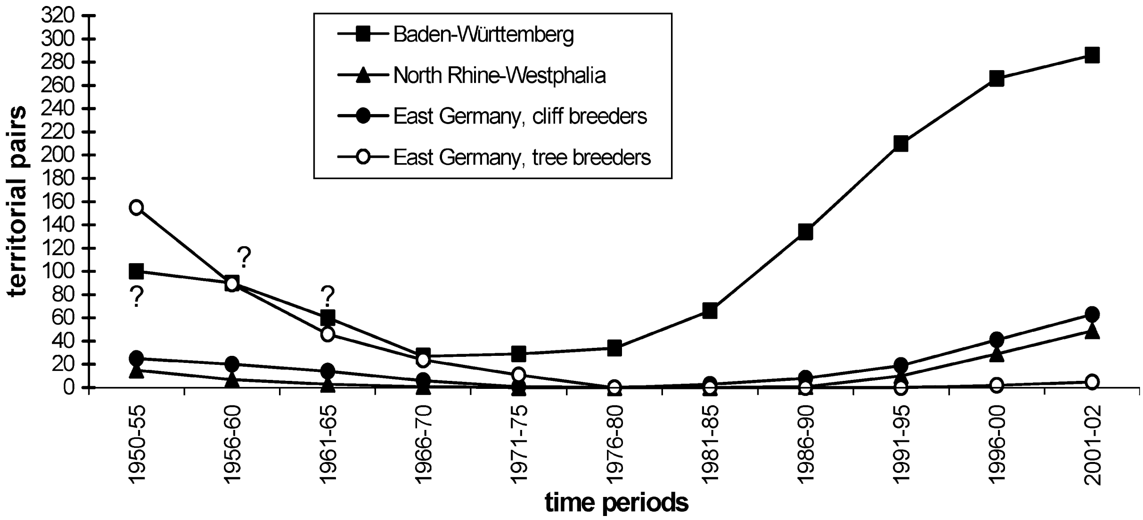
In Germany it was realised from the mid 1950s that the peregrine (subspecies *F. p. peregrinus*) was becoming increasingly rare, finally disappearing completely from large areas, as shown in Fig. 1 (Demandt 1950, 1955; Mebs 1960; Kleinstäuber 1963, 1987; Kleinstäuber and Schröder 1963; Fischer 1968; Knobloch 1970; Kirmse and Kleinstäuber 1977; Schilling and Rockenbauch 1985; Wegner 1989; Hepp et al. 1995; Kirmse 1995; Kleinstäuber and Kirmse 2001). Parallel declines were observed in the Eurasian sparrowhawk (*Accipiter nisus*) and the white-tailed eagle (*Haliaeetus albicilla*).

The clamour for a ban on these pesticides first became loud in the United Kingdom. Following legislative restrictions in various countries, the application of DDT and other CHC biocides in the Federal Republic of Germany was eventually forbidden in stages, starting in 1972. In the German Democratic Republic, the use of DDT was continued for 17 more years despite a formal ban being in place from 1972.

Significant differences were observed in the extent and time scales of decline and recovery of the peregrine falcon populations in the individual federal states. These differences can be clarified by comparing biocide burdens and eggshell parameters with the local amounts of biocide in use and the start of effective legal measures.

The present paper describes the development of biocide contamination of the peregrine falcon in Baden-Württemberg (BW), the new federal states in East Germany, and North Rhine-Westphalia (NRW) / Rhineland Palatinate (RP) over a time scale of up to 45 years. Information from earlier publications (Conrad 1977; Baum and Conrad 1978; Schilling and König 1980; Baum 1981; Schilling 1981; Schilling and Rockenbauch 1985; Kleinstäuber 1988, 1991; Baum and Hädrich 1995; Wegner 2000; Schilling and Wegner 2001) is included in this paper. The level of contamination was investigated by analysis of residues from unhatched eggs (incubated beyond normal hatching date, unfertilised and/or abandoned), eggshells, moulted feathers and organs.

**Fig. 1** Changes in peregrine (*Falco peregrinus*) populations (numbers of territorial pairs) in Baden-Württemberg, East Germany and North Rhine-Westphalia. All data are given as arithmetic mean values in 5- or 2-year-periods. Sources: AGW-BW (1966–2002); AWS (1990–2002); AGW-NRW (1990–2002)




## Methods

Number and origin of samples

The analysis material consisted of contents and shells from unhatched eggs that were recovered during ringing of young birds or taken from failed clutches, and which were therefore not collected on a standardised basis.

During the period 1955–2002, 960 eggs were analysed (Table 1), 742 for biocide content and 692 for shell index. The measurements of 755 eggs were taken and the shell thickness of 145 eggs recorded. Egg samples from the period 1950–1965, which were not available to us in the quantities we would have wished for, are of particular importance for this evaluation, as those are the years in which the greatest amounts of DDT were applied for agricultural and forestry purposes. This gap is largely compensated for by the extensive data series presented in this article, spanning trends in biocide application, breeding biology parameters and field observations. In addition, the studies encompass moulted and nestling feathers as well as random organ samples of dead falcons.

## Analysis methodology

At the commencement of the studies the analysis techniques employed were limited (quantitative Thin Layer Chromatography/TLC). For that reason, the results from BW for the years 1967–1969, as well as analyses from East Germany for the important years from 1970 to 1984, were not used. Particularly initially, problems arose with the evaluation and interpretation of the data in respect of the analysis quality, comparability and material heterogeneity, sample collection being non-standardised. In this respect, a degree of error tolerance in terms of the individual values must be accepted. A presentation of the results in box-whisker plot form, with mean values and percentiles, has therefore been omitted. Instead, where sufficient material for a single year was available, arithmetic mean values (AMV), maxima and minima, and in some cases standard deviations (SD) are given. Where local extreme values have been levelled out through the quoting of average values, such sites of unusually high contamination levels are mentioned in the discussion.

Egg contents were systematically analysed for residues of hexachlorobenzene (HCB), $\gamma$-hexachlorocyclohexane (HCH, lindane), cis-heptachlorepoxide (cis-HCE) and the main metabolite of DDT, dichlorodiphenyldichloroethylene (pp-DDE), as well as for polychlorinated biphenyls (PCB). For some samples, the analyses were extended to include DDT isomers and metabolites (op-DDT, pp-DDD and op-DDD), dieldrin, aldrin and all important PCB congeners. The standardised analysis procedure included drying of the egg samples, extraction of fat contents and purification of the resulting extracts. The identification and quantification of the individual substances were achieved by gas chromatography, in part with MS coupling. The analysis methods are described in detail by Baum and Hädrich (1995), Wegner (2000) and Schilling and Wegner (2001).

The total PCB concentration was measured according to the LUFA Karlsruhe-Augustenberg (state agricultural analysis and research laboratory, BW) method [total PCB = (PCB content 138×8.7 + PCB content 153×10.2 + PCB content 180×14.3) / 3; numbering according to Ballschmiter and Zell 1980]. The PCB "content" calculated in this way is consistently markedly higher than the sum of all PCB congeners together (by a factor of c. 1.5–2.2). The LUFA formula was retained, as a complete congener analysis only became available at a later date. The PCB analysis values showed the greatest variation due to strongly differing regional contamination levels and evince highest values for unhatched eggs from industrial urban conurbations.

Unhatched eggs, feathers and in some cases body organs from BW, East Germany and NRW were analysed for endogenous mercury residues using ZEEMAN Solid Sampling Atom Absorption Spectrometry or energy dispersive x-ray fluorescence (ED-XRF). The methods are described by Hahn et al. (1993) and Hennig (1993).

All analysis values were given as µg/g of dry mass (d.w.). In the conversion, an average dry mass comprising 21% of the total mass of "fresh" unhatched eggs was assumed. The fat content of "fresh" peregrine falcon eggs was on average 5.6% (SD 1.7%; $n = 65$). The conversion from fat to dry weight was egg specific.

## Shell analysis

The parameters length (L), breadth (B) (calculation tolerance 0.1 mm respectively) and shell mass (SM; tolerance 0.1 mg) were calculated on a routine basis. Critical parameters for damage caused by DDT/DDE contamination are, according to Ratcliffe, the shell index [$SI = SM/(L \times B)$ in mg/mm$^2$] and the shell thickness (ST). With an average egg wall thickness (of undamaged eggs) of 0.34 mm the egg skin alone measures 0.06–0.08 mm; that is 18–24% of the total egg wall thickness (Schilling and König 1980; Burnham et al. 1984; and own mea-

**Table 1** Number of analysed unsuccessful (non-hatching) peregrine falcon (*Falco peregrinus*) eggs from German federal states. Sources: Schilling, Wegner, Kleinstäuber, own data

| Year | Baden-Württemberg | North Rhine-Westphalia Rhineland Palatinate | Eastern Germany / Berlin | Sum |
|---|---|---|---|---|
| 1950–1960 | | | 2 | 2 |
| 1961–1970 | 23 | – | 1 | 24 |
| 1971–1980 | 124 | – | 6 | 130 |
| 1981–1990 | 226 | 9 | 74 | 309 |
| 1991–2000 | 202 | 47 | 120 | 369 |
| 2001–2002 | 71 | 25 | 30 | 126 |
| Total | 646 | 81 | 233 | 960 |

surements). With old material in particular, it was not always possible to be sure whether the egg skin was entirely or only in part included in the measurements, or if it was completely missing. In addition the calcium shell is not equally thick at every point on the egg; but is often especially thick, by up to 20%, at the poles. During the studies, meticulous care was taken to obtain the average ST by measuring the shell thickness near the equator and to exclude any residual egg skin.

Shell deficits are characterised by a decrease in thickness and a reduction of the shell weight, as a result of greater pore size or empty spaces (vacuoles), and thereby an increase in fragility (Hartner 1977; Prinzinger and Prinzinger 1980). During the preparation of the egg shells for determination of the SI, the egg skin was loosened and removed by blowing and washing out repeatedly with warm water. The SI index value is relatively insensitive to the influence of various egg shapes (from round to pointed oval) (Feige and Riedel 1988; Wiesner and Elvers, personal communication; and own measurements). From 1980 in BW only, the SI was measured. Where the SI could not be determined (e.g. egg fragments or halves) the ST was systematically recorded.

## Results

### Contamination values

From 1967 onwards, the most comprehensive collection of sample material was carried out in BW (Table 1). After the peregrine falcon breeding populations in all other federal states, with the exception of the Bavarian Alps, had become extinct, at the latest by 1970–1975, the peregrine falcon Working Group (AGW) in BW managed to stabilise a rump population of 25–30 territorial pairs by means of intensive protection measures. This population stagnated over a time frame of 15 years until 1980; after this time an increase and subsequent range extension of the population began, including recolonisation of other federal states (Fig. 1).

### DDT/DDE contamination

In Table 2, the changes in DDE contamination and the SI for the years 1970–2002 in BW are given. The steady fall in DDE burdens from a dramatically high contamination level of around 150 μg/g by an order of magnitude, and the increase in the SI of some 23%, are documented in long data sequences.

Only after a gap of 20 years, following the return of the peregrine falcon to NRW and the northern part of RP, was it possible to recover and analyse large numbers of unhatched eggs from these areas as well (Wegner 1994b; Table 3).

The average DDE contamination in the years 1992–2001 was around 6.5μg/g with only minor local deviations (SD 3.4 μg/g, range 1.0–18.0 μg/g, $n=59$). It is notable that at the edge of the northern Ruhr industrial complex the values are particularly low, AMV = 3.4 μg/g (SD 2.4 μg/g, $n=11$ from 5 years), whereas a significantly higher basic contamination level (up to 18 μg/g) appears to persist in vineyard habitats in the valley of the River Saar, and in certain restricted regions of the Lower Rhine basin with intensive arable cultivation, although this conclusion is based on small amounts of data.

Table 4 summarises the DDE/PCB contamination levels and SI values of East German eggs. Eggs from the intensively farmed regions of the East German Plain, and the Berlin conurbation surrounded by pine forests, still showed critically high DDE contamination values (AMV = 58.2 μg/g, SD 34.9 μg/g, range = 18.8–130 μg/g, $n=13$) in the period 1994–1998, with considerable local variations between neighbouring pairs.

### Contamination with HCB, cis-HCE, lindane, dieldrin, aldrin and endrin

HCB, a fungicidal seed dressing, was still present in 1971 in unhatched eggs in BW at an average concentration of some 57 μg/g (max 79) (Table 2, Fig. 2). Common pheasant (*Phasianus colchicus*) and northern goshawk (*Accipter gentilis*) eggs were even more affected (up to 100 μg/g) (Baum and Conrad 1978). After the introduction of restrictions on its use, followed by a complete ban in 1977, the contamination values fell continuously and have remained stable at under 1 μg/g since about 1980. Residues of the insecticides aldrin, dieldrin, endrin und lindane in BW stayed at a steady low level of under 1 μg/g (Fig. 3). However, heptachlor (in the form of its main metabolite cis-HCE) locally reached critical values of up to 5.6 μg/g in 1973. Information on contamination prior to 1973 could not be provided. Levels of these pesticides in unhatched eggs from NRW and East Germany were insignificant (no more than 1 μg/g).

### PCB contamination

The level of PCB contamination still shows no clear trend in any of the regions under study (Tables 2, 3, 4, Figs. 2, 3). The highest PCB concentrations were found in peregrine falcon eggs from the industrial conurbations of Berlin, Stuttgart, Mannheim/Ludwigshafen, Koblenz, Köln-Düsseldorf and the central and eastern Ruhr complex (average values consistently exceeding 50 μg/g). We recorded surprisingly low PCB values in eggs from the northern edge of the Ruhr complex in rural regions (AMV = 16 μg/g, SD 3.9 μg/g $n=10$) and in the Neckar valley and the Odenwald region. The total PCB values show the widest variations of all the parameters studied. The highly chlorinated congeners PCB 138, PCB 153 and PCB 180 (hexa- und heptachlorobiphenyl) dominated in all samples.

Table 2 Trends in DDE-, HCB- und Σ-PCB-contamination levels (in μg/g d.w.) and in eggshell indices SI in peregrine falcon eggs from not detectable; * extrapolation from measurements of eggshell thickness. Source: AGW-BW (1996–2002)

| Year | | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *n* | | 4 | 8 | 0 | 10 | 14 | 16 | 14 | 8 | 11 | 16 | 9 | 9 | 18 | 19 | 18 | 18 |
| DDE | Mean | 153 | 110 | – | 108 | 96 | 50 | 75 | 66 | 54 | 61 | 49 | 35 | 55 | 46 | 54 | 49 |
| | Range | 90–200 | 74–138 | | 80–175 | 69–120 | 18–112 | 25–140 | 12–128 | 11–136 | 26–99 | 25–74 | 8–56 | 24–122 | 8–88 | 14–146 | 21–76 |
| HCB | Mean | – | 57 | – | 45 | 31 | 13.2 | 7 | 3.3 | 3.4 | 6.2 | 2.1 | 1.8 | 1.4 | 0.8 | 0.7 | 1.1 |
| | Range | | 5–79 | | 4–77 | 13–73 | 2–30 | 1–21 | 1–6 | 2–8 | 0.7–12 | 0.4–6.6 | 0.1–6 | 0.4–5 | 0.1–1.6 | 0.3–1.4 | 0.2–2 |
| **PCB** | Mean | 75 | – | – | 21 | 9 | 35 | 74 | 57 | 87 | 118 | 75 | 36 | 46 | 47 | 84 | 78 |
| | Range | 55–100 | | | 14–32 | 2–17 | 9–91 | 31–110 | 11–92 | 34–213 | 77–199 | 30–160 | 1–68 | 30–134 | 12–96 | 8–196 | 7–145 |
| *n* | | 7 | 10 | 15 | 6 | 14 | 15 | 13 | 9 | 13 | 7 | 8 | 7 | 21 | 18 | 17 | 8 |
| SI | Mean | 1.53* | 1.43* | 1.56 | 1.57 | 1.63 | 1.62 | 1.58 | 1.62 | 1.65 | 1.58 | 1.55 | 1.60 | 1.65 | 1.621 | 1.63 | 1.60 |
| | Range | | | 1.24–1.87 | 1.32–1.68 | 1.44–1.85 | 1.43–1.85 | 1.36–1.86 | 1.38–1.79 | 1.35–1.77 | 1.37–1.80 | 1.41–1.72 | 1.38–1.70 | 1.35–1.85 | 0.42–1.91 | 1.43–1.85 | 1.42–1.88 |

## Mercury contamination

Table 5 provides an overview of endogenous Mercury (Hg) concentrations recorded in unhatched eggs, tissue samples and feathers.

In the East German states of Thuringia and Saxony Anhalt, the concentrations in eggs were often significantly higher than the threshold value of c. 2.5 μg/g, eggs from Sangerhausen (SGH/Saxony Anhalt) for the years 1986–1990, with a maximum value of 65 μg/g, possessing particularly high values. Eggs laid there had extremely thin shells or were completely shell-less ("flowing-eggs"), even though DDE contamination had in the meantime sunk to uncritical levels. It is probable in this case that the very high mercury contamination is the cause of the extreme shell thinness (ST between 0.03 and 0.15 mm!; SI between 0.308 and 1.441, DDE = c. 20–25 μg/g). It is less probable that the laying of eggs with extremely thin shells over a number of years is a shared individual trait of the resident paired females. The female F1 (up to 1988) had endogenous Hg deposits of between 21.5 and 127.2 μg/g in her primaries. Values between 21.4 and 32.2 μg/g were recorded from the moulted feathers of her breeding partner M1. The new female which settled in the SGH territory from 1989–1992 laid eggs with thicker shells, nevertheless they did not hatch (1990: SI = 1.502 mm, ST = 0.25 mm, Hg = 53 μg/g, DDE = 13 μg/g; 1991: only small shell splinters in the eyrie; 1992: clutch taken and hatched in the peregrine falcon station in Hamburg, the embryos died; the territory has been abandoned since 1993). As early as 1987, a freshly laid, thin-shelled egg was taken from the SGH breeding site for incubation in the East Berlin Zoo. The developing embryo died after 10 days. This must be put down to a toxic effect as death due to shell thinness should have taken place much later.

In the neighbouring territory on the southern edge of the Harz mountains, some 20 km away, where the resident breeding pair hunts partly over similar countryside to Sangerhausen, the breeding success even today (2003) does not usually exceed more than one young bird annually, despite multiple change of partner. On the other hand, those falcon pairs which reside deeper in the Harz, despite an apparent relative scarcity of food supply, have good fledging rates of 3–4 young falcons per successful clutch.

Unhatched eggs, feathers and tissue samples from BW and NRW showed at no stage signs of critical mercury concentration (Table 5). This was also true of moulted feathers collected in East Germany in the period 1953–1964.

## Shell parameters

Unhatched eggs from all regions under study are a representative random sample, as their average measurements do not differ from freshly collected eggs in German museum collections (Table 6). The details given in the table have been complemented with data on fresh eggs from Britain and Ireland (Ratcliffe 1980). Unhatched eggs from BW at the time of higher DDT contamination (1968–1980) show by their measurements of 53.12×40.83 mm (*n* = 125) significant length differ-

Table 3 Trends in DDE- and Σ-PCB-contamination levels (in μg/g d.w.) and in shell indices (SI) in peregrine falcon eggs from North Rhine-Westphalia / Rhineland Palatinate in the years 1989–2002. HCB levels since 1989 below 1 μg/g d.w. Source: AGW-NRW (1990–2002)

| Year | | 1989–91 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *n* | | 12 | 1 | 1 | 2 | 1 | 3 | 3 | 6 | 16 | 10 | 17 | 8 |
| DDE | Mean | 23 | 4 | 10 | 7 | 7 | 4 | 7 | 7 | 6 | 7 | 7 | 8 |
| | Range | | | | | | | | 3–12 | 2–10 | 1–11 | 3–18 | 2–15 |
| PCB | Mean | 175 | 14 | 48 | 43 | 36 | 28 | 18 | 86 | 38 | 71 | 42 | 53 |
| | Range | | | | | | 12–40 | 15–19 | 40–150 | 11–110 | 19–197 | 10–109 | 16–119 |
| *n* | | 3 | 1 | 2 | 2 | 1 | 2 | – | 5 | 15 | 7 | 14 | 7 |
| SI | Mean | 1.79 | 1.83 | 1.88 | 1.94 | 2.02 | 1.93 | – | 1.84 | 1.82 | 1.90 | 1.81 | 1.83 |

Baden-Württemberg in the years 1970–2002. The total PCB-concentrations have been determined according to LUFA.*n* sample size; n.d.:

| 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | 24 | 18 | 40 | 27 | 37 | 32 | 30 | – | 8 | 4 | 9 | 18 | 29 | 35 | 38 | 35 |
| 62 | 50 | 17 | 14 | 13 | 27 | 14 | 17 | – | 15 | 13 | 4 | 18 | 11 | 10 | 13 | 20 |
| 16–137 | 18–129 | 7–38 | 6–27 | 7–26 | 5–47 | 4–25 | 4–44 | | 2–26 | 7–17 | 0.6–6.4 | 0.3–36 | 0.3–14 | 0.4–33 | 1.2–55 | 2.7–107 |
| 0.7 | 0.82 | 0.29 | 0.27 | 0.23 | 0.22 | 0.16 | 0.18 | – | 0.14 | 0.11 | 0.2 | 0.62 | 0.2 | 0.1 | 0.18 | 0.06 |
| 0.15–1.2 | 0.12–2.11 | 0.08–0.84 | 0.14–0.78 | 0.07–0.75 | n.d.–0.91 | n.d –0.56 | 0.06–0.83 | | 0.11–0.18 | 0.10–0.114 | n.d.–0.8 | 0.10–1.00 | n.d.–1.3 | n.d.–0.8 | 0.01–0.7 | n.d.–0.21 |
| 139 | 139 | 39 | 42 | 54 | 54 | 40 | 42 | – | 35 | 25 | 59 | 32 | 43 | 22 | 30 | 56 |
| 41–625 | 42–538 | 14–73 | 13–121 | 16–123 | 6–140 | 9–81 | 20–117 | | 13–69 | 7–30 | 9–211 | 10–82 | n.d.–132 | n.d.–140 | 7–98 | n.d.–351 |
| 22 | 16 | 24 | 33 | 17 | 31 | 23 | 21 | – | – | – | 8 | 3 | 25 | 24 | 37 | 33 |
| 1.69 | 1.61 | 1.74 | 1.72 | 1.74 | 1.74 | 1.77 | 1.85 | – | – | – | 1.87 | 1.64 | 1.78 | 1.85 | 1.80 | 1.88 |
| 1.49–1.91 | 1.39–1.85 | 1.54–2.10 | 1.47–2.08 | 1.46–2.12 | 1.36–1.95 | 1.65–1.99 | 1.63–2.01 | | | | 1.68–1.97 | 1.60–1.72 | 1.42–2.14 | 1.54–2.09 | 1.51–2.06 | 1.46–2.27 |

ences to eggs from the period 1981–2002 with less DDE contamination (51.67×40.64 mm; $n = 408$). A decrease in egg dimensions with increasing age of the laying female has been described by Ratcliffe (1980), Burnham et al. (1984), and Wegner (2002). The shell thickness and the shell index are not related to the progress of incubation (Newton, personal communication; Wegner 2002).

## Shell index

Table 2 and Fig. 4 show a continuous increase of the SI in BW of 23%, from 1.48 (1970–1971) to the normal, healthy level of c. 1.82 (2000). Table 4 and see Fig. 7 demonstrate, in terms of mean values, a time lag of some 10 years in the recovery of the SI in East Germany. This was a consequence of massive and long term application of DDT in agriculture and forestry management in East Germany.

Figure 5 demonstrates the dependence of the SI (as a benchmark for the thinness of the shell) on the logarithm of the DDE contamination, the SI falling with increasing DDE contamination. The annual AMVs of DDE contamination are shown alongside the corresponding SI values from BW, East Germany and NRW/RP.

Figures 6, 7 and 8 show the downward and upward trends of SI and ST in East Germany for the populations as they died out and recovered. The reference points SI = 1.82 and ST = 0.28 mm (without egg skin) are measured values from peregrine falcon eggs from the period 1900–1939 without DDE contamination (see Table 8).

Complete eggshells from the 1950s and 1960s from reliable sources are rare. The two eggshells available from the year 1955 have index values of SI = 1.133 (Elbe Sandstone Mountains, Elbsandsteingebirge) and SI = 1.537 (Upper Saale valley). Trend calculations show that in the 1960s, when the East German cliff-dwelling territories had already ceased to produce offspring, the mean eggshell index must have been around 1.3 (minus 27%).

The differing regional SI increases in East Germany since the start of the re-establishment of the populations there since 1982 is shown in Fig. 7. Due to massive deployments of DDT in these areas, the SI fell to an even lower level in the central German pine heath land and the intensively farmed plain than in the forested and less cultivated hill country of the Harz and the Thuringia Forest/Thüringer Wald. The effects of a new intensive campaign of DDT use in 1983–1984 were visible until the beginning of the 1990s. Intervention by the then "Working Group for Protection of Endangered Animals against Extinction in the GDR" (AKSAT) only succeeded in having areas with resident eagles excluded from pesticide spraying from aircraft (Hauff and Wölfel 2002). These measures had, however, no effect on the wide scale contamination of the biocoenose, as the bioindicator peregrine falcon proves many years after these operations (Kleinstäuber 1988). For the spruce forest-covered East German hill country no massive application of DDT is known of since 1974.

Nine eggs laid by captive breeding pairs in 1993–1997 (Station Woblitz/Brandenburg) show, with controlled feeding, the expected "normal" index values with AMV = 1.94 (SD 0.09).

## Eggshell thickness

The ST of shell remnants collected in East Germany was systematically measured. Figures 6 and 8 show the downward and upward trends of ST in the populations as they died out and grew back again. The ST values fell from a normal c. 0.28 mm to c. 0.20 mm (a reduction of some 28%), the mean value reached in East Germany in the 1960s. The extreme values from the SGH territory (1987–1989) were even in the region of 0.03–0.16 mm. We do not know how many cases similar to those observed in the SGH territory up to 1989 occurred in other eyries in East Germany in the 1950s and 1960s, but this probably became the norm. The behaviour observed by the protection teams was often identical to that later recorded from SGH: weeks to months of display and copulation with sometimes "incubation" behaviour in an empty eyrie. The current explanation is that the extremely thin-shelled eggs could no longer be incubated or, like the shell-less eggs, they somehow "fell" out of the female's body before fully developing. Eggs with very thin shells, like those also found in Berlin in 1987, often show a weak pink coloured pigmentation instead

**Table 4** Trends in DDE- and Σ-PCB-contamination levels (in µg/g d.w.) and in shell indices (SI) in peregrine falcon eggs from Eastern Germany in the years 1955, 1972 and 1983–2002. Source: AWS (1990–2002)

| Year | | 1955 | 1972 | 1983 | 1984 | 1986 | 1987 | 1988 | 1989 | 1990 | 1992 | 1993 | 1994 | 1995 | 1996 | 1998 | 1999 | 2000 | 2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *n* | | | 1 | | 2 | 6 | 1 | 10 | 4 | 2 | 4 | 1 | 4 | 2 | 2 | 5 | | | | |
| DDE | Mean | | 40 | | ? | 25[a] | 22* | 31 | 26 | 50 | 33 | 125 | 53 | 25 | 18 | 48 | | | | |
| | Range | | | | | | | 25–82 | 22–30 | 27–73 | 10–53 | | 24–72 | | | 13–130 | | | | |
| PCB | Mean | | | | 10 | 17* | 20* | 35 | 29 | 40 | 61 | 185 | 122 | 116 | 128 | 144 | | | | |
| | Range | | | | | | | 5–87 | 19–37 | 13–68 | 11–98 | | 90–142 | | | 28–387 | | | | |
| *n* | | 2 | 1 | 1 | | 7 | 9 | 10 | 4 | 2 | 3 | 1 | 5 | 9 | 4 | 12 | 15 | 17 | 9 | 17 |
| SI | Mean | 1.34 | 1.75 | 1.47 | | 1.58 | 1.42 | 1.43 | 1.53 | 1.43 | 1.66 | 1.71 | 1.59 | 1.73 | 1.62 | 1.75 | 1.75 | 1.81 | 1.74 | 1.72 |
| | Range | 1.13–1.54 | | | | 1.50–1.72 | 0.31–1.85 | 1.23–1.79 | 1.43–1.66 | 1.36–1.50 | 1.62–1.69 | | 1.39–1.71 | 1.60–1.87 | 1.54–1.70 | 1.50–1.99 | 1.55–2.05 | 1.56–2.09 | 1.52–1.96 | 1.51–2.16 |

[a]Results partly uncertain

of the usual dark brown spots. They were often found broken beneath the eyrie, although the influence of predators or conflicts in the eyrie could usually be ruled out. Fimreite's (1971) experiments in giving common pheasants feed with a high Hg content resulted in abnormally coloured eggs.

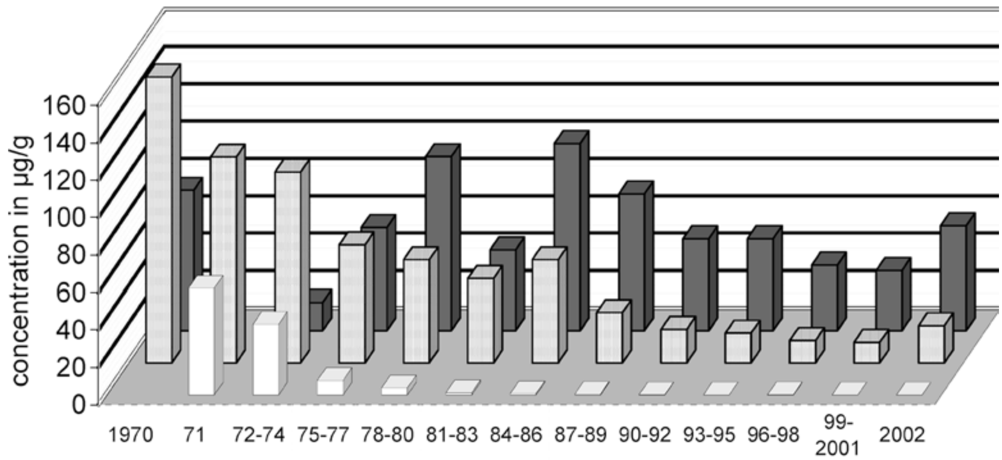
The regional ST values are compared in Fig. 8. That SI and ST should show identical trends for a particular region cannot be expected as a matter of course, as often non-identical eggs/clutches were used for the analysis of the two parameters. A reduction in SI as a result of DDE contamination does not necessarily mean a simultaneous decrease in the ST. The following approximate empirical relationship can be derived between the parameters SI and ST from the same egg: $SI = 5 \times ST + 0.3$ (in mm, and without egg skin).

## Museum egg specimens from the period 1950–1970

German oological museum specimens from the period of massive DDT use in 1950–1970 are rare, although there are examples from the period 1900–1939 (Table 6). The Museum für Naturkunde Berlin, the Potsdam Museum, the Müritz Museum Waren, the Staatliche Naturhistorische Museum Braunschweig and the Zoologische Museum der Christian-Albrechts-Universität Kiel all confirmed that they had no dated peregrine falcon eggs from the years 1950–1970 in their collections. The Niedersächsische Landesmuseum Hannover did, however, possess an egg from the year 1950, from an eyrie near Göttingen, with an SI of 1.78. This leads to the conclusion that there was no DDT influence at that time. The Staatliche Naturhistorische Sammlung Dresden had records from the former Makatsch collection of four clutches (10 eggs) collected between 1959 and 1961 in Mecklenburg with an average SI of 1.79. These eggs were given to collectors by Makatsch in exchange for other objects. As the index values for this time period are not credible (SI values of less than 1.5 would be expected) it is concluded that the records contain false information as to place or date of collection. We assume the same for a two-egg clutch from the Mark Brandenburg tree-nesting population from 1984 (over 10 years after the population there died out!) which were part of an egg collection confiscated in Brandenburg (Lippert 2002).

## Key population parameters

Continuous reference values for East Germany and NRW are available from 1954 onwards and from 1966 for BW where (as in the Bavarian Alps) the peregrine falcon never died out completely. Table 7 lists the parameters number of pairs, the percentage of successful pairs, young birds fledged per successful clutch and young per territorial pair or occupied territory, expressed in pentades. Summing the data over 5-year




| | 1970 | 71 | 72-74 | 75-77 | 78-80 | 81-83 | 84-86 | 87-89 | 90-92 | 93-95 | 96-98 | 99-2001 | 2002 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HCB | — | 57 | 38 | 7,8 | 3,9 | 1,3 | 0,8 | 0,46 | 0,2 | 0,16 | 0,32 | 0,16 | 0,06 |
| DDE | 153 | 110 | 102 | 63 | 55 | 45 | 55 | 27 | 18 | 16 | 12 | 11 | 20 |
| PCB | 75 | — | 15 | 55 | 93 | 43 | 100 | 73 | 49 | 49 | 35 | 32 | 56 |

**Fig. 2** Trends of DDE-, PCB- and HCB- contamination in peregrine eggs (in µg/g) from Baden-Württemberg in the years 1970–2002. The contamination in the years 1970, 1971 and 2002 are each shown separately, in the other years they are summarized in 3-year periods. Because of the haphazard nature of the accrual of unhatched eggs, all data are given as arithmetic means based on the averages from single years (compare with Table 2). After Schilling and Wegner 2001, supplemented

periods smoothes out the effects of individual bad weather years.

Important population reference values (percentage of successful pairs, fledged young per territorial pair) only improved significantly in BW from 1976 onwards, with the continuous decrease in DDE/HCB contamination as a result of bans on their use. The populations which had been extinct in East Germany and NRW for periods of 10 and 15 years, respectively, profited in the recolonisation begun in 1981 and 1986 from the improved environmental situation following the DDT ban. The reference values rose steadily back to the normal levels of an uncontaminated population.

## Discussion

Population collapses and reproduction failures in raptor populations occurred in many parts of the northern hemisphere from about 1950 onwards as a result of the use of particular biocides in agriculture and forestry management (Newton et al. 1993; Prestt 1965). The original relationship between the use of DDT and its effects on bird stocks were first detected in peregrine falcons by Ratcliffe in Great Britain (Ratcliffe 1958, 1967, 1970, 1980). This relationship was confirmed by corresponding population declines in other regions (cf. Hickey 1969; Cade et al. 1988; Meyburg and Chancellor 1989, 1994). The temporary decline of white-tailed eagle, Eurasian sparrowhawk and osprey (*Pandion haliaetus*) as a result of biocides is comprehensively documented. Reference is made to work by Oehme (1987), Oehme and Manowsky (1991), Kenntner (2002), Helander et al. (2002) on the white-tailed eagle; Bednarek et al. (1975), Newton (1986), Gedeon and Oehme (1993), Weber et al. (1997), Denker et al. (2001) on Eurasian sparrowhawk and Wiemeyer et al. (1988), Weber et al. (2003) on the osprey. In comparison, species which hunt small mammals such as common kestrel (*Falco tinnunculus*), Montagu's harrier (*Circus pygargus*), red kite (*Milvus milvus*) and lesser spotted eagle (*Aquila pomarina*), are and were contaminated to a much lesser extent, biocide burdens being more than an order of magnitude smaller and thus uncritical (Conrad 1977; Hölker 2002; Weber et al. 1996, 1998). For these species, CHC contamination very probably did not have a limiting effect on populations.

Some authors in West Germany suspect that the primary reason for the peregrine falcon decline was the escalating human persecution through keeping of

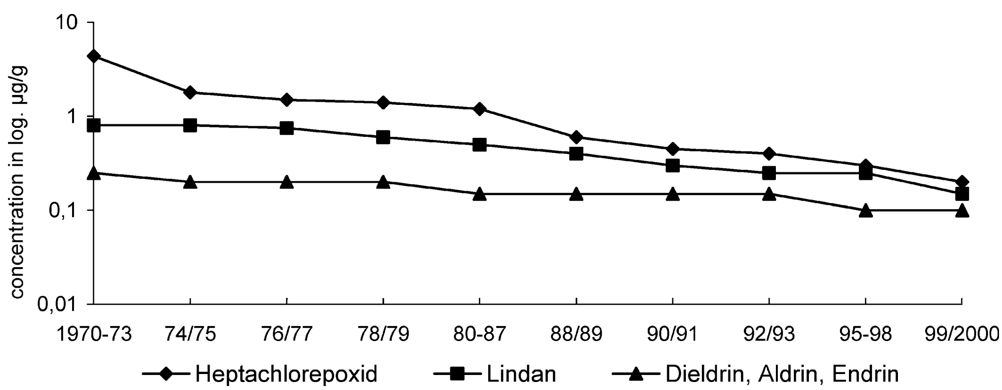



**Fig. 3** Trends of cis-HCE-, Lindan-, Dieldrin / Aldrin / Endrin–contamination in peregrine eggs (in µg/g d.w.) from Baden-Württemberg in the years 1970 to 2000. All data are given as arithmetic mean values as in Fig. 2. Source: Schilling and Wegner 2001

**Table 5** Mercury analyses (in µg/g d.w.). *n* sample size; n.d. not detectable. Sources: AGW-BW (1966–2002); AWS (1990–2002); AGW-NRW (1990–2002); Hennig 1993; Hahn et al. 1993

| Year | Federal state | Sample | *n* | Hg levels (mean and range) |
|---|---|---|---|---|
| 1969 | Baden-Württ. | Breast muscle | 1 | 0.4 |
| | | Moulted feathers | 7 | 1.36 (0.06–3.2) |
| | | Unhatched eggs | 11 | 0.02 (n.d.–0.05) |
| 1970 | Baden-Württ. | Brain, liver, muscle | 3 | 0.118 (0.068–0.21) |
| | | Feathers, adult | 5 | 3.18 (0.7–5.4) |
| | | Unhatched eggs | 6 | 0.74 (0.42–0.99) |
| 1973 | Baden-Württ. | Unhatched eggs | 7 | 0.29 (0.09–1.25) |
| 1987–1991 | Baden-Württ. | Nestling feathers | 150 | <0.1 |
| | | Moulted feathers | 35 | <3.0 |
| 2001–2002 | Baden-Württ. | Unhatched eggs | 5 | 0.75 (0.32 – 1.03) |
| 2003 | Baden-Württ. | Unhatched eggs | 5 | 0.66 (0.36–1.53) |
| 1953–1964 | East Germany | Moulted feathers | 13 | 3.8 (1.3–8.4) |
| 1987 | East Germany | Brain, liver, kidney, muscle | 3 | 6.9 (3.2–9.4) |
| 1980–1992 | East Germany | Moulted feathers | 56 | 20 (15–127.2) |
| 1983–1987 | | Unhatched eggs | 14 | 16 (3.1–64.5) |
| 1955–1990 | East Germany | Moulted feathers (wintering birds) | 18 | 26.8 (1.1–146.8) |
| 1992 | East Germany | Primaries, juv. | 22 | 0.6 (0.1–1.9) |
| 1994 | North Rhine-Westphalia | Moulted feathers | 4 | 3.5 (2.5–4.7) |
| 2001 | Schleswig-Holstein | Unhatched eggs | 2 | 1.58 (1.09–2.06) |

raptors in captivity, trade in birds of prey and activities by pigeon fanciers, which went chronologically hand in hand with the use of DDT (Rockenbauch 1998–2002). Although it cannot be denied that this persecution ultimately accelerated the extinction of all peregrine falcon populations to die out in the former West Germany, the ban on DDT in 1972 was the decisive factor for the recovery and reoccupation of former breeding areas. The success of this range expansion was secured by accompanying protection measures, beginning with the successful stabilisation of the BW and Bavarian populations (Fig. 1; Hepp et al. 1995; Wegner 1994a).

In the GDR, human persecution can be ruled out as an explanation for the decline to extinction of the peregrine falcon population. Many cliff-nesting territories in the central hill country had already declined in the first half of the twentieth century due to systematic eradication measures. This recorded decline prior to the use of DDT, together with the lack of offspring, probably also reflected an over-ageing of the breeding population (Kleinstäuber and Schröder 1963; for Westphalia: Demandt 1950). The rapid and complete collapse of the formerly large tree-nesting population of East Germany and Eastern Europe once ubiquitous in forested lowland areas confirms that from 1950 onwards a further, wide-ranging and significant environmental threat must have been at work (Kirmse and Kleinstäuber 1977; Kleinstäuber 1987).

The first biocide studies in Germany began in 1967. Usable analysis results only became available for the studies starting in 1970. The DDT ban was introduced in West Germany in 1972 (Fig. 9). By this time, the cliff-nesters in East Germany had ceased to produce fledged young and from 1973 the last remnants of the cliff nesting population, as well as the complete tree-nesting population, had been wiped out (Fig. 1; Kleinstäuber 1991; Kirmse 2001).

**Table 6** Measurements (length, width in mm) of peregrine falcon eggs from various studies in comparison to unsuccessful (non-hatching) eggs from the study area

| Reference | Number of eggs | Egg dimensions (length × width) | | |
|---|---|---|---|---|
| | | Mean | Maximum | Minimum |
| Museum eggs | | | | |
| Middle Europe: Glutz von Blotzheim et al. (1971) | 165 | 51.5×40.5 | 58.9×44.7 | 46.2×39.1<br>47.0×37.0 |
| Germany: Makatsch (1974) | 114 | 51.6×40.8 | 56.0×42.7<br>55.2×44.1 | 45.0×41.8<br>50.0×38.5 |
| Germany: Fischer (1968) | 66 | 50.9×40.7 | 58.9×44.7 | 46.9×40.6<br>47.0×37.0 |
| Britain: Ratcliffe (1980) | 2,253 | 51.5×40.8 | 58.0×43.0<br>55.0×44.5 | 45.3×37.7<br>46.5×32.5 |
| Unhatched eggs (this study) | | | | |
| Baden-Württemberg (1968–2002) | 533 | 52.0×40.7 | 58.2×40.7<br>55.4×44.5 | 45.0×39.3<br>50.2×38.3 |
| North Rhine-Westphalia (1992–2002) | 64 | 51.6×40.5 | 55.1×42.2<br>52.0×44.2 | 46.4×37.7<br>47.5×37.5 |
| East Germany (1938–2002) | 158[a] | 51.3×41.3 | 56.8×42.1<br>51.0×44.5 | 45.3×41.8<br>51.2×37.5 |

[a]Runt egg (41.6×33.3 mm) from GTH 1, Thuringia 2001 not taken into account

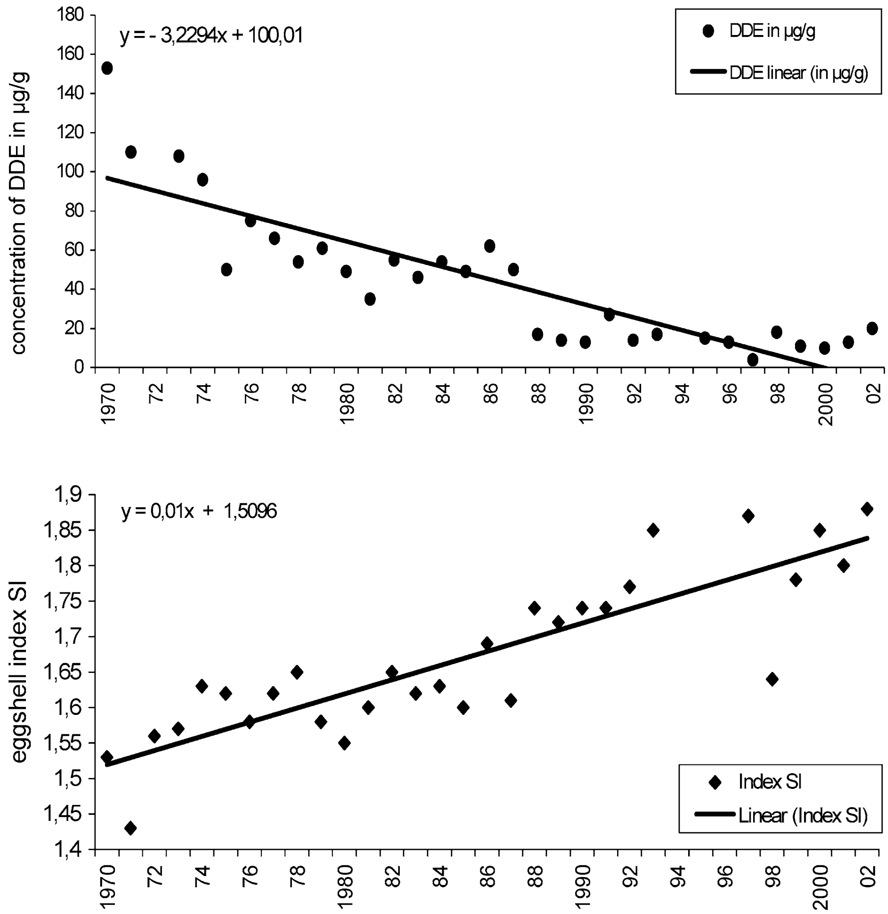



**Fig. 4** Trends in DDE contamination and in eggshell index in unhatched peregrine eggs from Baden-Württemberg in the years 1970–2002 (compare with Table 2). After Schilling and Wegner 2001, supplemented

## Residue analyses

### *DDT contamination*

The patterns of use of DDT in Germany, as shown in Fig. 9, differed considerably between regions. Consequently the level of contamination of peregrine falcons

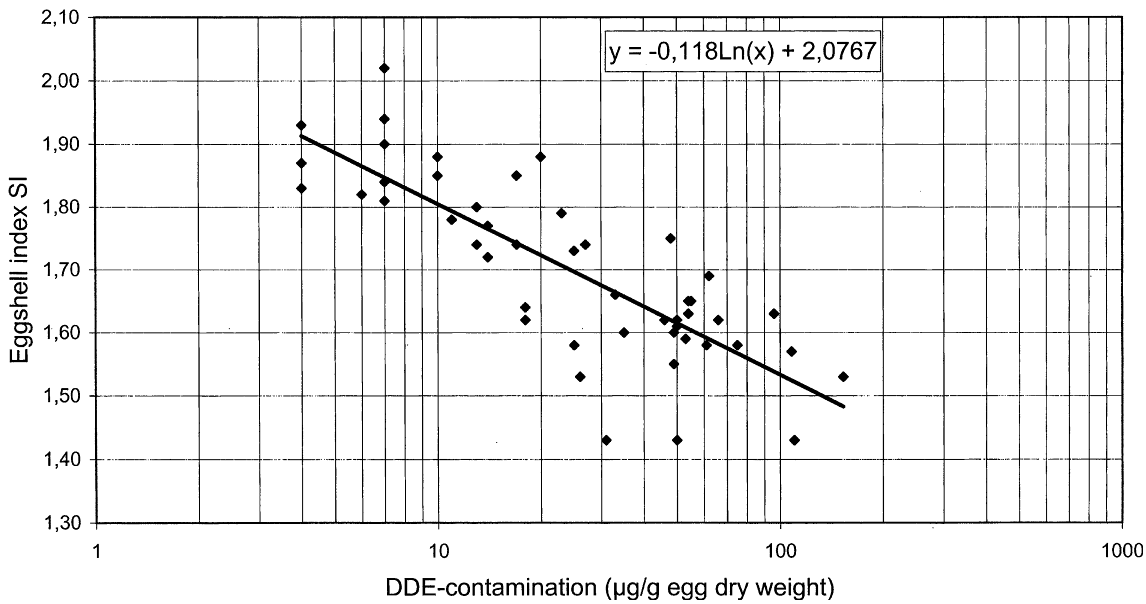



**Fig. 5** Correlation between DDE-contamination and eggshell index in unsuccessful peregrine eggs from Baden-Württemberg, East Germany and North Rhine-Westphalia/Rheinland Palatinate. Sources: AGW-BW (1966–2002); AWS (1990–2002); AGW-NRW (1990–2002)

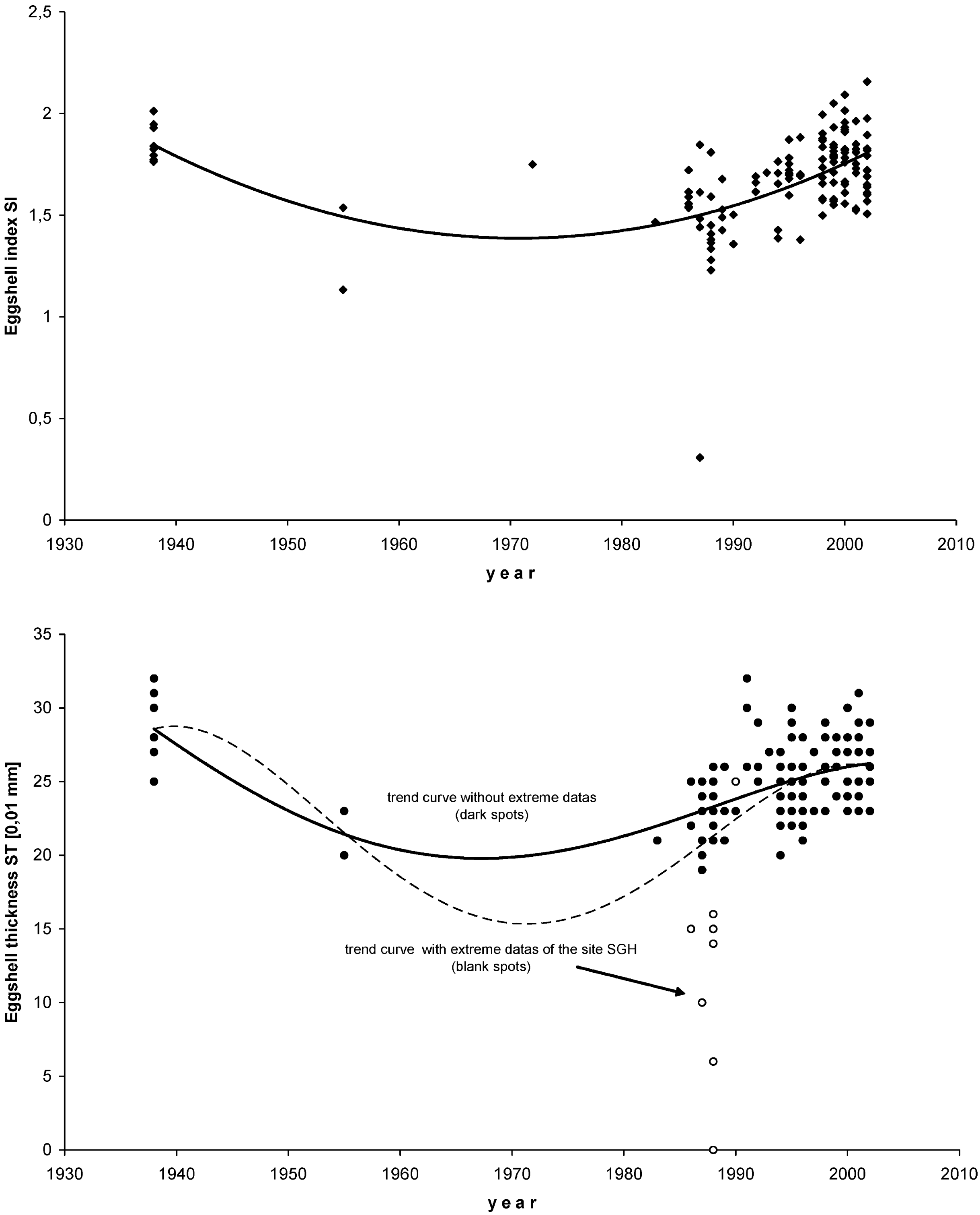



**Fig. 6** Change of eggshell index SI (*above*) and eggshell thickness (*below*) in unsuccessful (non-hatching) peregrine falcon eggs in East Germany

in West and East Germany still differs today and the decrease in contamination in East Germany is chronologically retarded.

DDT/DDE residues in egg content have a negative effect on the reproduction success of the peregrine falcon when a critical threshold is crossed. This threshold level was assumed to be 15–20 µg/g wet weight (w.w.) DDE, corresponding to a 70–100 µg/g dry weight (d.w.) content, by Ratcliffe (1980), Peakall (1967, 1969) and other authors (summarised in: Risebrough 1989, 1994). When these concentrations were exceeded, declines leading to extinction were the result (Peakall et al. 1975; Peakall and Kiff 1988). Here the DDE content in peregrine

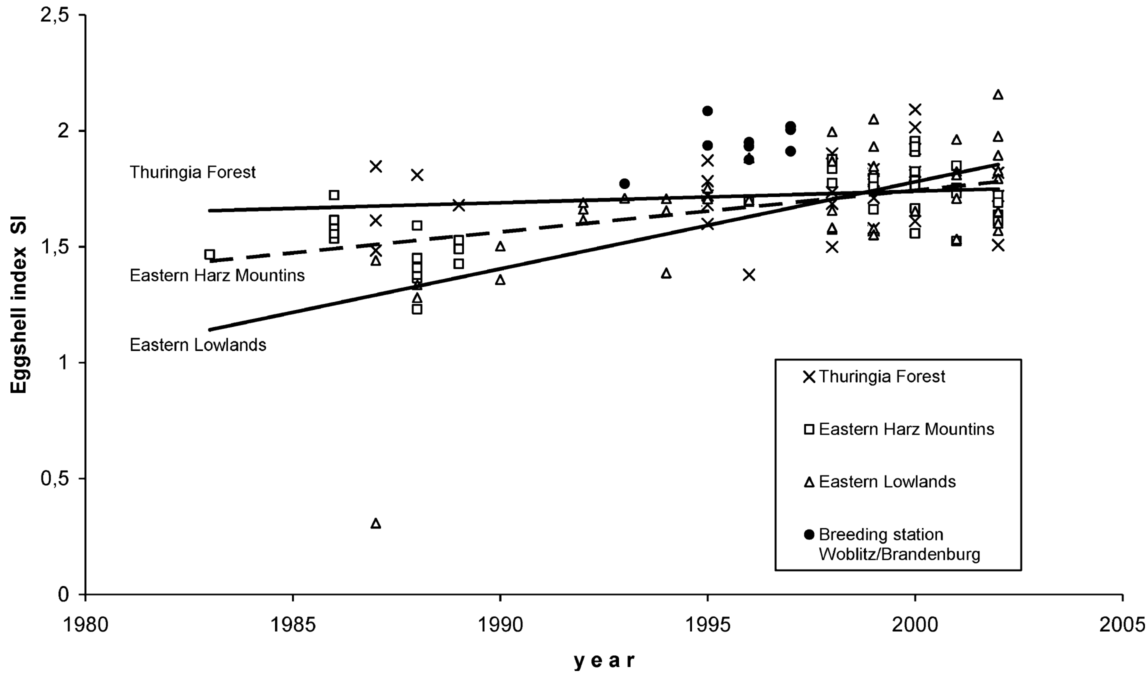
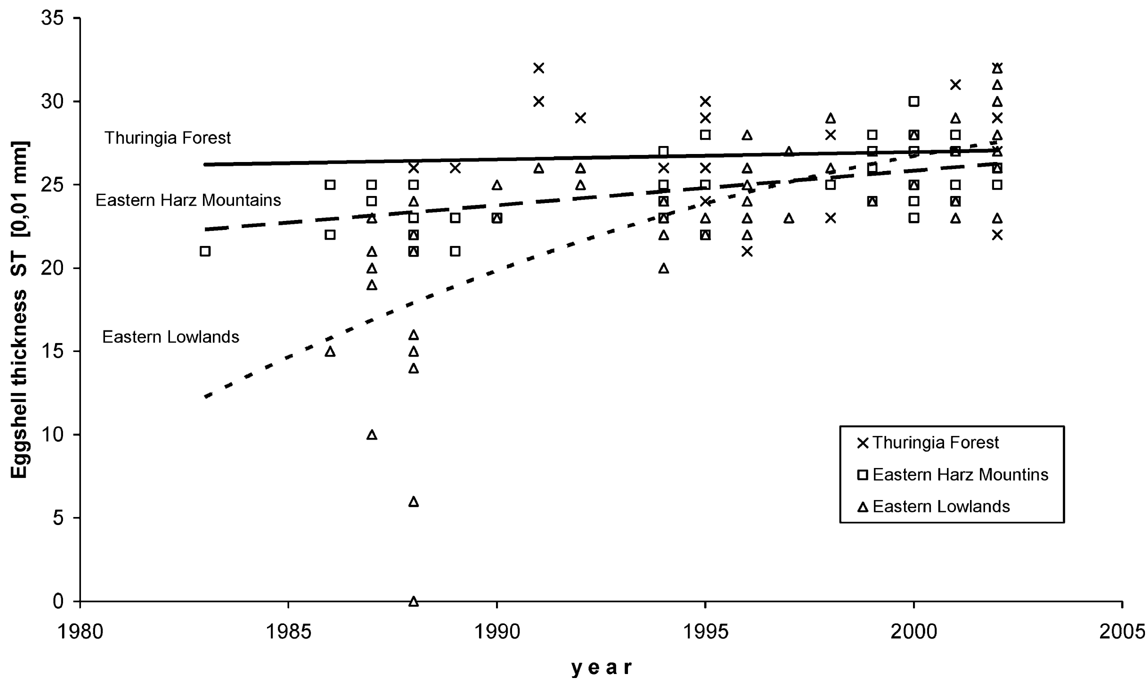



**Fig. 7** Changes in eggshell index SI for peregrine falcon eggs in various regions of East Germany

falcon eggs correlates to their shell-thinness (Fig. 5). The threshold levels given are generalised approximations as some individuals still enjoyed breeding success with DDE concentrations in eggs of up to 25 µg/g w.w. (c. 125–150 µg/g d.w.) (Henny 1998; Schilling and Wegner 2001).

**Fig. 8** Changes in eggshell thickness ST for peregrine falcon eggs in various regions of East Germany




Biocide analyses are available for BW from the year 1970 (König and Schilling 1970; Conrad 1977; Baum and Conrad 1978; Schilling and König 1980; Baum and Hädrich 1995; Schilling and Wegner 2001). At the start of the studies, very high DDE concentrations of up to 200 µg/g were recorded, double the presumed threshold levels. After the ban in 1972 the average levels fell steadily (Table 2, Figs. 2, 4). Important analyses from the main period of DDT use (1952–1970) could not be incorporated into the study as the attempted detection of all biocides by gas chromatography was hindered by interference from components of secondary origin.

**Table 7** Comparison of the reproduction rates of the monitored peregrine falcon pairs. All data are given as arithmetic mean values in 5- or 2-year periods. (Sources: Hepp et al. 1995; AGW-BW (1966–2002); AWS (1990–2002); AGW-NRW (1990–2002)

| Year | 1955–1960 | 1961–1965 | 1966–1970 | 1971–1975 | 1976–1980 | 1981–1985 | 1986–1990 | 1991–1995 | 1996–2000 | 2001–2002 |
|---|---|---|---|---|---|---|---|---|---|---|
| Baden-Württemberg | | | | | | | | | | |
| Average number of territorial pairs | 90? | 60? | 27 | 29 | 34 | 66 | 134 | 210 | 266 | 285 |
| Successful pairs in % | | | 35.8 | 35.4 | 48.8 | 58.4 | 57.9 | 61.7 | 62.6 | 46.9 |
| Fledged young / successful brood | | | 2.00 | 2.18 | 2.51 | 2.54 | 2.45 | 2.55 | 2.68 | 2.40 |
| Fledged young / territorial pair | | | 0.72 | 0.76 | 1.23 | 1.50 | 1.43 | 1.58 | 1.67 | 1.13 |
| East Germany (cliff–breeders only) | | | | | | | | | | |
| Average number of territorial pairs | 20 | 14 | 6 | 1 | 0 | 3 | 8 | 19 | 41 | 62 |
| Successful pairs in % | 23,8 | 16,2 | 3.4 | 0 | – | 37.5 | 47.4 | 57.3 | 55.5 | 61.3 |
| Fledged young / successful brood | 1,75 | 1,36 | 1.0[a] | – | – | 2.16 | 2.44 | 2.22 | 2.60 | 2.57 |
| Fledged young / territorial pair | 0,42 | 0,22 | 0.03 | – | – | 0.81 | 1.16 | 1.27 | 1.44 | 1.57 |
| North Rhine-Westphalia | | | | | | | | | | |
| Average number of territorial pairs | 7 | 3 | 1–2 | 0 | 0 | 0 | 1–2 | 10 | 29 | 49 |
| Successful pairs in % | 14.2 | 23.5 | 42.8 | – | – | – | 50.0 | 61.2 | 52.4 | 61.7 |
| Fledged young / successful brood | 3.0 | 1.75 | 1.67 | – | – | – | 2.75 | 2.83 | 2.79 | 2.58 |
| Fledged young / territorial pair | 0.43 | 0.41 | 0.71 | – | – | – | 1.38 | 1.73 | 1.46 | 1.59 |

[a]One successful brood only

Based on Figs. 2 and 4, a realistic average contamination level for BW of over 200 µg/g DDE in the years before 1970 can be extrapolated. This gap in the analytical data has provided room for speculative explanations over population decline in which the influence of biocides was disputed or greatly underestimated (Rockenbauch 1998–2002).

Mean DDE contamination values of less than 100 µg/g were recorded in BW only after 1974–1975. By this time, the population there had collapsed by around 80% due to reproductive failures. The few remaining successful pairs had below average breeding success (Table 7). For another 13 years until 1987 threshold levels of DDE were exceeded locally with up to 146 µg/g being recorded (Table 2). From 1988 onwards, the mean contamination level fell to below 50 µg/g and in the years following 1989–1990 stayed within the range 10–20 µg/g. In the period up to 1987, there were a few pairs exhibiting breeding success (reduced) although DDE contamination values were above the threshold level (Schilling and Wegner 2001). These individual occurrences of apparent increased toxin tolerances cannot be used as proof to deny the harmful influence of DDT and in order to play down the seriousness of DDT use. The mean values, because of inhomogeneous sample taking, show only trend developments. Maximum and minimum

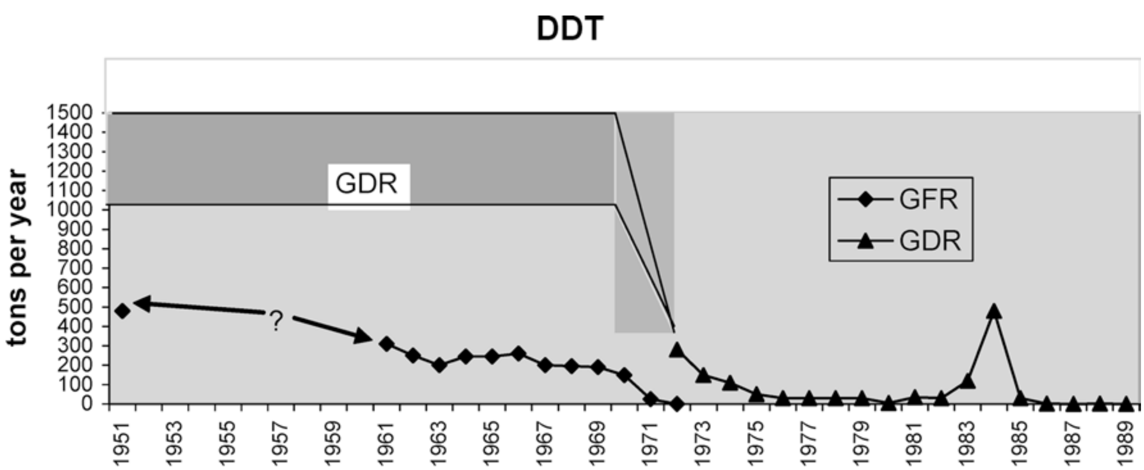



**Fig. 9** DDT-application (in tons per year) in West-(GFR) and East-(GDR) Germany. Modified after Hulpke 1981; Heinisch 1992

**Table 8** Eggshell index (SI in mg/ $mm^2$) and eggshell thickness (ST in mm) of peregrine falcon eggs in the years before DDT-application (all data as arithmetic mean values)

| Country | Reference | Number of eggs | Years | SI | ST[a] |
|---|---|---|---|---|---|
| Britain | Ratcliffe (1980) | 468 | 1850–1939 | 1.820 (1.45–2.24) | – |
| Germany | Schilling and König (1980) | 357 | 1900–1939 | 1.825 (1.44–2.20) | 0.341 |
| Sweden | Odsjö and Lindberg (1977) | 80 | 1861–1943 | 1.871 (±0.013) | 0.347 |

[a]Egg membranes included

values on the other hand reflect regional differences in quantities of DDT applied and/or the choice of variously contaminated prey.

Following the peregrine falcon recolonisation of NRW and the north of RP from 1989 onwards, unhatched eggs recovered were, as expected, uncritically contaminated with DDE (Table 3; Wegner 2000).

Systematic residue analysis of eggs from East Germany began with the regeneration of the population from around 1983 (Table 4). Collection of eggs from the tree-nesting population, which resided in the GDR and neighbouring Eastern Europe, could not be carried out before the complete extinction of this population at the beginning of the 1970s. Not all data from the analyses carried out on 57 eggs collected in East Germany can be used unrestrictedly because of problems with data quality. The data are subdivided into the contaminant burden parameters from the plain (especially near and at the Berlin conurbation) and those from the less contaminated falcons from the Thuringia Forest and (eastern) Harz hill country (Fig. 7, 8). In the case of the cliff-nesters of Thuringia and Saxony Anhalt, the recent DDE contamination level has now subsided (currently lying in the region of 10–45 μg/g) and no longer influences the reproduction rate, according to breeding data for the region (Kleinstäuber 1991; Wegner 2000). The low shell indices from the years 1986–1990 are very probably related to a new contamination episode occurring a couple of years previously (Fig. 9). This compromised a centrally ordered eradication operation against the black arches moth (*Lymantria monacha*) in 1983–1984, involving airborne spraying operations by 80 planes in 1,200 operational flights and the application of some 600 tonnes of DDT dissolved in diesel oil (!) with added lindane in unknown quantities (Heinisch 1992).

The degree of contamination still found in the Berlin conurbation at the start of the 1990s reflects the long-term and high-level application of DDT in the GDR. The contamination levels at the end of the 1990s were still some 3 times higher than corresponding values in BW, and 6 times higher than the average in NRW. The continuing breeding failures in the Berlin conurbation and the East German Plain today can thus be explained; the current data from these areas being similar to those found in BW around 1980. SI and ST values correlate well with the DDE measurement data (Table 4). The phenomenon of very different DDE contamination values and degrees of eggshell thinning in neighbouring breeding pairs is described repeatedly in the literature (cf. Altenkamp et al. 2001). The high peak values of up to 130 μg/g found in unhatched eggs of a particular pair can be caused by differences in the feeding spectrum compared with neighbouring pairs.

The results obtained using quantitative TLC from eggs dating before 1970 from BW and the GDR are insufficiently reliable to meet the rigorous demands required for proof of working hypotheses. There is thus no direct, toxicological data available to back up the premise that DDT contamination was definitely responsible for the complete population collapse in the GDR, due to the lack of reliable DDE analyses. This conclusion can, however, be clearly inferred from SI and ST measurements (Fig. 6). Moreover, Knobloch (1970) succeeded in having an egg from one of the last clutches from the Oberlausitz in 1965 analysed in England. The results from Monks Wood, which found an extremely high DDE contamination of 230 μg/g w.w. (dry weight unknown; probably extremely dehydrated giving a level of at least 500 μg/g (?) d.w.), shows vividly the dramatic extent to which the peregrine falcons in the GDR were contaminated with DDE/DDT (Newton, personal communication to Wegner 16 April 2002). This earliest analytical confirmation of the massive use of DDT in the GDR is of enormous importance.

From 1954 onwards, unexpected egg losses and dead embryos became apparent, even with pairs that displayed intensive breeding behaviour and which at times incubated weeks beyond the expected hatching date. With other pairs there were long breaks in incubation, poor eyrie site loyalty, extended display phases without egg-laying, apparent firm incubation on an empty eyrie and other abnormal behaviour, particularly in the final phase of territory abandonment. Such observations were at first seen as symptoms of the advanced age of the breeding birds and their associated sterility (Kleinstäuber and Schröder 1963). The first thin-shelled eggs were collected in 1955 (Ebert 1967; Kleinstäuber 1987), before the pioneering publication *Broken eggs in peregrine eyries* (Ratcliffe 1958), and represented indirect, but unambiguous indications of the underlying factors applying throughout the whole period of the peregrine's decline.

According to the data presented in this paper, the population collapses can be correlated with application of DDT. As a result of regional differences in quantities deployed only the remnant populations in certain areas, namely BW and the Bavarian Alps, could be rescued by the implementation of protection measures until a final DDT ban came into force. The extinction of the peregrine falcon populations in these regions as well could not have been prevented without the protection measures and the eventual ban on DDT. In all other federal states the conditions pertaining rendered it simply not possible to prevent the species' extinction. Direct persecution (pigeon fanciers, raptor captivity and trade) in the former West Germany, which escalated in the final phases, made a timely search for causes using chemical analysis difficult due to the unavailability of unhatched egg samples.

The present contamination level of c. 5–15 μg/g in West Germany, and c. 10–25 μg/g in the East German federal states (with the exception of wide-ranging agricultural areas and pine-covered heath land), is no longer of toxicological relevance for the peregrine falcon. Owing to a significant flux of DDT from distant application areas (e.g. Africa and India) globally redistributed via the atmosphere (according to the process "global distillation with cold-trap condensation" in colder regions; Larsson et al. 1995), the base level of contamination will probably not fall below 2 μg/g, but can be expected to fluctuate between 2 and 20 μg/g. In this connection, the dependence of DDT decay on temperature should be mentioned. Larsson et al. (1995) give a Σ-DDT half-life of only 190 days for sub-tropical regions such as India, and c. 3 years for temperate zones. For Germany, Mutschler (1996) even considers that a half-life of 10 years and more is likely.

### *HCB contamination*

HCB values in BW fell by more than two orders of magnitude, from c. 60 μg/g to < 0.2 μg/g, following the HCB ban in 1974, and since 1980 have remained at harmless levels (Table 2, Fig. 2). It is no longer possible to find out in retrospect whether or not HCB was ever a population limiting factor in the regions studied. As threshold values for the peregrine falcon are not known, a possible influence on population development cannot be quantified.

### *Contamination by cis-HCE, lindane, dieldrin, aldrin, endrin*

Harm to the peregrine falcon from 1960 onwards, including increased adult mortality (complemented by DDT induced breeding loss as a result of shell breakage) due to the highly toxic cyclopentadiene pesticides dieldrin, aldrin and heptachlor (all with c. 5-year half-lives), was either less obvious or not recognised outside the United Kingdom (Nisbet 1988; Risebrough 1989, 1994). The intensive use of these substances, and fatal poisoning of adult peregrine falcons in Britain, is well known (Newton et al. 1993). Figure 3 confirms that no values exceeding relevant thresholds have occurred in BW since 1970. The levels have remained stable at under 1 μg/g for aldrin, dieldrin and lindane and typically under 2 μg/g (maximum 5.3 μg/g) for cis-HCE. The rodenticide endrin was unmistakably responsible for secondary poisoning of birds following the combating of voles, e.g. in a large-scale operation at Lake Constance in 1982, which was then followed by a complete ban (Baum and Hädrich 1995). As late as 1989–1990 traces of lindane were found in two-thirds of all samples taken, the proportion having fortunately decreased since then (Baum and Hädrich 1995).

### *PCB contamination*

The PCB family of chemicals have a relatively low toxicity with respect to most bird species and an effect on adult mortality is only to be expected in cases of high contamination (Prinzinger and Prinzinger 1980). Domestic hen chicks are especially sensitive to PCB resulting in reduced laying rates and deformations in embryos (Vos and Koeman 1970). Risebrough (1994) points to the reduced productivity in raptors through changes in behaviour as a result of high PCB contamination. Values measured in peregrine falcon eggs currently still attain critical levels in some cases (Table 2, 3, 4, Fig. 2). In particular, eggs from urban conurbations still exhibit mean concentrations of > 50 μg/g. Indigenous peregrine falcons can apparently deposit high absolute amounts of PCB in their fatty tissues, which are only partly expelled from the body at egg-laying. Heidmann et al. (1987) show exemplarily that the PCB contamination in the body fat of the Eurasian oystercatcher (*Haematopus ostralegus*) can, in stress situations such as food shortages where the body fat reserves are suddenly mobilised, lead to poisoning followed by death. Baum (Schilling and Rockenbauch 1985) discovered 4,820 or 6,480 μg/g DDE and 7,515 or 7,750 μg/g PCB (allied to fat content) in the body fat of two peregrine falcons found dead in BW in the years 1984–1985. The excretion of this biocide at egg-laying is dependent on existing body fat and, in the case of well-fed falcons, amounts to only a small amount of the total body contamination.

The current, high PCB contamination levels, as found, for example, by Baum and Hädrich (1995) in eggs from peregrine falcons nesting on Cologne cathedral (AMV c. 180 μg/g of total PCB) and confirmed by Wegner (2000) with the analysis of, in part, even more highly contaminated eggs from Brandenburg and East Berlin (AMV = 132 μg/g, SD 81 μg/g, range = 58–380 μg/g; $n = 15$), show that analytical controls will still be necessary in the future.

In comparison red kite eggs (prey 70% mammals) from Saxony Anhalt only show an average PCB contamination of up to c. 1 μg/g and DDE contamination of under 0.2 μg/g (Weber et al. 1998). Both parameters are less than 3% of those from the peregrine falcon. Fresh and unhatched eggs of the bird hunting Eurasian sparrowhawk from the Saxon Ore Mountains (Erzgebirge) show on the other hand similar contamination levels to those of the peregrine falcon (PCB: 31 μg/g; DDE: 40 μg/g; AMV in d.w.; $n = 38$; years: 1989–1994).

Because of the high ubiquitous environmental presence of PCBs, only preliminary indications of a decrease in the contamination in peregrine falcons by this agents are evident to date, this decrease being less pronounced overall than for example in Eurasian oystercatchers and common terns (*Sterna hirundo*) from the North Sea coast (Thyen and Becker 2000).

*Mercury contamination*

According to Wiemeyer et al. (1988) and Lindberg et al. (1983) mercury content in excess of 2.5 μg/g d.w. in eggs of certain bird species leads to reproductive disruption due to increased embryo toxicity (see also Weber et al. 2003). Oehme (2003) believes the threshold value for white-tailed eagle to be about 5–7 μg/g d.w. He points to the relative insensitivity of the herring gull (*Larus argentatus*), where the breeding success remains uninfluenced at concentrations in the region of 2.3–15.8 μg/g per w.w.. According to Becker et al. (1993), there was no reduction in hatching success for eggs of the common tern with some 6 μg Hg/g w.w.. Stoewsand et al. (1971, 1978) and Fimreite (1971,1979) report shell-less and thin-shelled eggs of Japanese quail (*Coturnix coturnix japonica*) and common pheasant in experimental studies with high doses in feed of methyl-Hg and Hg salts respectively (summarised in: Thompson 1996). Becker et al. (1985) quote from relevant literature sources that in these species concentrations in the region of only 0.5–3.1 μg/g w.w. can cause increased embryo mortality and shell-less eggs.

In 1968 Steinbacher informed the BW peregrine falcon Working Group of an incidence of mass mortality of seed-eating songbirds in the agricultural provinces of Southern Sweden following the application of Hg-based seed treatment substance (Widmark et al. 1967; Jenning 1968) and recommended corresponding studies of falcons in Southern Germany. This resulted in the samples in Table 5 from BW being analysed by Westermark and Olsson in Stockholm with the outcome that eggs (0.09–1.25 μg/g d.w.) and moulted feathers (AMV 1.4 μg/g d.w.) revealed merely geological background contamination levels typical of the 19$^{th}$ century. This innocuous nature of the Hg contamination in BW was confirmed later by Hennig (1993) from 35 moulted and 150 nestling feathers for the period 1989–1991 (moulted feathers AMV $<3.0$ μg/g; nestling feathers AMV $<0.1$ μg/g).

Table 5 lists the Hg concentrations found in eggs, feathers and internal organs of German peregrine falcons. Although all eggs from BW yielded uncritical Hg contamination values, those from certain regions in East Germany had strikingly high concentrations of up to 65 μg/g.

The deposition of Hg in peregrine falcon feathers appears, in contrast to the case pertaining in the Northern Goshawk (Ellenberg et al. 1986), to indirectly follow the moult, the first of the outer primaries (P4) showing higher concentrations than the subsequently appearing feathers (Hahn et al. 1993). The Hg is concentrated in the vane and the tip area. Feathers collected from older falcons in East Germany during the period 1953–1964 contained an average Hg concentration of 3.8 μg/g (range = 1.3–8.4), more or less the same as in moulted feathers from BW and NRW: 1.4 and 4 μg/g (Table 5), whereas, for the period 1980–1992, the concentration reached approx. 20 μg/g (1.5–127.2) . This substantial increase can be attributed to the employment of Hg-containing compounds as seed dressings, as can the increase of Hg-concentrations in unhatched eggs. Prior to the first moult, falcons are much less contaminated (0.1–1.9 μg/g). Scandinavian peregrine falcons moult feathers in winter quarters in (East) Germany containing equally striking levels of Hg contamination. This confirms either that regionally high Hg values are to be found in the environment in North and Northeast Europe (Lindberg 1983), or that these winter guests absorb the Hg into their feather re-growth via their prey in the winter quarters.

According to Fimreite (1979), contamination by DDE plus Hg has an additive toxic effect, but high Hg levels lead to the production of shell-less eggs, or those with an extremely thin calcium carbonate shell, even without the influence of DDE. Scheuhammer (1987) observed the embryo toxic effects of Hg in the Common Pheasant at concentrations from only 0.5 μg/g w.w. (c. 2–3 μg/g d.w.) upwards. The Hg concentrations found in the extremely thin-shelled peregrine falcon eggs in the approaches to the South Harz Mountains at up to 65 μg/g an order of magnitude above the threshold, as well as those of over 100 μg/g found in the feathers of these birds (Table 5), are a clear indication that, in addition to the high level of DDT application in the GDR, the massive and long term use of Hg compounds as seed treatments (Oehme 1981) reduced the reproduction rate of peregrine falcons in East Germany. This combination is probably also the reason for the very rapid and total collapse of the vigorous tree-nesting populations in the intensively cultivated areas of the Central and Eastern European Plain. Oehme (1981) alludes to the great danger of Hg accumulation in organs even when small quantities are taken up (over a long period). Such an accumulation was possible for the decades in the GDR and Eastern Europe that the seed treatment based on phenyl-Hg acetate ("Falisan Nassbeize" from the Fahlberg-List Cooperative in Magdeburg) was widely distributed. Only following the escalation in environmental Hg deployment in the 1970s with the introduction of the highly toxic methyl-Hg compounds, when white-tailed eagles and others at the top of the seed-eating food chain were shown to have ingested lethal doses of over 20 μg/g (in liver and kidneys), were Hg-based seed preservatives banned. In the meantime the peregrine falcon population of the GDR had been wiped out.

## Eggshell studies

DDE and Hg contamination disrupt the calcium metabolism and thus the development of the eggshell, the DDE contamination correlating inversely to the firmness and strength (mass) of the shell (Fig. 5). During the incubating phase the embryo falcon absorbs only minimal amounts of calcium from the shell as newly-hatched falcons, being altricial as opposed to precocial (e.g. Gallinae), have a soft and cartilaginous skeleton to begin with. The egg content appears to cover the minimal calcium requirement. For this reason the SI and ST values of egg remnants analysed are to a great extent independent of the stage of incubation (Newton, personal communication).

### *Eggshell indices and shell-thickness*

Prior to the use of DDT in agriculture and forestry management, the peregrine falcon egg SI in Germany (museum specimens, $n=357$) comprised 1.825 and ST 0.341 mm (with egg skin) or around 0.28 mm (without egg skin) (Table 8). These are comparable with British values (Ratcliffe 1980) and were used as reference values for eggs free from DDE contamination.

The changes in SI and ST in all regions under study, in chronological order of DDE contamination decrease, are presented in Tables 2, 3, 4 and Figs. 4, 5, 6, 7, 8. Following SI declines of 19% in BW (1970–1971), the "reference value" of 1.82 was not reached again or exceeded there until after 1993 (an increase of 23% from 1.48 to c. 1.82). From the mid-1990s, the SI for the East German Plain also approached the assumed "normal" value in the absence of DDE of 1.82 (Table 4 and Figs. 6, 7). There, the SI value in the years 1980–1990 still lay below 1.50, corresponding to a deficit of $>18\%$ (Table 4). The same applies for the ST value of East German eggs (Figs. 6, 8), which were on average 30% below normal values. In extreme cases, the eggs were completely lacking in shell.

In spite of differing study methods (chemical analysis, index and thickness measurement), essentially identical results were achieved in respect of the main conclusion drawn from the data. The unavoidable methodological differences over a time scale of more than 30 years, and the minor inconsistencies in measurements and other marginal influences, were never so marked that the conclusion of a formerly high, and at present markedly decreased, influence of biocides on peregrine falcon population levels in Germany, can be called into question.

## Population parameters

The population parameters improved only from 1976 onwards in BW, after the decreases in DDE/HCB contamination following the bans on their use. In East Germany and NRW, the recolonisation and corresponding increase in the population parameters, only became possible from the point in time when the DDE (and for East Germany mercury) contamination levels fell to below toxic threshold values (Table 7).

The increasing proportions of successful pairs in all three regions reflects in addition the steadily improved protection measures such as site protection, building of artificial eyries and eyrie improvement carried out by the various working groups (Arbeitsgemeinschaft Wanderfalkenschutz Baden-Württemberg, Arbeitskreis Wanderfalkenschutz e.V. and the Arbeitsgemeinschaft Wanderfalkenschutz Nordrhein-Westfalen). Undisturbed natural populations free from biocide contamination, together with protection management measures, have led to the achievement of normal fledging rates of 2.4–2.6 young per successful brood (Ratcliffe 1980; Wegner 1994a).

The population parameters for the period 1928–1938 for the peregrine falcon stronghold in Saxony (Sächsische Schweiz: Kleinstäuber 1930, 1938), the only complete data available for the time before the employment of DDT in Germany, are valuable for comparison purposes: 12 territories, 79 breeding attempts studied of which 50 were successful producing 120 young falcons. This yields the following parameters: 63.3% successful broods, 2.4 young per successful brood and 1.52 young per territorial pair. These values agree well with the data presented for BW from 1976 onwards, and for East Germany and NRW from 1980 to 1986, when DDT and Hg, the most important factors previously affecting breeding success, no longer had a decisive effect.

## Conclusions

This final treatment of the biocide-related decline of peregrine falcon populations in Germany, leading regionally to extinction, is based on modern laboratory analysis, on the long term experience of members of the protection groups and the fusion of the accumulated knowledge in the former West Germany and the GDR.

The last minute introduction of the ban on CHC biocides (especially DDT) was crucial for the success of the working groups in BW and southern Bavaria (AGW-BW and Aktion Wanderfalken- und Uhuschutz, respectively) in rescuing the remnant indigenous German population. After the decrease in harmful contamination levels, reoccupation of the abandoned Central German cliff-nesting territories was also to be expected. This process, based on the recovery of the populations in BW and Bavaria, and despite a population surplus achieved through protection measures, would normally have taken decades owing to the species-specific dispersion strategies (Kleinstäuber 2003). The reintroduction of young captive-bred falcons by the peregrine falcon Protection Working Group (Arbeitskreis Wanderfalkenschutz) in East Germany and the Hesse Society for Ornithology and Nature Protection in Hesse and Bavaria has, however, accelerated the resettlement of the cliff-nesting territories in Central Germany. The young falcons were raised by the German falcon Order (Saar 1978–2002).

The studies presented here confirm that the former vigorous tree-nesting population also fell victim to a wide ranging blight as a result of DDT and Hg-based seed treatment, and did not die out because of its occupation of an "unsuitable" habitat. At present, the biocide contamination level in the East German Plain has receded to such an extent that its recolonisation by tree-nesting peregrine falcons is once again possible. A spontaneous resettlement of this region as a result of a natural spread of the cliff-nesting population is, however, not to be expected in the near future, if at all (Kirmse 2001). For this purpose, a planned release of young peregrine nestlings (either captive-bred or from cliff-building breeders), which are imprinted for this form of habitat and possess the necessary adaptation in breeding biological habits, is required. Such release attempts have been running since 1990. The ability to breed in trees formerly enabled the species to settle a habitat which contained a numerically high proportion of all peregrine falcons living in Europe before the DDT disaster, extending from Eastern Germany as far as Moscow. The present (2003) six pairs of tree-nesting falcons which once again reside in the pine woods of Brandenburg and Mecklenburg-West Pomerania have enjoyed good breeding success (Langgemach et al. 1997). The parent birds were without exception releases from captive-bred birds which had been imprinted for tree-nesting, or their offspring. Studies of unhatched eggs recovered from this population confirm that CHC contamination levels have now subsided substantially here as well (Kenntner et al., unpublished).

Familiarity with this tree-nesting population, formerly almost ubiquitously distributed in the wooded Central and Eastern European Plain is, due to the population crash some 30–40 years ago, largely absent in the present generation of ornithologists. Bezzel (2003) considers for instance tree-nesting as "manifestly never to have been a particularly good option for the peregrine falcon".

As has been presented here, the threshold contamination values for influencing reproduction rates are no longer reached in most parts of Germany. Research is still required, however, in respect of PCB and dioxin contamination in industrial conurbations.

## Zusammenfassung

Die Belastung deutscher Wanderfalken mit chlororganischen Bioziden und Quecksilber wurde über den Zeitraum 1955–2002 untersucht. Die untersuchten 960 Eiproben (überbrütet, unbefruchtet, aufgegeben) stammen aus Baden-Württemberg (1966–2002), Ostdeutschland (1955–2002) und Nordrhein-Westfalen / Rheinland-Pfalz (1989–2002). 742 Eier wurden auf die Biozide DDE, HCB u.a. sowie PCB analysiert, bei 692 Eiern konnte der Schalenindex, bei 145 Eiern die Schalendicke gemessen werden. Von 755 Resteiern wurden die externen Maße genommen. Quecksilber-(Hg)-Analysen von 367 Proben (Resteier, Mauser-/Nestlingsfedern, Gewebeproben) ergänzen die Untersuchung.

Die Untersuchungsergebnisse belegen, dass der Zusammenbruch deutscher Wanderfalkenpopulationen bis hin zum Aussterben in den meisten Bundesländern mit dem Einsatz des Insektizides DDT korreliert war. Die DDE-Durchschnittswerte lagen in Baden-Württemberg (BW) in den Jahren 1970–1976 über dem toxikologisch relevanten Schwellenwert von 70–100 µg/g (alle Konzentrationsangaben sind auf Ei-Trockengewicht bezogen) bei noch bis zum Jahre 1987 andauernden Einzelwertüberschreitungen von 100 µg/g. Das durchschnittliche Belastungsniveau in den 1960er Jahren muss aufgrund des DDE-Entwicklungstrends retrospektiv mit über 200 µg/g angenommen werden. Durch konsequente Schutzmaßnahmen gelang es nur in Baden-Württemberg und Südbayern, nach einem Bestandsrückgang um ca. 80% eine Restpopulation zu stabilisieren, welche sich nach dem westdeutschen DDT-Verbot (1972) und dem daraufhin erfolgten Nachlassen der CKW-Belastungen ab ca. 1980 erholte und bis heute verzehnfachte. Der Schalenindex verbesserte sich von 1.48 (1970–71) stetig auf den Normalwert von 1.80–1.88 (2000–02). Hg-Kontaminationen erreichten in Westdeutschland im Zeitraum 1969–1991 keine toxischen Schwellenwerte.

Die deutlich stärkere und länger andauernde DDT-Ausbringung in Ostdeutschland (bis 1989), die hier zum Aussterben der Art als Fels- und Baumbrüter führte, wird anhand von DDE-Messdaten und Schalendicken/-index-Untersuchungen, ergänzt um brutbiologische Beobachtungen ab dem Jahr 1955 detailliert beschrieben. Darüber hinaus hatte die in der DDR ausgeübte Saatgutbeizung mit Methyl-/Phenyl-Quecksilber lokal dramatische Auswirkungen auf Embryonentoxizitäten und die Eischalendicke bis zu Eiern gänzlich ohne Schalenbildung. In Mauserfedern und Resteiern aufgefundene endogene Hg-Belastungen lagen in Spitzenwerten (147 bzw. 65 µg/g) über bisherigen Literaturdaten. Die Kombination der beiden Umweltgifte (DDT und Quecksilber) ist für das Aussterben verantwortlich zu machen. Die gegenwärtig (1992–1998) gemessenen DDE-Belastungen von Resteiern der durch Auswilderung gezüchteter Falken wieder entstandenen Populationen Ostdeutschlands liegen vergleichsweise im Mittel immer noch ca. 3-fach höher als in Proben westdeutscher Falken. Schalenindex und Schalendicke haben sich bis zum Jahre 2002 weitgehend normalisiert, so dass für die Wiederbesiedlung der letzten in Ostdeutschland noch wanderfalkenfreien Felsgebiete eine günstige Prognose besteht. Die auf Prägung beruhende Baumbrutpopulation der ehemals im bewaldeten Tiefland Mittel- und Osteuropas siedelnden Wanderfalken wurde im Zuge der Schadstoffeinwirkung ausgelöscht, so dass der weit nach Osten reichende frühere Lebensraum von der Art heute noch nicht wieder genutzt werden kann.

In Nordrhein-Westfalen / Rheinland-Pfalz weisen Resteier im Zeitraum 1989–2002 unkritische DDE-Be-

lastungen im Bereich 4–20 μg/g mit normalen Schalenindices auf.

PCB-Analysen (nach LUFA) aus allen drei Regionen belegen höchste Belastungen in Ballungszentren mit max. 600 μg/g ohne bisher klare Entwicklungstendenz. HCB-Kontaminationen kulminierten in BW mit max. 80 μg/g und liegen seit 1983 stabil unter 1 μg/g. Kontaminationen mit cis-HCE, Lindan, Dieldrin, Aldrin, Endrin bewegen sich seit dem Jahre 1973 auf unkritischem Niveau. Populationskennwerte verbesserten sich in BW erst nach 1976 durch Rückgang der DDE-/HCB-Belastungen infolge Anwendungsverboten. In Ostdeutschland und Nordrhein-Westfalen wurde die Rückbesiedlung und der Anstieg dieser Erfolgsfaktoren erst zu dem Zeitpunkt möglich, als die DDE- und (für Ostdeutschland) Hg-Belastungen unter toxische Schwellenwerte fielen.

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