Contaminants in Bird Eggs in the Wadden Sea

Contaminants in Bird Eggs
Recent Spatial and Temporal Trends

Seabirds at Risk?
Effects of Environmental Chemicals on Reproductive
Success and Mass Growth of Seabirds at the
Wadden Sea in the Mid 1990s

WADDEN SEA ECOSYSTEM No. 18 - 2004

Colophon

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Preface

Birds play a prominent role as bioindicators: They are conspicuous, one of the best studied groups of organisms, relatively easy to observe and in the focus of public interest and care. As top predators, raptors and seabirds accumulate persistent chemicals, which affect their physiology, reproduction and even survival. This can cause population declines, which have frequently been an indicator of environmental change.

This value of birds was also recognized for the Wadden Sea by the Trilateral Monitoring and Assessment Group (TMAG 1997), which has an outstanding importance for the life cycle of millions of bird individuals each year. Consequently, among the parameters of the Trilateral Monitoring and Assessment Program (TMAP) selected to assess the ecological state of the Wadden Sea, five refer to birds: "Numbers and Distribution of Breeding Birds", "Monitoring of Migratory Birds", "Beached Bird Surveys (BBS)" and "Contaminants in Bird Eggs" are implemented; the fifth parameter "Breeding Success" was proposed, tested successfully in a pilot study (Thyen et al. 1998), but to date has still not been implemented trilaterally.

With respect to chemical pollution in the Wadden Sea, coastal birds have proven to be an excellent monitoring system. Bird eggs are a favorable matrix as they indicate the local pollution, and in the long-term they reveal temporal trends in the contamination of the reproductive females and by that in the environments. Therefore, on the German Wadden Sea coast, monitoring with bird eggs has been carried out since 1981. In two TMAP reports (Becker et al. 1998, Becker et al. 2001), the successful implementation of the parameter and its value to assess the current ecological state of the Wadden Sea ecosystem with respect to contamination was presented in detail.

The first report in this volume 18 is an update of the recent contamination status of birds in the Wadden Sea. The focus is on geographical variation of contamination from the Netherlands to Denmark, and on the temporal trends for three periods, 1998–2003, 1991–2003 and 1981–2003. For the first time, temporal trends of Chlordane levels are presented, which have been analyzed since 1998. The Wadden Sea burden by pollutants slowly moves towards meeting the Targets of the Wadden Sea Plan: Concomitant with the decreasing levels with time, also the strong inter-site and inter-specific differences present during the 1980s have been reduced. On the other hand, the results show stagnation or rather increases of pollution of Wadden Sea biota, including birds, and some local problems of recent anthropogenic discharges of micropollutants (e.g. at the western Wadden Sea, Ems estuary and Jade), even of contaminants prohibited long time ago such as Chlordanes. The results reveal that the Elbe estuary and the inner German Bight are still the hot spot of chemical contamination in the Wadden Sea.

Birds are vulnerable to the effects of chemicals, and the second report in this volume presents results of a specific investigation from the mid 1990s, which combined the parameters "Contaminants in Bird Eggs" and "Breeding Success" at selected sites to facilitate data assessment and give us a better understanding about the influence of pollutants on bird populations. The effects of environmental chemicals on reproductive success and mass growth of four common larid species were investigated, Common Tern (*Sterna hirundo*), Herring Gull (*Larus argentatus*), Common Gull (*Larus cannus*), and Black-headed Gull (*Larus ridibundus*), breeding at highly (Elbe) and low polluted areas (Jade). In general, the contaminants levels were not clearly associated with parameters of reproduction, with the exception of hatching success in Common Gulls breeding at the Elbe Estuary which was probably impaired by HCB, DDE and HCH. The report comes to the conclusion that during the 1990s bird reproduction in general was not at risk by toxic substances on the Wadden Sea coasts.

The presentation of both reports in this volume of Wadden Sea Ecosystem No. 18 aims to show that the combination of different TMAP parameters provides deeper insight into the dynamics and effects of chemical contamination of breeding birds in the Wadden Sea. Just the use of birds in their function as both accumulative and sensitive indicators of chemical contamination, demonstrates their full value as an early warning system to monitor the ecological state of the Wadden Sea with respect to chemical pollution. We hope that this issue will support the final implementation of the parameter "Breeding Success" at selected sites of the Wadden Sea.

Peter H. Becker and Jacqueline Muñoz Cifuentes

WADDEN SEA ECOSYSTEM No. 18

Contaminants in Bird Eggs
Recent Spatial and Temporal Trends

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2004
Trilateral Monitoring and Assessment Group
Common Wadden Sea Secretariat

Abstract

Since 1998, when the parameter "Contaminants in Bird Eggs" was successfully implemented within the Trilateral Monitoring Assessment Program (TMAP), it has contributed to the understanding of trends and dynamics of environmental chemicals' levels in coastal birds and in the Wadden Sea environment. This report presents and evaluates latest levels of contaminants in bird eggs from the Wadden Sea and its recent trends. We focus on the geographical variation of contamination from The Netherlands to Denmark in 2002, and on the temporal trends for three periods, 1998–2003, 1991–2003 and 1981–2003. For the first time, temporal trends of Chlordane levels, which have been analysed since 1998, are presented.

Geographical Trends

Our results reveal that in the German Wadden Sea, the Elbe estuary and the inner German Bight are still hot spots of chemical contamination (Figs. 2 - 3). The spatially lowest egg residue levels in Common Tern and Oystercatcher eggs were recorded in the Danish Wadden Sea. The concentrations of most chemicals (PCBs and mercury, PCBs, DDT, and Chlordanes, respectively) decreased from the western to eastern parts of the Dutch Wadden Sea. For PCBs and Chlordanes, these spatial trends were continuing towards the north-eastern Wadden Sea, indicating pollutant sources in its western parts. Also the Ems estuary was recognized as a pathway discharging contaminants into the Wadden Sea, which was reflected by higher levels of HCB and Chlordanes in Oystercatcher eggs.

Temporal Development

The temporal trends of coastal bird egg pollution from 1981–2003 in the German Wadden Sea (Figs. 4 - 7, Tab. 1) showed that the contamination of Common Tern and Oystercatcher eggs with environmental chemicals had decreased strongly since the beginning of the 1990s, especially the contamination with mercury, ΣPCB, HCB and ΣHCH. During the 1990s, concentrations of chemicals were roughly lesser than half of those of the decade before. Since the mid of the same decade, however, the decrease of egg concentrations seemed to stagnate at levels above the target concentrations. The short-term trends from 1998–2003 surprisingly reveal that during recent times at various sites concentrations of some pollutants increased again on a lower level. Chlordane concentrations in Common Tern and Oystercatcher eggs increased throughout most sites.

Effects on Bird Populations and Target Assessment

The current levels of contaminants are in general lower than known critical concentrations for birds' reproduction. However, the increases of environmental pollution with some chemicals over the last six years, which seem to be due to new inputs or remobilization of chemicals, remind us of the necessity of further efforts and measures to reduce anthropogenic inputs of chemicals into the Wadden Sea, in order to avoid possible impacts on bird populations. The available data of contaminants in bird eggs show that the Wadden Sea burden with pollutants slowly moves towards meeting the Wadden Sea Plan Targets: Concomitant with the decreasing temporal levels, the strong inter-site and inter-specific differences present during the 1980s have also been reduced (Fig. 7). On the other hand, the results showed stagnation or rather increases of pollution of Wadden Sea biota, including birds, and some local problems of recent anthropogenic discharges of micropollutants (e.g. at the western Wadden Sea, Ems estuary, Jade) and even problems with contaminants, prohibited long time ago such as Chlordanes. The present concentrations of PCBs and DDT, especially in Common Terns, are still very high in comparison with the proposed target levels, whereas the proposed target levels for HCB and HCH may be reached sooner. In case of mercury, the concentrations measured in Oystercatcher and Common Tern eggs were still higher than the recommended levels, e.g. at the Elbe estuary.

Recommendations

Considering the current contamination status of bird eggs on the Wadden Sea coast and their temporal development, we recommend: (1) to continue the monitoring of the TMAP parameter "Contaminants in Bird Eggs" on a long-term basis, especially at the hot spots; (2) to analyse the interrelation between different TMAP parameters; (3) to also continue the monitoring of those chemicals already prohibited by law, but still remain in the environment (e.g. PCBs); (4) to broaden the set of substances measured by some new environmental chemicals with persistence and toxicological relevance (e.g. TBT, polybrominated biphenyls, bromocyclen or musk xylol); (5) to supplement the geographical coverage by an additional sampling area at the Rhine delta; and (6) to implement the TMAP parameter "Breeding Success" to use birds as sensitive indicators.

1. Introduction

Common Tern
(Photo: J.-D. Ludwigs)

The aim of the Trilateral Monitoring and Assessment Program (TMAP) is to provide a scientific assessment of the status of the Wadden Sea ecosystem and to assess the implementation of the Targets of the Wadden Sea Plan (Stade Declaration 1997). One of these Targets is to achieve concentrations of contaminants in the marine environment and in indicator species near background values for naturally occurring substances such as heavy metal mercury and close to zero for man-made synthetic substances (xenobiotic compounds) (OSPAR 1997; ICES 2001, 2002, 2003).

Since the beginning of the 1980s, bird eggs have successfully been used as bioindicators of environmental pollution on the southern North Sea coast (e.g. Becker et al., 2001). Egg levels of chemical contaminants reflect pollutant uptake by the female, foraging close to the colony in the few days prior to egg-laying (Gilbertson et al., 1987; Becker, 1989; Becker et al., 1991, 1998, 2001). Furthermore, bird eggs are powerful biomonitors in long-term studies, since they reveal spatial and temporal trends in the contamination of environments (Furness, 1993; Bignert et al., 1995, 1998; Becker et al., 2001; Braune et al., 2001, Becker, 2003, Becker et al., 2003, Muñoz Cifuentes et al., 2003).

In order to assess variability in chemical contamination of the Wadden Sea, Common Tern and Oystercatcher eggs (*Sterna hirundo* and *Haematopus ostralegus*, respectively) have been sampled at selected sites from the western to the northern part since 1981. Both species are among the most common waterbirds using the Wadden Sea as breeding area (Rasmussen et al., 2000). The Common Tern is a long-distance migrant that arrives in the Wadden Sea in spring and forms large breeding colonies (Becker and Ludwigs in press). Oystercatchers, however, are resident birds in the Wadden Sea area. Both species display different habits of foraging and have different diets: Common Terns feed mainly on fish which is taken by plunge-diving, and is considered as a top-predator of the Wadden Sea food-chain, while Oystercatchers mainly feed on macrozoobenthic organisms like mussels and worms (Smit and Wolff, 1980; Cramp and Simmons, 1985). The good knowledge of the biology and ecology of these species, their large populations and high abundance in the Wadden Sea, the high position they occupy within the marine food-chains, and the capacity to accumulate persistent contaminants make them especially suitable as monitors of the contamination of the environment (Becker et al., 1998a).

Since 1998, contaminants in bird eggs have been monitored within the framework of the TMAP and as an integrate part of the joint bird monitoring in the Wadden Sea. A first trilateral report was published in 2001 (Becker et al. 2001). In this second report, results from a five-year period (1998 – 2003) can now be analysed with statistical tools for the entire Wadden Sea.

The Wadden Sea Quality Status Report 1999 (Bakker et al., 1999) revealed that until 1997, mercury levels in eggs of both bird species tended to decrease, especially at the input source, the Elbe estuary, followed by the sites at the Jade Bight. Also the assessment of Polychlorinated Biphenyls (PCB), of insecticides and other organochlorines showed a decrease in concentrations in bird eggs, which was clearly related to the reduction of riverine inputs reduction during the period 1989 - 1993. Organochlorine residues in bird eggs were in general highest at the Elbe estuary (SH1), intermediate at the inner German Bight (SH2), and lowest in the remaining areas, irrespective of the year of study, indicating the high pollutant inputs by the river Elbe.

The objectives of this report are to present and to evaluate the levels of contaminants in bird eggs of the Wadden Sea since 1998, when for the first time the entire Wadden Sea area was covered by this parameter as part of the TMAP. We focus on (1) geographical trends of contamination from The Netherlands to Denmark; (2) temporal development for three periods, 1998–2003, 1991–2003 and 1981–2003; (3) trends of Chlordane levels, which have been analysed since 1998; (4) the status of the recent bird contamination with respect to possible negative effects on bird populations, and regarding the targets of the Wadden Sea Plan; and (5) recommendations for the future monitoring of contaminants in bird eggs.

Oystercatcher (Photo: J.-D. Ludwigs)

2. Sampling Sites

In order to study spatial patterns in bird pollution, sampling sites from the western to the northern parts of the Wadden Sea have been chosen, including different habitats of the Wadden Sea coast (Fig. 1 and Table 1, for details, see Becker et al., 2001).

Bird eggs were collected in the following subareas of the Wadden Sea (numbering according to Essink et al., 2005): Balgzand and Griend (NL1: Western Dutch Wadden Sea), Julianapolder (NL2: Eastern Dutch Wadden Sea), Delfzijl and Dollard (NL3: Ems-Dollart estuary, the first site in The Netherlands and the second one in Germany), Minsener Oog and Mellum (LS2: Jade Bight), Neufelderkoog and Hullen (SH1: Elbe estuary), Trischen (SH2: Inner German Bight), Norderoog (SH3: Halligen), Margrethekoog (DK1: Sylt-Rømø basin), and Langli (DK3: Varden and Sneum estuary).

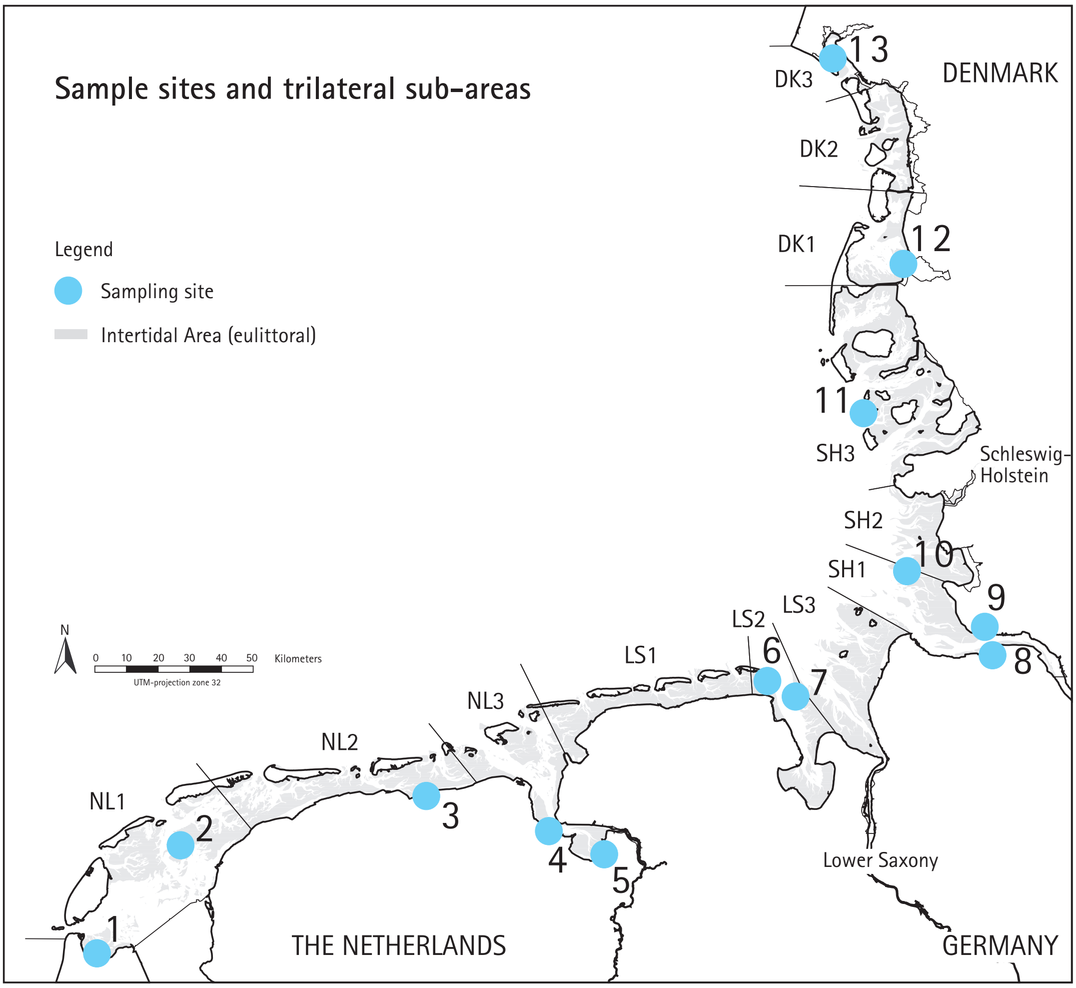


Figure 1: Sampling sites of Common Tern and Oystercatcher eggs in the Wadden Sea in 2002. The Netherlands: 1 Balgzand, 2 Griend, 3 Julianapolder, 4 Delfzijl; Germany, Lower Saxony: 5 Dollart, 6 Minsener Oog, 7 Mellum (6 and 7 = Jade), 8 Hullen, 9 Neufelderkoog (8 and 9 = Elbe estuary); Germany, Schleswig Holstein: 10 Trischen, 11 Norderoog; Denmark: 12 Margrethekoog, 13 Langli. At sites 5, 7, 8,11 and 13 only Oystercatcher eggs, at sites 6, 9 and 12 only Common Tern eggs have been taken; at all other sites eggs of both species have been collected.

3. Methods

The sampling, preparation and chemical analyses follow the standardized methodological guideline for JAMP Biota Monitoring (OSPAR 1997) which is part of the TMAP guidelines.

To analyze contaminant levels, 10 fresh eggs per species per year were sampled, if possible, at these sampling sites. In the German Wadden Sea, eggs were collected in 1981 and from 1985 – 2003. Common Tern eggs have been sampled at Griend since 1993 and at Julianapolder since 1997, Oystercatcher eggs at Griend since 1995. Since 1998, eggs of both species have been collected at Balgzand and Delfzijl. Since 1999, egg samples from Denmark have been collected, but not in 2003 due to the lack of financial resources.

Concentrations of these chemicals have been determined: Mercury (Hg), ΣPCB (including 62 polychlorinated biphenyl congeners), hexachlorobenzene (HCB), ΣDDT (including p,p'-DDT, o,p'-DDD, p,p'-DDD, o,p'-DDE, and p,p'-DDE), ΣHCH (including α-, β- and γ-isomers of hexachlorocyclohexane) and ΣChlordane. The o,p'-isomers of DDT, DDD and DDE have been excluded since 1999, as they were no more detected. Chlordanes have been included since 1998 and their levels are presented as ΣChlordane, summing up levels of cis- and trans-chlordane, and cis- and trans-nonachlor. Mercury determination was carried out by atomic absorption spectrometry and organochlorines were determined by gas chromatography. The determination limit for mercury was 0.1 $ng\cdot g^{-1}$ and for organochlorines varied between 0.3 and 0.4 $ng\cdot g^{-1}$ for single organochlorines, and for p,p'-DDT it was 0.9 $ng\cdot g^{-1}$. For details about chemical procedures see TMAP 2001 (Becker et al., 2001). The residue levels are given in ng g^{-1} fresh egg mass. Since 1991 all egg samples have been analyzed at the ITI of the University of Applied Sciences or, since 2000, at TERRAMARE research center, Wilhelmshaven. The ITI participated in an intercalibration with two other labs, in 1996, 1997 and 2000 also in an international quality assurance (QUASIMEME project), and results were ranked as satisfactory in most analyses.

In the figures, arithmetic means ± 95% confidence intervals are shown. If the confidence intervals of two groups do not overlap, a significant difference of at least $p<0.05$ is given.

4.1 Interspecific Differences in Contaminant Levels in Bird Eggs

The general pattern of contaminant levels in eggs of the two species is shown exemplary in the samples of the year 2002 (Fig. 2). Among the analysed chemicals, ΣPCB had highest levels in the eggs of both species and at all sites. In addition, mercury and ΣDDT were found in higher concentrations than the remaining contaminants.

In general, Common Tern eggs were significantly higher contaminated at most sampling sites than Oystercatcher eggs (Fig. 2). However, some exceptions were found: ΣChlordane levels were higher in Oystercatcher eggs from Griend, Balgzand, Delfzijl and Norderoog. In some sites the levels of mercury, ΣPCB and ΣHCH were similar in Common Tern and Oystercatcher eggs: Mercury concentrations were similar in eggs from Balgzand, PCBs in Delfzijl (Ems estuary), Jade and the inner German Bight, and ΣHCH at the Elbe and at the inner German Bight.

4.2 Spatial Trends of Contaminants

Intersite variation of chemical levels in coastal bird eggs in the Wadden Sea is exemplarily presented for the most recent year of this study (2002), when the sampling included sites from The Netherlands, Germany and Denmark (Fig. 2).

Common Tern

The spatial pattern of Common Tern pollution showed higher levels of contaminants at the Elbe estuary and in some cases at Trischen (Fig. 2). With the exception of ΣPCB and ΣChlordane levels, the concentrations of the other contaminants were on a similar and lower level in the other areas of the Wadden Sea. The ΣPCB concentrations tended to decrease from the Western Dutch Wadden Sea to the coast of Denmark, with a peak of PCB contamination at the Elbe estuary. At Balgzand and Griend, slightly higher HCH levels were determined than at the other Dutch sites. The concentrations of mercury, ΣDDT and HCB in eggs, sampled at the Elbe, were significantly higher than in eggs from the other sites, and were usually followed by the levels of eggs collected on Trischen. Also the ΣHCH levels in bird eggs found at the Elbe and on Trischen were found to be considerably higher in comparison to samples found on other sites. The concentrations of ΣChlordanes reached the highest levels in samples from the western Wadden Sea, at Trischen and Margrethekoog. In samples from Delfzijl, Jade, and Elbe, residues of Chlordane were very low (on average below 1 ng·g^{-1}).

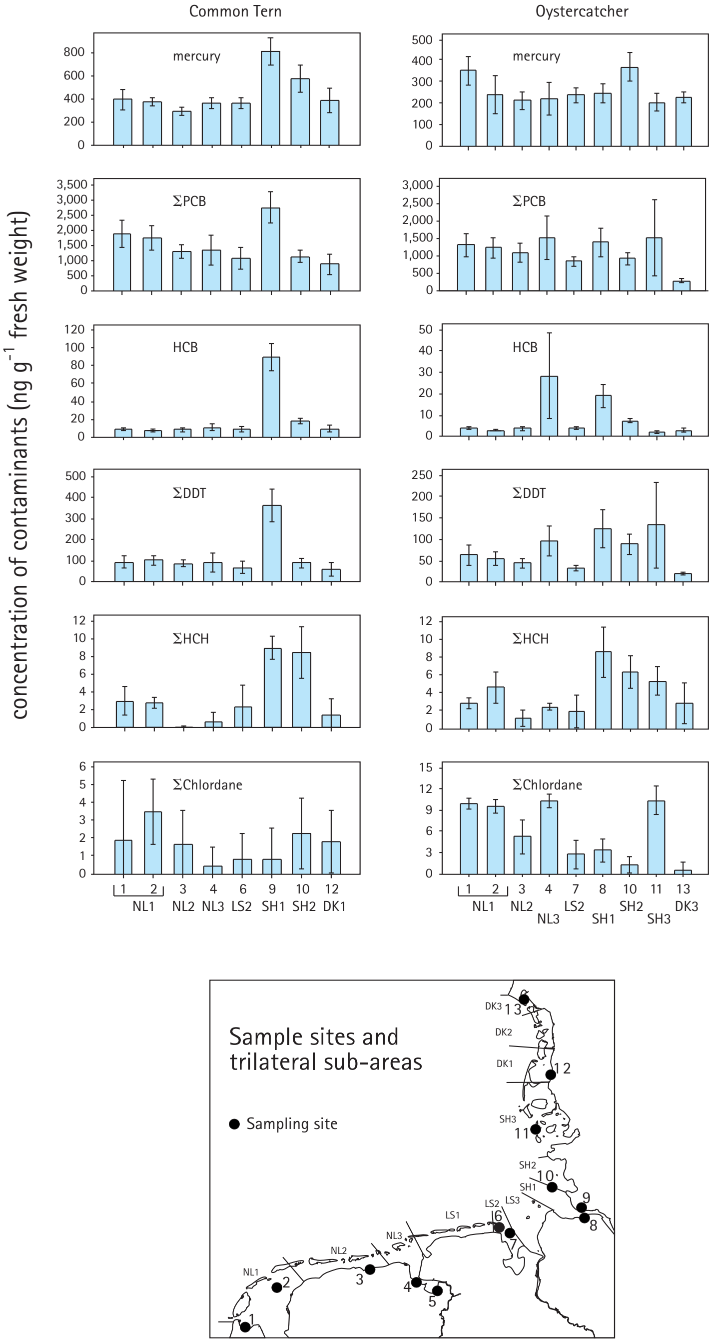


Figure 2:
Sampling sites and geographic variation of the contaminants analyzed in Common Tern and Oystercatcher eggs in the Wadden Sea in 2002. The Netherlands: 1 Balgzand, 2 Griend, 3 Julianapolder, 4 Delfzijl; Germany, Lower Saxony: 5 Dollart, 6 Minsener Oog, 7 Mellum (6 and 7 = Jade), 8 Hullen, 9 Neufelderkoog (8 and 9 = Elbe estuary); Germany, Schleswig Holstein: 10 Trischen, 11 Norderoog; Denmark: 12 Margrethekoog, 13 Langli. At sites 5, 7, 8,11 and 13 only Oystercatcher eggs, at sites 6, 9 and 12 only Common Tern eggs have been taken; at all other sites eggs of both species have been collected. Mean concentration (ng·g^{-1} fresh weight of egg content) and 95% confidence intervals are presented. At most sites, n=10 eggs per species were analyzed.

Oystercatcher

Mercury levels were rather similar on all sites, with slight increases at Balgzand and Trischen. Also the ΣPCB concentrations were similar among the sites, although in Lower Saxony (Jade) and Schleswig-Holstein (Trischen), and at the Danish site Langli, slightly lower and significantly lower ΣPCB levels were found, respectively. HCB concentrations were considerably higher in eggs sampled at the Ems and at the Elbe estuary. Eggs from Delfzijl, Elbe estuary and Norderoog contained high levels of ΣDDT. At the Dutch Wadden Sea, ΣHCH levels were lower than at the Elbe estuary. ΣHCH decreased gradually from the Elbe estuary towards the Danish Wadden Sea. The geographical pattern of Chlordane concentrations revealed higher levels at the Western Wadden Sea, at Delfzijl (Ems estuary), and in Schleswig-Holstein.

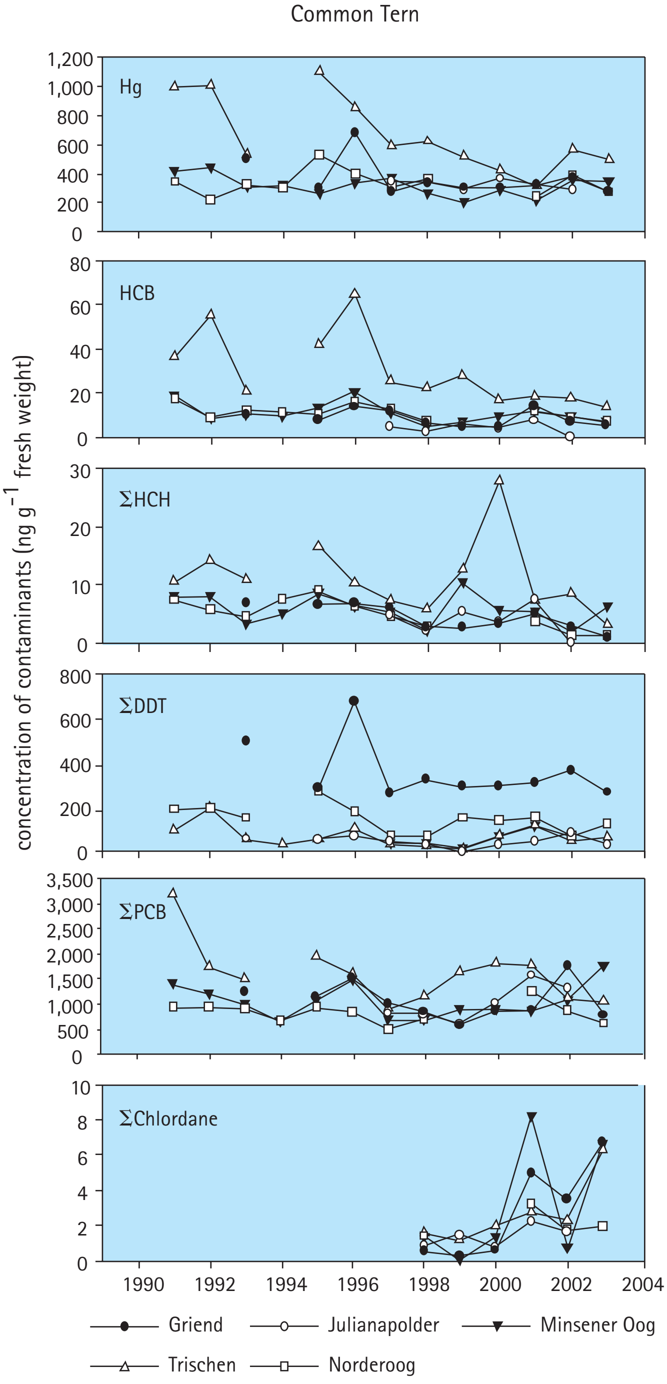


Figure 3: Temporal trends of mercury, HCB, sum of HCH-isomers (ΣHCH), Sum of DDT and metabolites (ΣDDT), sum of PCB congeners (ΣPCB), and sum of cis- and trans-chlordane, cis- and trans-nonachlor (ΣChlordane) concentrations in eggs of Common Tern from selected sampling sites 1991-2003. Arithmetic means ($ng \cdot g^{-1}$ fresh weight of egg content) are presented.

4.3 Temporal Development for the Period 1991-2003

The temporal variation of chemical contamination in Common Tern and Oystercatcher eggs in the Wadden Sea is exemplarily presented for five selected areas throughout the period 1991-2003 (Figs. 3, 4, Table 1). Between 1991 and 2003, mercury, HCB and ΣHCH decreased gradually. HCH levels decreased significantly at all selected areas (see Table 1 for p-values of Spearman rank correlation), with the exception of Common Tern eggs sampled at Julianapolder and Norderoog, where no significant trends were found. In Oystercatcher eggs from the Elbe, significant increases of mercury were found (Table 1). ΣDDT didn't show significant trends in Common Tern and Oystercatcher eggs sampled at Griend (between 1993-2003 and 1995-2003, respectively), nor did Oystercatcher eggs from Trischen and Norderoog. Significant decreases of ΣDDT levels, however, were detected in Common Tern eggs sampled at the Jade, Trischen

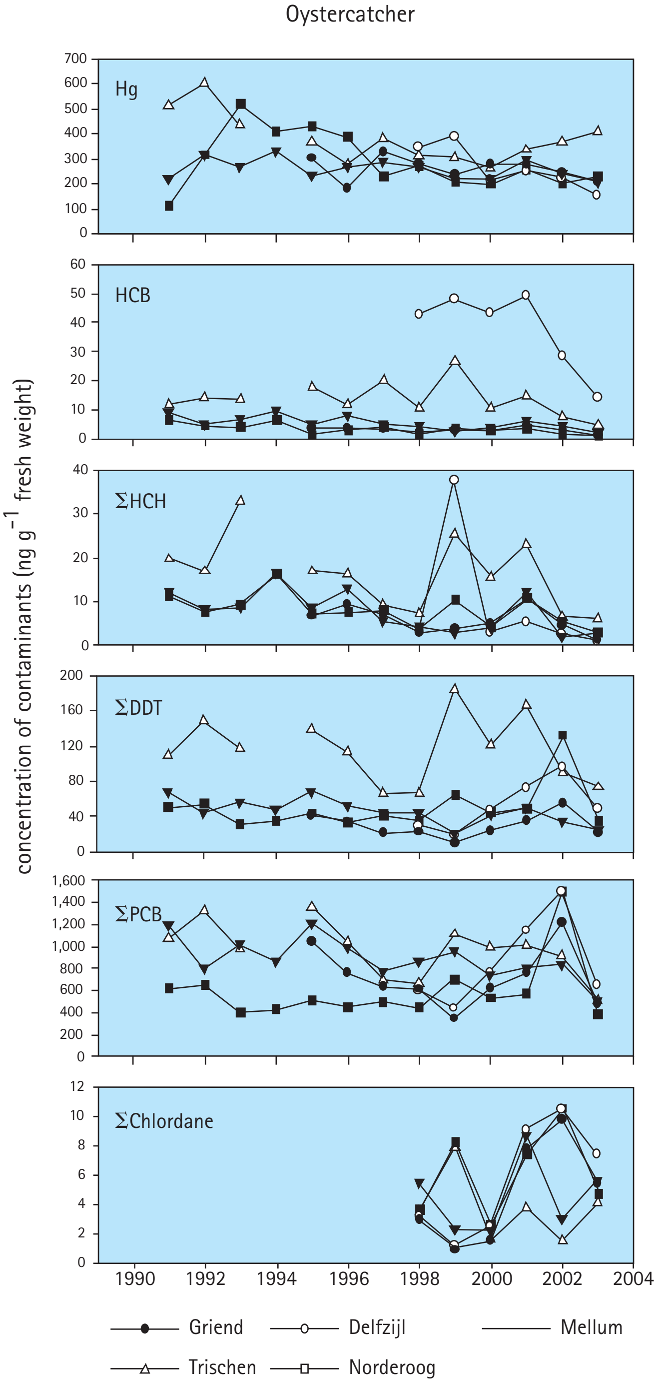


Figure 4: Temporal trends of mercury, HCB, sum of HCH-isomers (HCH), Sum of DDT and metabolites (ΣDDT), sum of PCB congeners (ΣPCB), and sum of cis- and trans-chlordane and cis- and trans-nonachlor (ΣChlordane) concentrations in Oystercatcher eggs from selected sampling sites 1991-2003. Arithmetic means (ng·ng^{-1} fresh weight of egg content) are presented.

and Norderoog. ΣDDT concentration decreased also in Oystercatcher eggs from the Jade. ΣDDT increased significantly in Common Tern eggs sampled at Julianapolder (between 1997-2002) and in Oystercatcher eggs from Delfzijl (1998-2003). ΣPCB levels in Common Tern eggs increased significantly at Julianapolder, decreased at the Elbe, Trischen and Norderoog, and were stable at Griend (1993-2003) and Jade. Likewise, the contamination by PCBs in Oystercatcher eggs increased at Delfzijl (1998-2003), and decreased significantly at the Jade, Elbe, and Trischen. No significant PCB-trend was observed in Oystercatcher eggs sampled at Griend (1995-2003) and Norderoog.

Considering only the last six study years (1998-2003), remarkable increases in contaminant levels were obvious at several sites (Figs. 3 and 4, Table 1). At Balgzand, significant increases of levels of ΣDDT in Common Tern, of mercury in Oystercatcher, and of ΣChlordane in eggs of both bird species were found, whereas decreases of ΣHCH were observed; HCB decreased only in Oystercatcher eggs. On Griend, PCBs, ΣDDT, and ΣChlordane levels increased in Common Tern and Oystercatcher eggs. Also at the Julianapolder and Ems estuary (Delfzijl and Dollart), increases in the levels of organochlorines were recognized. But the HCB levels in Oystercatcher eggs from Delfzijl have strongly decreased since 2002, owing to measures against a source of industrial pollution (Eggens and Bakker, 2001). The concentrations of all analyzed chemicals, with the exception of ΣHCH, increased significantly in Common Tern eggs sampled at the Jade Bight. At the Elbe estuary, significant increases in ΣDDT and ΣChlordane were found in Oystercatcher eggs. In Oystercatcher and Common Tern eggs from Trischen, positive trends were found in levels of mercury and ΣChlordane, and the same trends were found in Oystercatcher eggs from Norderoog and Langli, respectively. The ΣChlordane levels in eggs from the Western Wadden Sea had been increasing in both species since 2001.

Table 1:

Temporal trends in pollutant levels in Common Tern and Oystercatcher eggs for one or two time periods. Chlordanes studied since 1998. For significant trends, Spearman rank coefficients (rs) calculated on the basis of n eggs and p-values are presented. N.s.: not significant, ***<0.05,** ****<0.01*******<0.001.**
Positive trends are given in bold.

		Hg	n	HCB	n	ΣPCB	n	ΣDDT	n	ΣHCH	n	ΣChlordane	n
Common Tern													
Balgzand	1998-2003	n.s.	60	n.s.	60	n.s.	60	**0,278***	60	-0,528***	60	**0,438*****	60
Griend	1993-2003	-0,320**	100	-0,363***	100	n.s.	100	n.s.	100	-0,698***	100		
	1998-2003	n.s.	60	n.s.	60	**0,282***	60	**0,419****	60	n.s.	60	**0,726*****	60
Julianapolder	1998-2002	n.s.	33	n.s.	33	**0,771*****	33	**0,647*****	33	-0,653***	33	n.s.	33
Delfzijl	1998-2003	n.s.	60	-0,258*	60	n.s.	60	n.s.	60	-0,506***	60	**0,318***	60
Minsener Oog	1991-2003	-0,251**	130	-0,334***	129	n.s.	130	-0,195*	130	-0,274**	130		
(Jade)	1998-2003	**0,418****	60	**0,291***	60	**0,476*****	60	**0,418****	60	n.s.	60	**0,418****	60
Elbe	1991-2003	-0,626***	135	-0,228**	135	-0,269**	135	n.s.	135	-0,250**	135		
	1998-2003	n.s.	60	-0,653***	60	-0,422**	60	n.s.	60	-0,601***	60	n.s.	60
Trischen	1991-2003	-0,548***	120	-0,448***	120	-0,387***	120	-0,352***	120	-0,355***	120		
	1998-2003	n.s.	60	-0,270*	60	n.s.	60	n.s.	60	-0,352**	60	**0,382****	60
Norderoog	1991-2003	n.s.	109	-0,352***	110	-0,205*	110	-0,341***	110	-0,588***	110		
	1998-2003	n.s.	40	n.s.	40	-0,320*	40	n.s.	40	-0,478**	40	n.s.	40
Oystercatcher													
Balgzand	1998-2003	**0,396****	60	-0,283*	60	n.s.	60	n.s.	60	-0,536***	60	**0,654*****	60
Griend	1994-2003	-0,278*	82	-0,315**	82	n.s.	82	n.s.	82	-0,389***	82		
	1998-2003	n.s.	60	n.s.	60	**0,263***	60	**0,408****	60	n.s.	60	**0,620*****	60
Julianapolder	1998-2003	-0,337*	58	-0,448***	58	**0,443*****	58	**0,533**	58	-0,647***	58	**0,634*****	58
Delfzijl	1998-2003	-0,579***	60	-0,261*	60	**0,460*****	60	**0,626*****	60	-0,542***	60	**0,682*****	60
Dollart	1991-2003	n.s.	85	-0,322**	75	**0,320****	75	n.s.	75	n.s.	75		
	1998-2003	-0,330*	36	**0,600*****	36	**0,677*****	36	**0,716*****	36	**0,368***	36	**0,414***	36
Mellum (Jade)	1991-2003	-0,276**	130	-0,562***	130	-0,359***	130	-0,494***	130	-0,625***	130		
	1998-2003	n.s.	60	n.s.	60	-0,381**	60	n.s.	60	-0,285*	60	n.s.	60
Elbe	1991-2003	**0,334*****	130	-0,424***	130	-0,218*	129	n.s.	130	-0,289**	130		
	1998-2003	n.s.	60	-0,286*	60	n.s.	60	**0,403****	60	n.s.	60	**0,510*****	60
Trischen	1991-2003	-0,373***	118	-0,346***	118	-0,406***	118	n.s.	118	-0,503***	118		
	1998-2003	**0,423****	58	-0,627***	58	n.s.	58	n.s.	58	-0,336*	58	n.s.	58
Norderoog	1991-2003	-0,276**	129	-0,512***	129	n.s.	129	n.s.	129	-0,490***	129		
	1998-2003	n.s.	59	-0,389**	59	n.s.	59	n.s.	59	n.s.	59	**0,268***	59
Langli	1999-2002	**0,453****	40	n.s.	40	n.s.	40	n.s.	40	-0,579***	40	n.s.	40

4.4 Temporal Trends 1981-2003

The comparison of the temporal trends in the German Wadden Sea from 1991 to the present time with the trends during the 1980s reveals that the burden of Common Tern and Oystercatcher eggs with environmental chemicals had decreased strongly since 1989 (Figs. 5 and 6), especially the contamination with mercury, ∑PCB, HCB and ∑HCH. Additionally, the strong interannual fluctuations of the concentrations in eggs from the Elbe estuary, Trischen and Jade were also constantly reduced. This process of pollutant reduction was most pronounced in samples from the Elbe estuary, followed by Trischen and Jade. During the 1990s, concentrations were roughly more than half of those from the decade before (Figs. 5 and 6), but since the mid 1990s, the decrease of concentrations seemed to have stagnated at levels above the target concentrations.

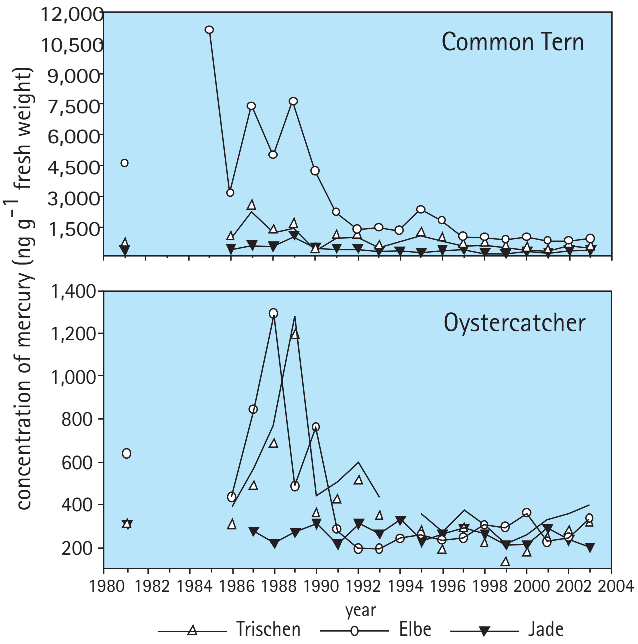


Figure 5: Temporal trends of mercury concentrations (ng·ng^{-1} fresh weight, arithmetic means) in common tern and oystercatcher eggs from selected breeding sites from the German Wadden Sea 1981-2003. Data from 1981-1990 after Becker et al. 1991, 1992.

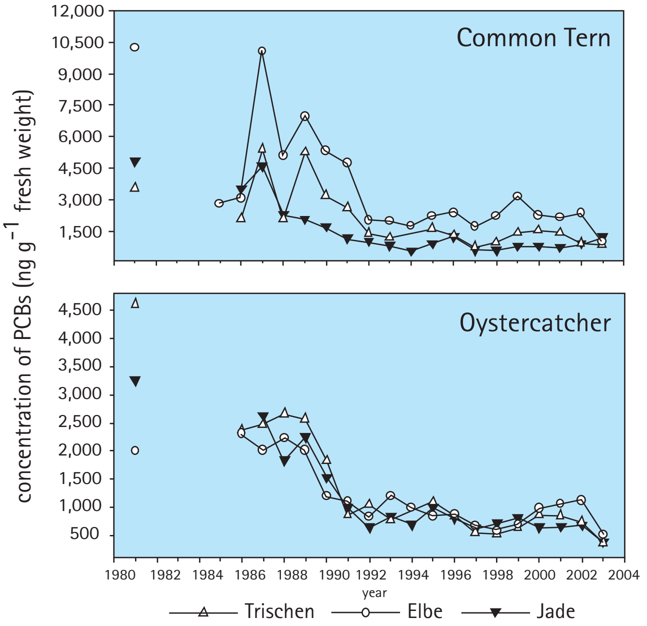


Figure 6: Temporal trends of Σ32PCB (sum of 32 congeners) concentrations (ng·ng^{-1} fresh weight, arithmetic means) in Common Tern and Oystercatcher eggs from selected breeding sites from the German Wadden Sea 1981-2003. Data from 1981-1990 after Becker et al. 1991, 1992.

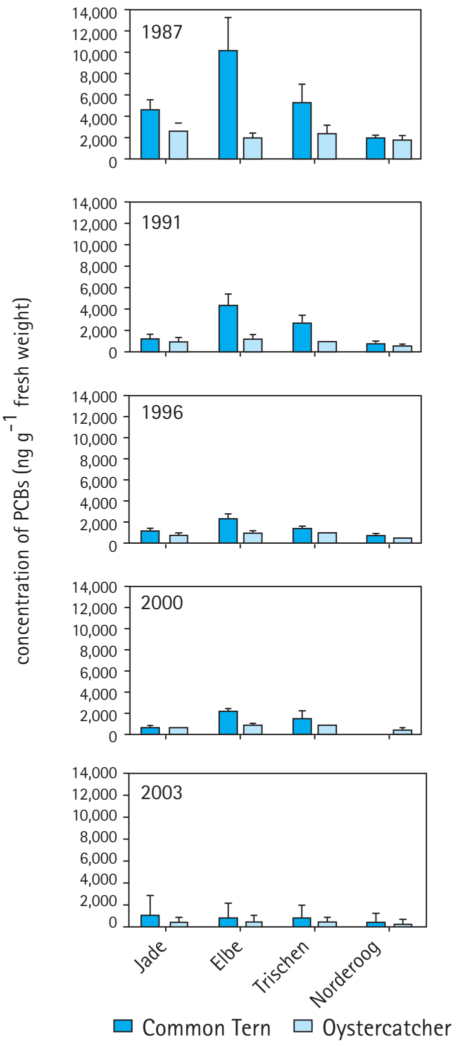
5. Assessment and Conclusions

5.1 Scientific Assessment

As result of differences in diet choice, reproductive ecology and migration, Common Terns accumulate higher residues of most persistent contaminants than Oystercatcher (Becker et al., 1998, 2001; Thyen and Becker, 2000). Common Terns feed on fish occupying higher trophic levels than benthic organisms taken by Oystercatchers. Through biomagnification, fish is contaminated stronger by most of the environmental chemicals examined than benthic invertebrates (Mattig et al., 1996). This fact explains the higher tern contamination although Oystercatchers are exposed to the chemical load of the Wadden Sea for longer periods of the year than the terns. Thus, Common Tern and Oystercatcher reflect the contaminant load of their prey representing specific trophic levels.

However, the degree of the interspecific difference is linked with the level of chemical contamination in the environment: The higher the environmental contamination with a compound was, the greater was the difference between Common Tern and Oystercatcher egg levels. Consequently, the difference in egg contamination between the two species as well as between the sites was reduced if the total chemical burden of the ecosystem had declined temporally (Fig. 7).

Figure 7: Temporal, spatial and interspecific variation in the concentrations of ΣPCB (sum of 32 congeners) in Common Tern and Oystercatcher eggs from selected breeding sites on the German Wadden Sea coast between 1987 and 2003 (see Fig. 1 for sites). Mean concentration (ng·g^{1} fresh weight of egg content) and 95% confidence intervals are presented.



5.2 Spatial Trends

The North Sea contamination originates mainly in three pathways: riverine inputs, atmospheric deposition, and direct discharges (e.g. Albrecht and Schmolke, 2002; Weigel, 2002). Near the coast, the most important pathways are riverine and direct inputs. Coinciding with that, our results reveal that the rivers still are the most important path introducing pollutants into the Wadden Sea. Consequently, at the German Wadden Sea, the Elbe estuary and the inner German Bight still were the "hot spots" of chemical contamination. Also at the western part of the Wadden Sea, effects of riverine inputs could be recognized; hence, concentrations of some chemical were higher at the Dutch Wadden Sea than in the eastern parts: The ΣPCB levels of Common Tern eggs diminished from Balgzand to Julianapolder, as did the levels of mercury, ΣPCBs, ΣDDT, and ΣChlordane in Oystercatcher eggs. This could suggest that the Dutch Wadden Sea ecosystem was still influenced by contaminant loads originating from the river Rhine or IJsselmeer (Jonge, 1990; Jonge and Essink, 1991; Bester and Faller, 1994) or from other local sources. Also the negative spatial trend in PCB and ΣChlordane levels in Common Tern and Oystercatcher eggs, respectively, from the western towards the north-eastern parts of the Wadden Sea indicates pollutant sources in its western parts. In this respect, the Ems estuary was also recognized as pathway discharging contaminants into the Wadden Sea, which has been reflected by higher levels of some pollutants (e.g. HCB and ΣChlordane in Oystercatcher eggs). Atmospheric deposition may explain the relative uniform spatial pattern of egg contamination with mercury and PCBs on high levels, apart from the distinct inputs of the Elbe river (Fig. 2). Atmospheric inputs, however, are known to be important also for some pesticides as DDT and Chlordanes (Fischer et al., 1994; Franzaring and Eerden, 2000; Weigel, 2002), which, however, is not evident from the contamination of bird eggs in the Wadden Sea.

In the Danish Wadden Sea, lowest egg residue levels were recorded (Fig. 2). Because of the direction of North Sea currents, the pollutant loads originating from the Elbe are transported into north-eastern and northern directions (e.g. Lee, 1980). Accordingly, bird contamination decreased from the Elbe estuary via Trischen to Norderoog, Margrethekoog and Langli in the Danish Wadden Sea, obviously in parallel with an increasing dilution of chemicals in water, sediment and food web (Fig. 2).

Yet despite the lowered inputs of chemicals into the North Sea through rivers and by atmosphere, the contamination of the seabird eggs clearly indicates distinct geographical variation even today, with the Elbe estuary still persisting to date as a hot spot. During the 1980s, however, the spatial variation in bird egg contamination in the German Wadden Sea was more distinct, and intersite differences were more pronounced, owing to the formerly huge contaminant inputs mainly by the river Elbe into the North Sea (Fig. 7; see Becker et al., 1985a,b, 1991, 1992; Bakker et al., 1999). Nevertheless, the Wadden Sea adjacent to the Elbe estuary was and will further be the hot spot where birds are most likely at risk of hazardous environmental chemicals, which should be kept under careful observation.

5.3 Temporal Trends

In contrast to the long-term data series on egg contamination from the German Wadden Sea sites, eggs from the Dutch coast had not been sampled before 1997 (except Griend, Table 1), and eggs from the Danish sites were only sampled between 1999 and 2002. Therefore, the preliminary time trend analyses for the Danish sites have to be treated with caution. Furthermore, the occurrence of local and short-term events affecting contaminant levels in the environment and in biota have to be considered, as they could mask a temporal trend in contamination (Becker et al., 2001).

The long-term monitoring results show strong contamination decreases at the beginning of the 1990s and further reductions during the last decade, which is corroborated by the analyses of abiotic and other biotic samples in the Wadden Sea (Bakker et al., 1999, 2005). The comparison of the temporal trends from the 1990s to the present time with the temporal development of coastal bird pollution during the 1980s in the German Wadden Sea reveals that the burden of Common Tern and Oystercatcher eggs with environmental chemicals have decreased since the beginning of the 1990s (Figs. 5 and 6), especially the contamination with mercury, ΣPCB, HCB and ΣHCH. Additionally, the strong fluctuations of the concentrations in eggs from the Elbe estuary, Trischen and Jade were also constantly reduced. This process of pollutant reduction was most pronounced in samples from the Elbe estuary, followed by Trischen and Jade. Concentrations in the 1990s were roughly lesser than half of those from the decade before (Figs. 5 and 6), but since the mid 1990s, the decrease of concentrations seems to stagnate at levels above the target concentrations. The long-term trends from 1981 onwards which showed strong decreases of the contaminant levels in birds corrrespond with results of other seabird species and sea areas in Europe (e.g. Bignert et al., 1998; Olafsdóttier et al., 2005).

The comparison between the trends from 1991–2003 and 1998–2003 surprisingly reveals that during recent time concentrations some pollutants had increased again on a lower level, at various sites in the eastern and southern Wadden Sea; Chlordane concentration increased throughout all sites. These results indicate that pollution by environmental chemicals, also by historical ones, is ongoing, even though production and use of these chemicals have been forbidden in central Europe since the 1980s. The quantification of the riverine inputs (Bakker et al. 2005) since the mid 1990s partly corresponds well with the bird data: for example, the increase in mercury and PCB levels in Common Tern eggs from Minsener Oog can be related to the higher input of these substances by the Weser, and the reduction of HCH emissions by the Elbe since 2001 corresponds to decreased levels in eggs of Common Terns breeding at the estuary of this river.

After the river Elbe flooding in August 2002, it was expected that large amounts of contaminants were mobilised from contaminated areas and transferred to the German Bight and North Sea, respectively. But results from various studies have shown that the levels of most contaminants have not increased, and that the water quality of the German Bight through the Elbe flooding did not get worse (Nies et al., 2002). Water mercury concentrations measured after flooding were within the range of variability of the years before. In case of organochlorines, only HCH concentrations were affected by flooding, and the isomers α-HCH and β-HCH showed higher concentrations after flooding (Nies et al., 2002). However, HCH levels were back to "normal" levels at the end of 2002. Also the bird egg contamination in 2003 compared with the years before didn't give any evidence of exceptional contaminant levels related to the Elbe flooding in August 2002.

5.4 Toxicological Aspects

Effects of chemical contaminants on avian reproduction have been frequently studied (e.g. Moriarty et al., 1986; Furness, 1993; Keith & Mitchell, 1993; Wiemeyer, 1996; Burger and Gochfeld, 1997; Willet et al., 1998). Becker et al. (1993) found that although the hatching success of Common Tern colonies breeding at highly and low contaminated sites at the German Wadden Sea coast was similar, PCB contents of unhatched eggs (7,600 $ng \cdot g^{-1}$) sampled at the Elbe were significantly higher than in eggs collected at random (5,100 $ng \cdot g^{-1}$). In a more recent study on the possible effects of chemical pollution on the reproduction of birds, HCB, p,p'-DDE, and β-HCH seemed to be related with decreases in the hatching and overall reproductive success of Common Gulls (*Larus canus*) breeding at the Elbe Estuary in the mid 1990s (Muñoz Cifuentes, 2004). The other bird species considered in this study were Common Tern and herring gull (*Larus argentatus*). In the case of the Common Tern, the fledging success was probably affected by ΣHCH, and ΣDDT and the total organochlorine level seemed to play an important role, determining the overall reproductive success of herring gulls. Furthermore, the chick development of both species at the Elbe estuary possibly was injured by HCB, p,p'-DDE, and β-HCH. ΣDDT concentrations in herring gull eggs, as well as and TEQ levels found in herring gull and Common Tern eggs were within the range associated with embryonic toxicity and impaired hatching success in fish-eating birds. Owing to the long-term exposition and additive and synergistic effects of single compounds, chronic effects should not be excluded.

Our results show, that although the current levels of contaminants were in general lower than known tolerable concentrations for bird reproduction, the increases of environmental pollution with some chemicals over the last six years, which seem to be due to new inputs of chemicals, remind us of further efforts and measures necessary to reduce anthropogenic inputs of chemicals into the Wadden Sea to avoid possible impacts on bird populations.

5.5 Assessment of the Targets

The long-term trends gained by the monitoring of contaminants in bird eggs from the Wadden Sea have shown that the Wadden Sea burden by anthropogenic micropollutants converges slowly towards the Wadden Sea Plan Targets (see also Bakker et al., 1999; Becker et al., 2001). This process is well illustrated by Fig. 7, showing that the interspecific and intersite differences in bird egg contamination have been reduced more and more by the years, arriving now at equalized levels closer to the Targets. However, the evaluation of the most recent results revealed stagnation or rather ongoing increases of pollution of Wadden Sea biota, including birds. The monitoring of contaminants in bird eggs from the Wadden Sea indicates some local problems of recent anthropogenic discharges of micropollutants (e.g. at the western Wadden Sea, Ems estuary and Jade), or problems of persistence of contaminants prohibited long time ago, such as in Chlordanes. These problems need further efforts of environmental protection, accompanied by the control of the success of those activities through the continuation of relevant TMAP parameters including top predators, such as birds, on the basis of long-term and annual sampling.

Presumably the Target levels for man-made chemicals of zero values in biota, including bird eggs, cannot be achieved in the near future as these persistent chemicals have long half-life periods. Despite the immense efforts in preventing chemical pollution of the Wadden Sea by legal regulations over the last two decades, more measures are needed to reduce the chemical inputs into the environment and to come closer to the Targets or Ecological Quality Objectives. ICES (2003, 2004) recommends the average concentrations of PCBs should not exceed 20 $ng \cdot g^{-1}$ in fresh mass of the eggs of Common Tern and Oystercatcher, of DDT and metabolites should not exceed 10 $ng \cdot g^{-1}$and of HCB and HCH should each not exceed 2 $ng \cdot g^{-1}$ at each site. Our results show that current concentrations of PCBs and DDT, especially in the Common Tern, are still very high in comparison with these proposed target levels; the target levels of HCB and HCH may be reached sooner. ICES (2003, 2004) recommends in case of mercury, that environmental levels should be reduced to concentrations measured at habitats in southwestern Norway and in the Moray Firth, or at least to the lowest recorded values in current monitoring schemes (Oystercatcher: 100 $ng \cdot g^{-1}$; Common Tern 200 $ng \cdot g^{-1}$, Becker et al., 2001).

5.6 Recommendations with regard to Monitoring and Research

Considering the recent development of contamination, we recommend that at "hot spots" and those sampling sites where increases of pollution were observed, intensive and careful observations should be carried out in order to elucidate the causes of this trend and to reduce or avoid anthropogenic inputs of contaminants. A recent successful example was the reduction of HCB contamination near Delfzijl whose success is clearly shown by the Oystercatcher egg levels (Fig. 4, Eggens and Bakker, 2001). Relevant parameters of the TMAP, including birds as top predators and accumulative indicators, also have to be measured further on a long-term basis, in order to distinguish short-term fluctuations from time-trends. Spatial and temporal trend monitoring of different TMAP parameters should be interrelated in order to discriminate whether an increase in contamination is caused by new inputs or by remobilization of chemicals, released a long time ago and being a latent risk. Also xenobiotics, which have been forbidden many years ago in Europe as some pesticides and PCBs, but still causing recent local chemical contamination, should be continued to be monitored. Furthermore, the spectrum of chemicals studied should be adapted, and some "new" toxic substances should be assessed whether they should be included into the monitoring of bird eggs (e.g. TBT, polybrominated biphenyls, bromocyclen or musk xylol). Additional sampling sites at the Rhine delta with its important industries should be included in using birds as monitors in this area, in order to record the impact of contaminants originating from this river and being transported to the Wadden Sea. Finally, the proposed TMAP parameter "Breeding Success" (Thyen et al., 1998; Thyen et al., 2000; Becker, 2003; Muñoz Cifuentes, 2004) should be implemented to also utilize birds as sensitive indicators of chemical contamination and as an early warning system, in addition to the other parameters within the TMAP, making use of birds to monitor the ecological state of the Wadden Sea.

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WADDEN SEA ECOSYSTEM No. 18

Seabirds at Risk?

Effects of Environmental Chemicals on Reproductive Success and Mass Growth of Seabirds Breeding at the Wadden Sea in the Mid 1990s

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Summary

During the mid 1990s, the possible effects of chemical contaminants on the overall reproductive success and chick development of common and widespread bird species breeding at the North Sea coast were investigated. Levels of mercury and PCBs, HCB, HCHs, and DDTs were determined in eggs of Common Terns (*Sterna hirundo*), Herring Gulls (*Larus argentatus*), Common Gulls (*Larus canus*), and Black-headed Gulls (*Larus ridibundus*). Simultaneously, reproductive parameters, such as hatching success, breeding success, fledging success, and growth rates of the chicks were evaluated. The Common Tern and the Herring Gull were investigated both at highly and low polluted areas at the Elbe Estuary and at the Jade Bay, respectively. The Common Gull and the Black-headed Gull were studied during the breeding seasons 1995 and 1996, the first one at the Elbe Estuary and the second one at the Jade Bay. In general, the contaminants levels were low and not clearly associated with parameters of reproduction, with the exception of the hatching and overall reproductive success related to HCB, p,p'-DDE, and β-HCH in Common Gulls breeding at the Elbe Estuary.

The species most contaminated were the Common Tern and the Herring Gull, which accumulate higher contaminant levels than the Common and the Black-headed Gull. In the case of the Common Tern, the fledging success was probably affected by ΣHCH, and for the Herring Gull, ΣDDT and ΣOHa seemed to play an important role determining the overall reproductive success. The chick development of both species at the Elbe estuary was possibly injured by HCB, p,p'-DDE, and α-HCH. DDT concentrations found in Herring Gull eggs, as well as TEQ levels determined in the Common Tern and the Herring Gull, were within the limits associated with embryo toxicity and impaired hatching success in fish-eating birds. The Common Gull was more sensitive to contamination than the above mentioned species, being HCB, p,p'-DDE and β-HCH related with reduced hatching success, and HCB with reduced overall reproductive success. The Black-headed Gull was not affected by environmental chemicals. But owing to the long-term exposition and additive and synergistic effects of single compounds, chronic effects should be not excluded.

Other environmental factors, such as food supply and availability, disturbance by man or predators, and weather, might affect the overall reproductive success of birds. In order to recognize effects caused by pollution, the influence of those factors have to be identified. Consequently, the monitoring of contaminants in bird eggs, carried out in the framework of the Trilateral Monitoring and Assessment Program (TMAP) for the entire Wadden Sea since 1998, using birds as accumulative indicators of environmental chemicals should be combined with the proposed TMAP-parameter "Breeding Success", in order to utilize birds as suitable indicators of chemical contamination and as an early warning system to monitor the ecological state of the Wadden Sea. The present study suggests several approaches to be considered in further investigations about the influence of chemicals on the bird populations.

1. Introduction

Common Gull colony on the „Pionier"-island, Elbe estuary (Photo: Institute for Avian Research)

Effects of chemical pollutants on avian reproduction have been well documented, especially in the past when the contaminant levels in the environment were higher than today (Ratcliffe 1970, Gress et al 1973, Blus et al. 1974, Blus 1982, Newton et al. 1989, Boudewijn & Dirksen, 1995). High levels of organochlorine compounds and heavy metals in birds have shown to influence negatively the overall reproductive success, not only by affecting the embryonic development, owing to the contaminant burden in eggs, but also chick development and fledging success, owing to additional intake of chemicals from contaminated environments via the food. Contaminants like DDT, PCBs, and dioxins have been linked with reproductive failure through eggshell thinning, biochemical and toxic effects resulting in reductions of Vitamin A and thyroid hormone levels, in mortality of embryos and small chicks, and in morphological aberrations in chicks (Fox 1976, Gilbertson 1983, Weseloh et al. 1983, Fox et al. 1991, Gilbertson et al. 1991). Furthermore, several authors have suggested that the reproductive success and the chick development may possibly be affected by organochlorines affecting pre-mating behavior, e.g. nest building (McCarty & Secord 1999) and/or reducing parental care of highly polluted individuals, which should increase the mortality risk by predation (intra- and interspecific), starvation, and hypothermia (Kubiak et al. 1989, Dirksen et al. 1995, Bustnes et al. 2001).

Also in Germany, overall reproductive success and abundance of bird populations have been negatively affected by environmental pollution (Becker et al. 1993, Denker et al. 2001, Schillig & Wegner 2001). However, contamination of seabirds and raptors by OC and heavy metals have become considerably lower over the last years, and are nowadays below the threshold levels known to affect wild life (e.g. Becker et al. 2001). When the concentration of a specific chemical substance reaches or exceeds the threshold level of toxicity, it is possible to analyze the causation of a particular effect, but when the toxicant levels are below hazardous levels and they are not associated with observable effects (e.g. lethality or malformations in chicks), it is difficult to differentiate the effect of chemicals from other factors that also affect the population dynamic. However, even low concentrations of single compounds of a pollutant mixture may injure reproduction by synergistic interactions (Wachs 1994, Busch 1996). Thus, long-term exposition to chemical mixtures could play an important role affecting the reproduction and dynamics of bird populations. Accordingly, the implementation of long-term monitoring of breeding success of birds combined with chemical pollution monitoring is very important in order to understand the interactions between organisms, contaminant levels and other biotic and abiotic factors, since they will throw light on the recovery of populations and communities after environmental perturbations. Consequently, as has been recommended by Becker et al. (2001), the monitoring program "Monitoring Pollutants in Coastal Bird Eggs in the Wadden Sea" (Becker et al. 1998, Becker et al. 2001) should be combined with the proposed TMAP-parameter "Breeding Success" (Thyen et al. 1998), in order to utilize birds as sensitive indicators of chemical contamination and as an early warning system to monitor the ecological state of the Wadden Sea.

In this sense, this study aims to determine possible effects of chemical contamination on the reproduction of common and widespread seabirds breeding at the German Wadden Sea coast in the mid 1990s. The species considered were the Common Tern (*Sterna hirundo*), the Herring Gull (*Larus argentatus*), the Common Gull (*Larus canus*), and the Black-headed Gull (*Larus ridibundus*), which are abundant on the Wadden Sea coast (Spaans 1998, Südbeck & Hälterlein 1999, Rasmussen et al. 2000). These bird species are top-predators of the aquatic system, and therefore they tend to accumulate lipophilic chemical contaminants, which, during the breeding season, will be eliminated through the eggs and transferred finally to the hatchlings, affecting the reproductive success of the populations. This study was carried out using three different approaches: First, eggs of selected breeding pairs were analyzed for organochlorine compounds and for the heavy metal mercury; in addition reproductive success and development of chicks in those samples-nests, from which eggs were taken for chemical analyses, were studied. This approach is based on the method "sample egg technique", which provides hints to critical residues of pollutants that negatively affect nest success (Blus et al. 1974, Blus 1984, Henny et al. 1984, Becker et al. 1993). As the overall reproductive success in a specific colony and area may depend on the degree of chemical contamination, a second approach was chosen: breeding colonies from highly polluted areas at the Elbe Estuary and from adjacent areas in the Wadden Sea characterized by lower contamination have been selected and compared with respect to their reproductive success, in order to detect possible effects of different local contaminant levels on reproduction. Finally, as the bird species breeding in the Wadden Sea differ in the degree of contamination with environmental chemicals (Mattig et al. 2000) and may differ in the degree of sensitivity to contaminants (Neuman & Blokpoel 1996, Ryckman et al. 1997), a third approach was chosen: Several species were selected in order (i) to investigate differences in sensitivity and (ii) to evaluate their suitability as bioindicators.

2. Material and Methods

2.1 Areas of Study

During 1995 and 1996, breeding colonies located at highly and lowly polluted areas of the Wadden Sea coast (Elbe Estuary and Jade Bay, respectively) were selected to study the influence of chemical contaminants on the reproductive biology and on the development of juveniles (Fig. 1 and Table 1). Common Terns were investigated only in 1996, at the Elbe Estuary in Neufelder Koog and on Minsener Oog Island at the Jade Bay. Herring Gulls were only studied in 1995, the breeding colonies were located on Pionier Island (at the Elbe Estuary near Hamburg) and on Mellum Island (Jade Bay). Common Gull and Black-headed Gull colonies were studied in 1995 and 1996, on the Pionier Island and at Augustgroden (Jade Bay), respectively.

2.2 Collection of Egg Samples

One egg was collected under license from selected and marked nests (Table 1). The second egg of a clutch was taken for chemical analyses, representing the contamination of the clutch (for details and discussion see Becker et al. 1991). Because egg levels reflect the contamination of the egg-laying female (e.g. Becker et al. 1989, Lewis et al. 1993), the eggs indicate the current contamination of the females breeding in the respective area and year. The eggs were frozen at –18°C until they were analyzed.

2.3 Reproductive Parameters and Body Mass Development of Chicks

All nests found in a selected area of each colony (those with higher nest density) were considered to study reproductive biology (Table 1). The nest checks were performed according to Thyen et al. (1998) and Wagener (1998) and carried out every two days during the first hours of the day to avoid heating of eggs and/or chicks. Each nest was marked by a numbered stick and eggs were marked with respect to laying sequence. Laying date (date of finding the first egg minus 1 day) and hatching date were determined for all individuals. Chick growth rates were only recorded at nests enclosed with a metal mesh (50 cm of height). The mesh was buried approximately 10 cm into the ground to avoid that the chicks escaped before fledging. The nests of Common Gulls, Black-headed Gulls and in part of Common Terns, were enclosed collectively, since they nest aggregated. On the other hand, Herring Gull nests were individually enclosed, because of large inter-nest distance.

2.4 Definitions

The following reproductive parameters are considered: clutch size (number of eggs/clutch), brood size (number of hatched chicks/clutch), breeding success (number of fledged chicks/clutch), hatch-

Table 1:
Bird species, colony sites, years of study, number of nests and eggs produced. Besides, the number of eggs taken for chemical analyses and the number of the nests, from which reproductive and chemical date are available, are presented.

Species	Colony	Year	Number of nests	Number of eggs	Eggs analyzed	Nests with reproductive data and chemical data
Common Tern	Elbe Estuary (Neufelder Koog)	1996	20	56	11	11
	Jade Bay (Minsener Oog)	1996	18	46	10	-
Herring Gull	Elbe estuary (Pionier Island)	1995	105	258	28	28
	Jade Bay (Mellum)	1995	12	36	12	12
Common Gull	Elbe estuary (Pionier Island)	1995	70	169	22	22
		1996	17	49	8	8
Black-headed Gull	Jade Bay (Augustgroden)	1995	25	63	10	10
		1996	16	39	10	6

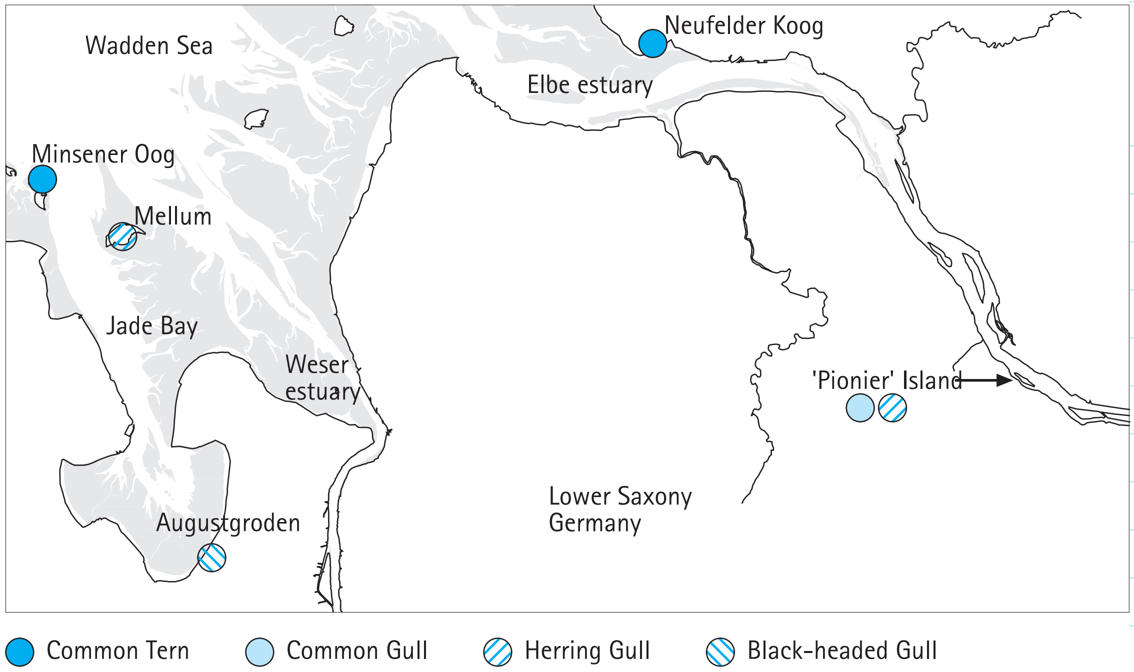

Figure 1: Map of the German Wadden Sea coast and geographical location of the study areas.

ing success (number of hatched chicks in % of all eggs), fledging success (number of fledged chicks in % of hatched chicks), and reproductive success (number of fledged chicks in % of all eggs). Considering the body mass development of chicks, further parameters were determined: Linear growth rate of all chicks, maximum body mass, fledging mass, and fledging age. The linear growth rate was defined as the increase of body mass during the phase of linear growth, which is different for each species (Thyen et al. 1998). In Common Tern nestlings, the phase of linear growth was defined 3-13 d, in Herring Gull at an age of 5-25 d, in Common Gulls at an age of 5-21 d, and in Black-headed Gulls at an age of 5-15 d. Maximum mass corresponds to the highest body mass during the development of fledged chicks (g), fledging mass is the last mass record before fledging (g), and fledging age the last age on record before fledging (d).

2.5 Chemical Analyses

The eggs were analyzed at the University of Applied Sciences, Wilhelmshaven, Germany. The homogenate of the yolk and the white of egg was used for chemical analyses. All concentrations are given in ng·g^{-1} fresh weight of egg content.

Mercury determination: 100 mg of the homogenated egg was prepared with a mixture of nitric acid, chloric acid and perchloric acid in a partly closed test tube according to Kruse (1979). An atomic absorption spectrometer (FIMS-400, Perkin Elmer) with an integrated flow injection module of the FIAS series was used for the measurements (Sommer et al., 1997). The determination limit was 0.1 ng·g^{-1}.

Organochlorine determination: Hexachlorobenzene (HCB), an isomer mixture of Hexachlorocyclohexane (ΣHCH) consisting of a, b, and g-HCH (lindane), and Σ DDT including the metabolites o,p'-DDT, p,p'-DDT, o,p'-DDD, p,p'-DDD, o,p'-DDE, and p,p'-DDE were analyzed. Furthermore, 62 congeners of polychlorinated biphenyls were determined (ΣPCB, for the whole spectrum of congeners examined see Becker et al., 2001). Two grams of each homogenated egg was dried with sodium sulfate, cleaned with a silica gel filled column, eluted with n-hexane:dichloromethane (8:2), evaporated and taken up in 250 ml toluene. A GC HP 5890, series II coupled to a mass selective HP 5971 (electron impact ionization, SIMmode) with helium as carrier gas was used for the measurements. A HT-5-column from SGE with a length of 25m was used for the separation (Sommer et al., 1997). The limit of determination varied between 0.3-0.4 ng·g^{-1}for single organochlorines, and for p,p'-DDT it was 0.9 ng·g^{-1}. The identification and quantification of pesticides and CB congeners was achieved according to Büthe & Denker (1995). It was possible to determinate 41 of the 62 PCBs separately. The other 21 eluate together within nine peaks with two PCBs and one with three PCBs

(Becker et al., 2001). The value ΣOHa represent the sum of all analyzed organochlorine compounds (ΣPCB, HCB, ΣDDT , and ΣHCH).

Furthermore, bird-specific 2,3,7,8-TCDD toxic equivalency factors (TEF) proposed by the World Health Organization (van den Berg et al., 1998) were used to estimate the toxic equivalents (TEQs) of non- and mono-ortho PCB congeners detected in eggs of the considered bird species. Non-ortho congeners detected were PCB126 and PCB169, and mono-ortho congeners PCB105, PCB114, PCB118, PCB123, PCB156, PCB157, PCB167, and PCB189.

2.6 Statistical Methods

Contaminant values in eggs were log-transformed (log n + 1) to achieve homogeneity of variances and normal distribution. Variation of the chemical concentrations in eggs between breeding colonies or between years was analyzed by t-tests. Reproductive parameters and growth of chicks were compared between breeding colonies or between years using Mann-Whitney tests. Significant differences in the fate of the chicks between breeding colonies or years were determined using c^2-tests or Fisher's exact tests. Only those nests where one egg for chemical analyses was taken were considered in order to estimate the effects of chemical pollutants on the reproductive parameters and on the body mass development of chicks (Table 1). Relationships between chemical pollutants and reproductive parameters (hatching success, fledging success and reproductive success) were tested comparing the chemical levels in eggs between unsuccessful and successful nests using t-tests and ANOVA with post-hoc Scheffé tests, and in some cases non-parametric tests (Kruskal-Wallis). These comparisons were carried out only if n was ≥ 3. Possible negative effects of pollutants on the increase of body mass of nestlings were ascertained by means of Spearman's rank-correlation (n = number of the chicks). Results were considered as significant at p-values < 0.05, < 0.01 (highly significant), and < 0.001 (very highly significant). All tests were conducted two-tailed by SPSS 8.0 for Windows.

Sampling site „Pionier"-island in the Elbe estuary (Photo: Institute for Avian Research)

3. Results

3.1 Chemical Contaminants in Bird Eggs

The highest concentrations of mercury were found in Common Tern eggs followed by Herring Gull eggs, whereas Common Gull and Black-headed Gull eggs displayed the lowest levels. The contamination with organochlorines (ΣOHa) was higher in Common Terns and Herring Gulls, Black-headed Gulls showed intermediate levels and Common Gull eggs exhibited a lesser contamination with these chemicals (Table 2).

In the case of Common Tern and Herring Gull eggs, significant differences in the concentrations of all measured chemicals were found between breeding colonies from the Elbe Estuary and the Jade Bay, the eggs collected at the Elbe being always more contaminated than those from the Jade Bay (Table 2). Considering the levels of single contaminants, at both breeding sites, PCB congeners with 5 to 7 chlorine atoms represented over 90% of the SPCB. In Common Terns and Herring Gulls SDDT corresponded mainly to p,p'-DDE (more than 90% of the total DDT contamination). Furthermore, both bird species displayed the same pattern of HCH contaminations, at the Elbe, ΣHCH was mainly represented by b-HCH (more than 80%), whereas at the Jade Bay, similar proportions of b and g isomers were observed.

Common Gull eggs from the Elbe Estuary collected in 1995 were statistically higher contaminated with ΣPCB, HCB, and ΣOHa than the eggs sampled in 1996 (Table 2). The samples from both years displayed the same patterns of the PCB mixture. Although in the case of ΣHCH no inter-year differences were observed, the proportions of β- and γ-HCH varied: in 1995, β-HCH represented approximately 81% and γ-HCH 18%, and in 1996, the proportions were 72% and 28%, respectively.

Black-headed Gull eggs from the Jade Bay were contaminated similarly with the analyzed chemicals in 1995 and 1996 (Table 2). Nevertheless, the PCB mixture was different between years, in 1995, corresponding mainly to congeners with 6, 7, and 8 chlorine atoms, whereas in 1996 to PCBs with 4 and 5 chlorine atoms. In 1995 and 1996, ΣHCH did consist exclusively of β-, and γ-HCH, which were found in similar proportions.

3.2 Reproductive Success

Common Terns breeding at the Elbe Estuary and at the Jade Bay exhibited a similar clutch size and hatching success, but the brood size was significantly higher at the Jade Bay (Table 3). Breeding success, fledging success and reproductive success were higher at the Elbe Estuary than at the Jade Bay (Table 3). Egg losses at the Jade Bay represented only 6.5% of the laid eggs, but 20% at the Elbe. At the Elbe, 9.5% of the eggs disappeared as a result of predation and in 4.8% embryos died. At the Jade Bay, 2.2% of the eggs were lost by unknown causes and 4.3% were unfertilized eggs. With respect to the fate of the chicks,

Table 2: Average concentrations of chemical contaminants (arithmetic mean ± 1 s.d.) found in eggs of Herring Gulls, Common Terns, Common Gulls, and Black-headed Gulls breeding on the German North Sea coast. Differences in the chemical concentrations between breeding colonies were tested parametrically using t-tests. p-values are presented. n.s.: not significant, * p<0.05, ** p<0.01, and *** p<0.001.

		Hg	ΣPCB	HCB	ΣDDT	ΣHCH	ΣOHa
Common Tern	Elbe Estuary (N=11)	1806.8 ± 503.9	2838.0 ± 542.1	372.3 ± 83.5	488.4 ± 110.1	13.3 ± 2.5	3712.0 ± 707.6
(1996)	Jade Bay (N=10)	339.7 ± 109.1	1490.1 ± 446.4	20.9 ± 6.2	125.3 ± 40.4	6.5 ± 2.6	1642.6 ± 485.8
	p	***	***	***	***	**	***
Herring Gull	Elbe Estuary (N=28)	934.7 ± 601.6	2992.5 ± 1519.5	185.6 ± 135.3	607.8 ± 370.6	30.8 ± 19.7	3818.3 ± 1975.4
(1995)	Jade Bay (N=12)	163.1 ± 102.6	1622.8 ± 1081.5	11.3 ± 10.6	70.5 ± 90.4	11.2 ± 2.4	1716.6 ± 1168.3
	p	***	**	***	***	***	***
Common Gull	1995 (N=22)	109.7 ± 42.0	445.0 ± 178.2	35.0 ± 16.7	98.7 ± 52.1	6.5 ± 8.5	585.2 ± 218.1
(Elbe Estuary)	1996 (N=8)	80.8 ± 31.0	255.9 ± 63.3	23.1 ± 3.9	138.8 ± 144.0	5.7 ± 3.8	423.4 ± 153.4
	p	n.s.	**	*	n.s.	n.s.	*
Black-headed Gull	1995 (N=10)	73.4 ± 28.2	756.2 ± 506.5	8.3 ± 4.5	203.0 ± 284.0	6.5 ± 5.1	974.9 ± 644.1
(Jade Bay)	1996 (N=10)	104.4 ± 44.7	785.0 ± 221.5	15.0 ± 11.2	144.7 ± 127.4	8.5 ± 2.5	953.2 ± 307.6
	p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Table 3: Reproductive parameters of each colony are presented. The clutch size represents the number of eggs per clutch ± 1 s.d. Brood size corresponds to the hatched chicks per clutch ± 1 s.d. Hatching success is the percent of hatched chicks from all produced eggs. Nest differences were tested non-parametrically with Mann-Whiney tests. p-values are presented. n.s.: not significant, * p<0.05, ** p<0.01, and *** p<0.001.

Species	Colony	Year	Clutch size	Brood size	Hatching success (%)	Breeding success	Fledging success (%)	Reproductive success (%)
Common Tern	Elbe (N=20)	1996	2.7 ± 0.7	1.8 ± 0.4	87.5	1.3 ± 0.8	72.5	63.3
	Jade (N=18)	1996	2.6 ± 0.6	2.4 ± 0.7	95.4	0.6 ± 0.5	33.3	30.6
	p		n.s.	**	n.s.	**	**	*
Herring Gull	Elbe	1995	2.5 ± 0.7 (N=105)	1.6 ± 0.5 (N=22)	17.0 (N=105)	0.3 ± 0.7 (N=22)	13.6 (N=22)	2.9 (N=105)
	Jade (N=12)	1995	3.0 ± 0.0	1.8 ± 0.4	91.7	1.3 ± 0.8	70.8	62.5
	p		**	n.s.	***	***	**	***
Common Gull	Elbe	1995	2.4 ± 0.8 (N=70)	1.6 ± 0.5 (N=23)	25.0 (N=70)	0.4 ± 0.6 (N=23)	30.4 (N=23)	7.1 (N=70)
		1996	2.9 ± 0.3 (N=17)	1.7 ± 0.5 (N=13)	60.8 (N=17)	0.5 ± 0.5 (N=13)	30.8 (N=13)	15.7 (N=17)
		p	*	n.s.	**	n.s.	n.s.	*
Black-headed Gull	Jade	1995	2.5 ± 0.8 (N=25)	2.1 ± 0.6 (N=17)	62.0 (N=25)	1.2 ± 0.9 (N=17)	61.8 (N=17)	38.7 (N=25)
		1996	2.4 ± 0.7 (N=16)	1.7 ± 0.6 (N=11)	58.3 (N=16)	0.7 ± 1.1 (N=11)	31.8 (N=11)	19.8 (N=16)
		p	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

more Common Tern chicks survived and fledged at the Elbe Estuary than at the Jade Bay (p<0.001, Fisher's exact test; Table 4). The number of dead chicks was significantly higher at the Jade Bay, but the proportion of predated chicks was similar in both colonies.

The mean clutch size of Herring Gulls breeding at the Elbe Estuary was significantly higher than that found at the Jade Bay, whereas the brood size did not significantly vary between colonies (Table 3). In contrast, Herring Gulls breeding at the Jade Bay had significantly higher hatching success, breeding success, fledging success, and reproductive success than the colony situated at the Elbe Estuary. In 1995 and 1996, Herring Gulls and Common Gulls breeding at the Elbe Estuary were intensively predated by a Red Fox family (*Vulpes vulpes*). In 1995, 51.3% of the Herring Gull eggs were predated and 32.7% disappeared for unknown causes. In 1996, Herring Gulls breeding at this place were totally predated, only one egg hatched successfully and the chick disappeared before fledging. Considering the fate of the chicks, in 1995, a higher proportion of Herring Gull fledglings was registered at the Jade Bay than at the Elbe Estuary (c^2= 21.018, d.f.=2, p<0.001; Table 4). The proportion of chicks dead by starvation, hypothermia or diseases was similar at both colonies (approximately 32%; Table 4). At the Jade Bay, predation was not observed, unlike at the Elbe Estuary, where 50% of the chicks were predated (Table 4).

Table 4: Number and fate of chicks in Herring Gulls, Common Terns, Common Gulls, and Black-headed Gulls at different colony sites in 1995 and 1996.

	Common Tern		Herring Gull		Common Gull		Black-headed Gull	
	1996		1995		Elbe		Jade	
	Jade	Elbe	Jade	Elbe	1995	1996	1995	1996
Chicks hatched	43	36	22	36	36	22	35	19
Chicks fledged[a]	10 (23.3)	25 (69.4)	15 (68.2)	6 (16.7)	10 (27.8)	6 (27.3)	21 (60.0)	10 (52.6)
Chicks predated[a]	4 (9.3)	3 (8.3)		18 (50.0)	12 (33.3)	4 (18.2)	4 (11.4)	3 (15.8)
Chicks dead[a,b]	25 (58.1)	8 (22.2)	7 (31.8)	12 (33.3)	12 (33.3)	12 (54.5)	10 (28.6)	6 (31.6)
other causes[a]	4 (9.3)				2 (5.6)			

[a] In parentheses, percent with respect to hatched chicks

[b] Starvation, hypothermia or disease

Common Tern breeding pair (Photo: Dietrich Frank)

Clutch size, hatching success, and reproductive success of Common Gulls breeding at the Elbe Estuary were significantly higher in 1996 than in 1995 (Table 3). On the other hand, brood size, breeding success, and fledging success were similar in both years (Table 3). As the colony of Herring Gull breeding at the Elbe, Common Gulls were also in 1995 predated by the foxes. During 1995, predation caused at least approximately 29% of egg losses, and 32% of the eggs disappeared for unknown causes. Other causes for losses in this colony were unimportant, because they only represented 3% of the total eggs laid in 1995. In 1996, there was no evidence of egg predation in this colony (e.g. by egg shell remains near the nests), only in case of Herring Gulls which were totally predated at the same place. Considering the chicks, the number of fledglings and predated chicks was similar between 1995 and 1996 ($p>0.05$, Fisher's exact tests; Table 4). Although the proportion of dead chicks in 1996 was higher than in 1995 (55% and 39%, respectively; Table 4), significant differences were not observed ($p>0.05$, Fisher's exact tests).

In case of Black-headed Gulls breeding at the Jade Bay, no significant differences in the reproductive parameters were observed between 1995 and 1996, although the values were always higher in 1995 than in the subsequent year (Table 3). The eggs were predated in 1995 and 1996 in similar rates (approximately 32% of the laid eggs), and in 1996, almost 10% of the eggs were lost by flooding. The proportions of fledged, predated, and dead chicks of Black-headed Gulls was similar in 1995 and 1996 (Table 4; $p>0.05$, Fisher's exact test).

3.4 Body Mass Growth of Chicks

During the phase of linear growth, Common Tern nestlings from the Elbe Estuary showed a higher mass increase than those growing at the Jade Bay ($p<0.001$, Mann-Whitney test; Fig. 2). The nestlings growing at the Elbe tend to reach higher maximum (129.4 g) and fledging masses (122.6 g) than at the Jade Bay (121.5 g and 116.1 g, respectively). Significant differences were found in fledging age: the chicks from the Elbe fledged at an age of 22.2 ± 1.6 d, whereas those from the Jade Bay fledged at more advanced age (29.7 ± 3.9 d; $p<0.001$, Mann-Whitney test).

The body mass of Herring Gull chicks from the Elbe Estuary and from the Jade Bay increased with similar rates during the phase of linear growth ($p>0.05$, Mann-Whitney test; Fig. 2). The mean linear growth rates were approximately 24.5 g·day^{-1}. Herring Gull chicks growing at the Jade Bay fledged at an age of 42 9.8 d, fledglings from the Elbe at an age of 36.2 ± 2.7 d ($p>0.05$, Mann-Whitney test). At both colonies, Herring Gull chicks reached similar maximum and fledging masses (approximately 850 g and 800 g, respectively).

In 1995 and 1996, the linear growth rates of Common Gull hatchlings from the Elbe were similar (approximately 15 g·day^{-1}, $p>0.05$, Mann-Whitney test; Fig. 2), but in 1996 the nestlings fledged earlier (in 1995 at an average age of 35.0 ± 3.2 d, in 1996, at an age of 31.7 ± 3.4 d; $p>0.05$, Mann-Whitney test). Also the maximum body mass and fledging mass were not statistically different between 1995 and 1996 (Mann-Whitney tests; in 1995 maximum body mass was 404.4 ± 58.2 g and in 1996, 396.2 ± 35.5 g; fledging mass was 381.9 ± 60.0 g in 1995, and 374.5 ± 27.9 g in 1996).

At the Jade Bay the growth rate of Black-headed Gull hatchlings did not show differences between 1995 and 1996 (about 10 g·day^{-1}, $p>0.05$, Mann-Whitney test; Fig 2). The maximum body mass was significantly higher in 1995 than in 1996 (260.3± 26.6 g and 225.8 ± 42.2 g, respectively; $p = 0.021$, Mann-Whitney tests). The fledging age was similar between years (26.0 ± 3.1 d in 1995, and 25.2 ± 4.3 d in 1996; $p>0.05$, Mann-Whitney test). The fledging mass was higher in 1995 than in 1996 (255.1 ± 25.7 and 211.6 ± 58.3 g, respectively; $p = 0.038$, Mann-Whitney test).

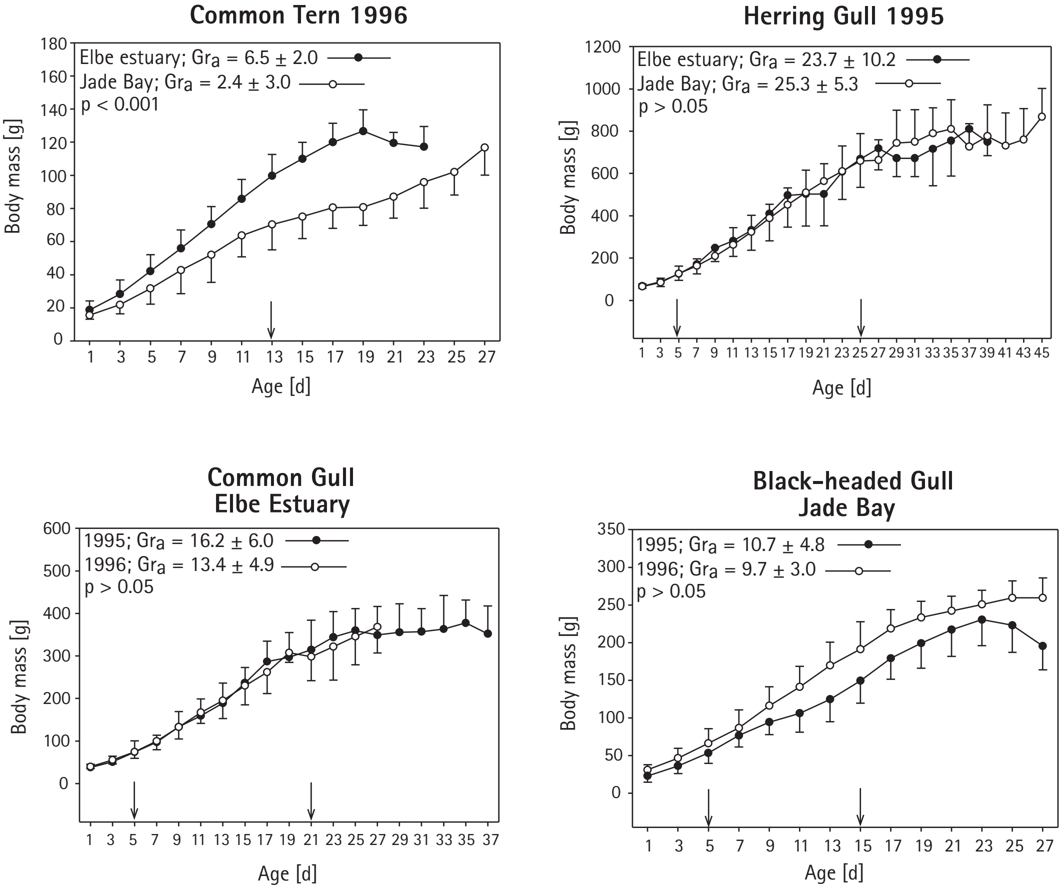

Figure 2: Body mass development of chicks of four coastal bird species and/or years. at different colony sites. Mean masses of each age group ± S.D. and mean growth rates with regard to all chicks during the period of linear growth (Gra in g/d ± S.D.) are presented. ¯ indicates empirical limits of the phase of linear growth, p-values differences in the growth rates (Mann-Whitney).

Table 5: Levels of chemicals contaminants in Common Tern eggs sampled at the Elbe estuary in 1996. The eggs were sampled in nests with different hatching success, fledging success and reproductive success, respectively. Differences between successful nests and nests of reduced success were tested using t-tests. Arithmetic mean of the chemical concentrations ± 1 S.D. are presented. p-values between groups are presented. n.s: not significant.

	Hatching success		Fledging success			Reproductive success		
	<50% (N=1)	100% (N=10)	≦50% (N=4)	100% (N=7)	p	≦50% (N=5)	100% (N=6)	p
Hg	1963.0	1791.2 ± 528.4	1697.5 ± 545.5	1869.3 ± 511.8	n.s.	1750.6 ± 487.1	1853.7 ± 558.8	n.s.
ΣPCB	2441.4	2877.7 ± 554.3	3075.1 ± 463.3	2702.6 ± 568.8	n.s.	2948.4 ± 491.2	2746.1 ± 610.2	n.s.
HCB	316.1	377.9 ± 85.8	423.7 ± 72.8	342.9 ± 78.8	n.s.	402.2 ± 79.3	347.4 ± 85.4	n.s.
ΣDDT	387.7	498.4 ± 110.6	539.4 ± 81.2	459.2 ± 119.1	n.s.	509.0 ± 97.7	471.2 ± 125.8	n.s.
ΣHCH	12.1	13.4 ± 2.6	15.5 ± 2.2	12.0 ± 1.7	*	14.8 ± 2.4	12.0 ± 1.8	n.s.
ΣOHa	3157.3	3767.5 ± 720.3	4053.6 ± 560.5	3516.8 ± 745.2	n.s.	3874.4 ± 629.5	3576.7 ± 797.6	n.s.

3.5 Relationships between Reproductive Parameters, Body Mass Development and Contaminants

The hatching success and the reproductive success of Common Terns breeding at the Elbe Estuary in 1996 were not related to the levels of chemical pollutants measured in their eggs (Table 5). In case of fledging success, eggs sampled in nests with lower success displayed slightly higher concentrations of ΣHCH than those eggs from successful nests (Table 5). Negative relations were determined between body mass development of chicks and levels of HCB, ΣDDT, p,p'-DDE, ΣHCH, and β-HCH (Table 6).

Table 6: Relationship between chemical concentrations in eggs and development of body mass in Common Tern chicks growing in the Elbe estuary in 1996. Mean concentrations of the contaminants (ng·g^{-1} fresh weight of egg content) and standard deviations are presented. For significant trends, Spearman rank coefficients (r_s) calculated on the basis of n chicks and p-values are presented. n.s: not significant. The analyses were carried on the basis of the raw data, but for a better representation, ranges of body mass growth are presented.

	Growth rates				
	chick lost weight ^{A} (N=1)	chick gained weight (5-7 g/day) ^{B} (N=5)	(7.1-9g/day) ^{C} (N=12)	R_s	p
Hg	1331.0	2026.0 ± 477.0	1837.1 ± 541.0	-0.07	n.s.
ΣPCB	2824.7	3041.9 ± 458.0	2693.2 ± 570.8	-0.35	n.s.
HCB	502.4	385.0 ± 76.1	340.0 ± 73.0	-0.63	**
ΣDDT	542.5	530.3 ± 104.2	454.7 ± 110.7	-0.55	*
ΣHCH	13.1	14.4 ± 1.0	12.3 ± 2.5	-0.60	**
ΣOHa	3882.7	3971.6 ± 618.9	3500.2 ± 734.2	-0.44	n.s.
p,p'-DDE	518.7	469.9 ± 80.7	409.4 ± 90.4	-0.51	*
β-HCH	13.1	12.8 ± 1.0	10.8 ± 1.7	-0.69	**

Table 7: Levels of chemicals contaminants in Herring Gull eggs sampled at Elbe estuary in 1995. The eggs were sampled in nests with different hatching success, fledging success and reproductive success. Differences between successful (with 100% success) and unsuccessful (without success) nests were tested using t-tests. Arithmetic mean of the chemical concentrations ± 1 S.D. are presented. For significant trends p-values are presented. n.s: not significant.

	Hatching success			Fledging success			Reproductive success		
	without (N=17)	with (N=11)	p	without (N=8)	with (N=3)	p	without (N=25)	with (N=3)	p
Hg	882.1 ± 670.3	1015.9 ± 496.4	n.s.	942.4 ± 383.6	1212.0 ± 798.7	n.s.	901.4 ± 585.9	1212.0 ± 798.7	n.s.
ΣPCB	3172.2 ± 1680.6	2714.7 ± 1255.1	n.s.	2999.9 ± 1373.0	1954.2 ± 292.1	n.s.	3117.0 ± 1561.9	1954.2 ± 292.1	n.s.
HCB	203.2 ± 161.7	158.3 ± 79.3	n.s.	170.8 ± 90.6	125.2 ± 22.1	n.s.	192.8 ± 141.6	125.2 ± 22.1	n.s.
ΣDDT	623.9 ± 399.9	582.9 ± 337.3	n.s.	659.5 ± 371.2	378.4 ± 21.5	n.s.	635.3 ± 383.5	378.4 ± 21.5	*
ΣHCH	33.5 ± 21.9	26.5 ± 15.7	n.s.	29.2 ± 18.0	19.5 ± 2.5	n.s.	32.1 ± 20.4	19.5 ± 2.5	n.s.
ΣOHa	4033.9 ± 2190.6	3485.0 ± 1629.9	n.s.	3862.7 ± 1779.9	2478.0 ± 321.0	n.s.	3979.1 ± 2032.2	2478.0 ± 321.0	*

Table 8: Relationship between chemical concentrations in eggs and development of body mass in Herring Gull chicks growing at the Elbe estuary in 1995. Mean concentrations of the contaminants (ng·g^{-1} fresh weight of egg content) and standard deviations are presented. For significant trends, Spearman rank coefficients (r$_s$), calculated on the basis of n chicks, and p-values are presented. The analyses were carried on the basis of the raw data, but for a better representation, ranges of body mass growth are presented. n.s.: not significant, * $p<0.05$, ** $p<0.01$, and *** $p<0.001$.

	Growth rates				
	0-20 g/day^{A} (N=5)	21-30 g/day^{B} (N=7)	31-40 g/day^{C} (N=4)	p**	r$_s$
Hg	1158.4 ± 414.0	969.3 ± 585.6	1150.5 ± 663.6	n.s.	0.27
ΣPCB	3597.1 ± 1814.4	2638.7 ± 1155.7	2025.1 ± 277.5	n.s.	-0.15
HCB	250.6 ± 93.5^{B,C}	124.4 ± 52.5^{A}	110.7 ± 34.1^{A}	*	-0.50*
ΣDDT	699.2 ± 374.9	535.9 ± 295.5	361.4 ± 38.2	*	-0.11
ΣHCH	44.2 ± 25.2	20.7 ± 4.9	18.1 ± 3.6	n.s.	-0.62**
ΣOHa	4595.5 ± 2287.4	3323.0 ± 1479.1	2516.3 ± 273.1	n.s.	-0.15
β-HCH	44.2 ± 25.2	19.7 ± 5.3	17.3 ± 2.8	n.s.	-0.65**

**For mercury and HCB pAnova < 0.05. Letters A,B,C represented the groups with different growth rates, and are used to show significant differences. ΣPCB, ΣDDT, ΣHCH, ΣOHa, and β-HCH were tested using Kruskal-Wallis.

Table 9: Relationship between chemical concentrations in eggs and development of body mass in Herring Gull chicks growing at Jade Bay in 1995. Mean concentrations of the contaminants (ng·g^{-1} fresh weight of egg content) and standard deviations are presented. For significant trends, Spearman rank coefficients (r$_s$), calculated on the basis of n chicks, and p-values are presented. n.s: not significant.

	Growth rates				
	0-20 g/day^{A} (N=3)	21-30 g/day^{B} (N=10)	31-40 g/day^{C} (N=2)	R$_s$	p$_{Spearman}$
Hg	120.3 ± 19.6	236.4 ± 102.6^{C}	54.0 ± 19.8^{B}	-0.24	
ΣPCB	1458.5 ± 145.3	2013.6 ± 1483.4	887.5 ± 79.5	-0.57	*
HCB	9.5 ± 2.6	13.6 ± 11.7	6.2 ± 3.6	-0.30	
ΣDDT	66.7 ± 12.8	105.2 ± 130.3	20.6 ± 0.4	-0.55	*
ΣHCH	12.8 ± 0.1	10.6 ± 2.6	9.2 ± 3.5	-0.41	
ΣOHa	1548.1 ± 159.5	2144.2 ± 1613.6	923.4 ± 86.3	-0.57	*

In case of Herring Gulls nesting at the Elbe Estuary, a significant relationship between reproductive success and levels of ΣDDT and ΣOHa was found: eggs from nests with 100% of reproductive success had lower levels of ΣDDT and ΣOHa than eggs from unsuccessful nests (without reproductive success, Table 7). Mean concentrations of ΣPCB, HCB and ΣHCH were always lower in nests with 100% hatching rate, although the differences were not statistically significant. On the other hand, in eggs from unsuccessful nests, mercury levels were lower, although not significant. The growth rates of Herring Gull chicks from the Elbe Estuary were negatively correlated with the levels of HCB, ΣHCH, and β-HCH. The levels of these chemicals were lower in nests with higher growth rates (Table 8).

In the Herring Gull colony from the Jade Bay, negative correlations between body mass growth of chicks and concentration of chemicals were observed in case of ΣPCB, ΣDDT, ΣOHa, mono-ortho-PCBs, di-ortho-PCBs, 3PCB$_{6Cl}$, and 3PCB$_{7Cl}$ (Table 9).

The hatching success of the Common Gulls breeding at the Elbe Estuary in 1995 was lower in nests where the eggs contained higher concentrations of HCB, ΣDDT and ΣHCH (Table 10). No relationships were observed between fledging success and concentration of chemicals in eggs (Table 11), but in 1995, the reproductive success was lower in nests whose eggs showed higher levels of HCB (Table 11). In 1996, fledging success and reproductive success were higher in nests with lower levels of ΣOHa (Table 11). In both years, no relationship between body mass development of chicks and concentration of chemicals was determined.

In 1995 and 1996, no interactions between reproductive parameters of Black-headed Gulls breeding at the Jade Bay and concentration of chemical in eggs were found. In both years also, the development of body mass of the chicks was not affected by chemicals.

Table 10: Levels of chemicals contaminants in Common Gull eggs sampled at the Elbe estuary in 1995. The eggs were sampled in nests with different hatching success, fledging success and reproductive success. Fledging success and reproductive success had the same values. Differences between successful and unsuccessful were tested using t-tests. Arithmetic mean of the chemical concentrations ± 1 S.D. are presented. For significant trends p-values are presented. n.s: not significant.

	Hatching success			Fledging success			Reproductive success		
	without (N=6)	≥50% (N=16)	p	without (N=7)	≥50% (N=9)	p	without (N=13)	≥50% (N=9)	p
Hg	115.5 ± 36.6	107.6 ± 44.7	n.s.	106.7 ± 24.5	108.2 ± 57.5	n.s.	110.8 ± 29.7	108.2 ± 57.5	n.s.
ΣPCB	478.5 ± 153.5	432.4 ± 189.7	n.s.	435.9 ± 191.0	429.7 ± 200.3	n.s.	455.5 ± 169.0	429.7 ± 200.3	n.s.
HCB	53.2 ± 15.1	28.2 ± 11.4	**	32.0 ± 10.0	25.2 ± 12.2	n.s.	41.8 ± 16.3	25.2 ± 12.2	**
ΣDDT	146.3 ± 63.9	80.9 ± 34.6	*	84.5 ± 17.7	78.0 ± 44.6	n.s.	113.0 ± 53.7	78.0 ± 44.6	n.s.
ΣHCH	12.2 ± 15.1	4.4 ± 2.7	*	4.2 ± 2.3	4.6 ± 3.0	n.s.	7.9 ± 10.7	4.6 ± 3.0	n.s.
ΣOHa	690.2 ± 228.5	545.8 ± 207.6	n.s.	556.5 ± 209.6	537.5 ± 218.4	n.s.	618.2 ± 220.3	537.5 ± 218.4	n.s.

	Fledging success *		
	0% (N=4)	≥50% (N=4)	p
Hg	66.8 ± 24.8	94.8 ± 33.1	n.s.
Σ PCB	279.3 ± 83.1	232.5 ± 31.5	n.s.
HCB	21.3 ± 1.1	24.9 ± 5.1	n.s.
Σ DDT	223.3 ± 170.5	54.4 ± 16.0	n.s.
Σ HCH	6.8 ± 4.2	4.6 ± 3.5	n.s.
Σ OHa	530.6 ± 154.5	316.3 ± 21.0	*

Table 11: Levels of chemicals contaminants in Common Gull eggs sampled at the Elbe estuary in 1996. The eggs were sampled in nests with different hatching success, fledging success and reproductive success. Fledging success and reproductive success had the same values. Differences between successful and unsuccessful were tested using t-tests. Arithmetic mean of the chemical concentrations ± 1 S.D. are presented. For significant trends p-values are presented. n.s: not significant.

3.6 Toxicological impact of non-, and mono-ortho-PCBs

Mean concentrations of toxic equivalents (TEQs) were considerably high in eggs of Common Terns sampled at the Elbe and at the Jade Bay and in Herring Gull eggs from the Jade Bay (Table 12). Statistically significant intersite or interyear differences were found in case of Herring Gulls, Common Gulls and Black-headed Gulls: Herring Gull eggs from the Elbe Estuary had higher concentrations of TEQs than eggs from the Jade Bay, and TEQs found in Common Gulls and Black-headed Gulls were higher in 1995 than in 1996 (Table 12).

Table 12: Average concentrations of toxic equivalents (TEQs) of non- and mono-ortho PCBs (arithmetic mean ± 1 s.d.; in pg·g^{-1}) found in Herring Gull, Common Tern, Common Gull, and Black-headed Gull eggs, breeding on the German North Sea coast. Differences were tested parametrically using t-tests. p-values are presented. n.s.: not significant, * p<0.05, ** p<0.01, and *** p<0.001.

		Sum of TEQs
Common Tern (1996)	Elbe Estuary (N=11)	198.7 ± 16.0
	Jade Bay (N=10)	192.6 ± 67.7
	p	n.s.
Herring Gull (1995)	Elbe Estuary (N=28)	197.2 ± 211.8
	Jade Bay (N=12)	33.9 ± 70.2
	p	*
Common Gull (Elbe Estuary)	1995 (N=22)	1.9 ± 0.7
	1996 (N=8)	1.3 ± 0.5
	p	*
Black-headed Gull (Jade Bay)	1995 (N=10)	62.5 ± 96.2
	1996 (N=10)	3.0 ± 0.7
	p	*

4. Discussion

In general, the effects of chemical contaminants on the reproduction of the studied species were of much lesser extent than effects of other environmental factors (e.g. disturbance by man or predators, food availability, weather). Nevertheless, some impacts of the chemical pollution were observed, both between low and highly contaminated areas and among species.

4.1 Contaminant Levels in Eggs

Owing to the transport of pollutants from industrial areas situated within the catching area of the river Elbe and to the constant release of contaminants deposited in estuarine sediments, the Elbe Estuary was recognized as a "hot spot" of contamination (Kausch 1996, Becker et al. 1998; Becker et al. 2001). Yet despite lowered inputs of chemicals into the North Sea through rivers and atmosphere, seabird eggs are clearly indicating distinct geographical trends in contamination today, with the hot spot Elbe Estuary persisting to date (Becker et al. 2001). Consequently, the birds breeding at the Elbe have been highly exposed to persistent chemicals, which are bioaccumulated throughout the aquatic food chains. Also at the Jade Bay, the burden of chemical contaminants was higher in the past, although its environments and biota have been historically less exposed to pollution than at the Elbe (Becker et al. 2001). The emissions of pollutants and therefore the total burden of the Elbe, including those of its biological communities, have significantly decreased during the last decade (Haarich 1996, Bakker et al. 1999). This decrease has been reflected by the contamination of seabirds eggs in the Wadden Sea, which have revealed a continuous reduction in the levels of most organochlorines and mercury from the early 1990s onwards (Becker et al. 1998, 2001). According to the spatial pattern of contamination, with "hot spots" in the estuarine areas, the results of this investigation show that the eggs of Common Tern and Herring Gull sampled at the Elbe were significantly higher contaminated by mercury and organochlorines than those from the Jade Bay. The contaminant levels in Common and Black-headed Gull eggs were distinctly lower than those found in eggs of Herring Gulls and Common Terns, and moreover, the organochlorine levels of Common Gulls from the Elbe have been lower than those measured in Black-headed Gull eggs from the Jade Bay (cf. Mattig et al. 2000).

Such differences in the chemical contamination between species might be due to interspecific differences in feeding strategies and/or in differential rates of chemicals' accumulation, metabolism, and elimination (Becker et al. 1998, Thyen & Becker 2000). Common Terns and Herring Gulls are top-predators of aquatic food chains. The terns feed exclusively on fish (Becker et al. 1987, Frank & Becker 1992), and Herring Gulls in the Wadden Sea mostly feed on mussels, fish, crustaceans, and garbage (Goethe 1980, Hüppop, 1987). For the Common Gulls breeding at the Elbe, fruits of cultures located in the neighborhoods, terrestrial worms and small mice constitute the main food (pers. obs., Del Hoyo 1996), whereas Black-headed Gulls have a more general diet including mainly terrestrial and marine worms, insects but also fish and crustaceans (Brandl 1987, Gorke 1990). Considering the diets and the chemical levels found in eggs, the results confirm that bird species that feed on fish accumulate higher proportions of persistent chemicals, being therefore more suitable to be used as bioindicator of environmental pollution.

4.2 Effects of Pollutants on Reproductive Parameters

Effects of PCBs on avian reproduction have been frequently studied, and concentrations of more than 3,000 to 5,000 $ng \cdot g^{-1}$ can influence the bird reproduction (Lorenz & Neumeier 1972). Becker et al. (1993) found that although the hatching success of Common Tern colonies breeding at highly and low contaminated sites at the German Wadden Sea coast (Hullen at the Elbe Estuary and Augustgroden at the Jade Bay, respectively) was similar, PCB contents of unhatched eggs (7,600 $ng \cdot g^{-1}$) sampled at the Elbe were significantly higher than in eggs collected at random (5,100 $ng \cdot g^{-1}$). In this study, PCB levels in Common Tern eggs from the Elbe were slightly lower than those levels considered as critical for avian reproduction, and were not linked with reproductive parameters or chicks' growth rates. At the Jade Bay, PCB levels in eggs were significantly lower than those found at the Elbe, therefore negative effects on the reproduction are not expected. Also Herring Gull eggs from the Elbe were more contaminated with PCBs than eggs from the Jade Bay, but no relationships between PCB levels and reproductive parameters were detected. However, PCB levels were linked with body mass development of Herring Gull chicks reared at the Jade Bay, although the tendency was weak and not necessarily indicates causality. On the other hand, the same tendency was observed in Herring Gull chicks growing at the Elbe, where chicks from nests with high PCB levels displayed lower growth rates (n.s.).

The congeners that specifically might affect the development of chicks were those with 6 and 7 chlorine atoms, and mono- and di-ortho PCBs. The toxicity of the PCBs depends on the chlorination degree (the toxicity increases with rising chlorine number) and on the number of chlorine atoms in ortho-positions: several authors have concluded that congeners with smaller number of chlorine atoms in this position show a higher toxicity (e.g. Parkinson & Safe 1987). Mono- and di-ortho PCBs are included among the more toxic PCB congeners owing to their coplanar structure, similar to those of dioxins and dibenzofurans, and their ability to bind to the Ah receptor. The most common adverse effects of PCBs on the avian reproduction are reduction of egg hatchability, and chick growth rates (CCME 2001). Nevertheless, in order to estimate the real effect of PCBs on chick development, the change in PCB concentrations and contents from egg to chick due to degradation, elimination or intake with food must be considered, since egg contents affect mainly the early development of chicks (Becker & Sperveslage 1989). Therefore, further studies considering not only the development of the chicks, but also their diets might throw light on possible effects of PCBs on chick growth.

With respect to the toxicity of the PCB mixture (based on 1998 WHO, van den Berg et al. 1998) found in the eggs of the studied bird species, influences of chemical pollution on the overall reproductive success, and chick growth rates can be expected in the case of Common Terns (breeding at the Elbe Estuary and at the Jade Bay) and Herring Gulls (from the Elbe Estuary). Hence, although the concentrations of pollutants are lower in comparison to other sites and to previous years at the Wadden Sea coast, the estimated toxicity of the PCB mixture was within the limits associated with embryo toxicity and impaired hatching success in fish-eating birds (90 – 4000 pg TEQ$\cdot g^{-1}$, Hoffman et al. 1996). However, the TEQ levels found in this study are lower in comparison with several published data, e.g. Elliot et al. (1996) suggested an LOAEL of 210 pg TEQg^{-1} wet weight in Bald Eagle eggs for CYP1A induction, Powell et al. (1997) found that the injection of the White leghorn chicken eggs with an extract of Double-crested Cormorant eggs containing approximately 322 pg$\cdot$TEQ$\cdot g^{-1}$ wet weight resulted in 77% mortality at hatch, and Tillit et al. (1992) determined mortality rates of about 40% in Double-crested Cormorant eggs from the Great Lakes with about 350 pg TEQ$\cdot g^{-1}$ wet weight. In view of the fact that the differences in the TEQ levels causing negative effects reflect interspecific differences in the ability to transform and to eliminate xenobiotic compounds, threshold TEQ levels must be carefully considered to evaluate possible effects on the reproduction of a bird species.

Also HCB, ΣHCH, ΣDDT showed some relation to reproductive failure and/or to low chick growth rates at the Elbe Estuary. Van Birgelen (1998) has postulated that HCB is able to bind to the aryl hydrocarbon (Ah) receptor producing dioxin-like effects; therefore adverse effects on the reproduction and development of birds could be expected. These dioxin-like effects might explain the inverse relation between HCB levels and reproductive parameters hatching-, and reproductive success of Common Gulls in 1995 as well as the negative correlation between HCB and body mass development of Common Tern and Herring Gull chicks. Nevertheless, literature data about toxic HCB effects on avian reproduction vary widely, both intra- as interspecifically, and they are extremely high in comparison with the levels found in eggs from the Elbe. Wiemeyer (1996) reviewed several studies and reported that the effects of HCB on reproduction of birds vary widely among species, e.g. in one exposure study the egg hatchability of Japanese quail (*Conturnix conturnix japonica*) with an estimated HCB burden of 35 ppm was not affected, while in another study, hatchability of chicken eggs containing 100 ppm was normal.

In case of HCH, the effects caused by the HCH mixture from those caused by single isomers have to be separated. The technical mixture of HCH consists of at least 5 isomers, whose toxicity is variable (approximately 60–70% α-HCH, 5–12% β-HCH, 10–15% γ-HCH, 6–10% δ-HCH, and 3–4% ϵ-HCH). With respect to acute exposure, g-HCH is the most toxic, followed by α-, δ-, and β-HCH. With chronic exposure, however, β-HCH is the most toxic followed by α-, γ-, and δ-HCH. With chronic exposures, the increased toxicity of β-HCH is probably due to its longer biological half-life in the body, its accumulation in the body over time, and thus its higher bioconcentration factor (Willet et al. 1998). For these reasons, β-HCH is still found in bird eggs, although in low levels. There are no studies of the effects of this chemical on the reproduction and development of birds; however, some studies in rats have found a decrease in body weight after oral exposition to β-HCH (van Velsen et al. 1986). ΣHCH was inversely correlated with the hatching success of Common Gulls, the fledging success of Common Terns, and with the growth rates of Common Terns and Herring Gulls. The developmental effects observed in Common Terns and Herring Gulls were mainly linked with the levels of β-HCH. Nevertheless, effects of HCH on the hatching success, i.e., on the embryonic development, and on chick growth and fledging success are not known.

Many studies have associated high concentrations of p,p'-DDE with significant egg shell thinning, embryo toxicity and reduced reproductive output in a variety of species including gulls, terns, raptors and cormorants (see reviews, e.g. Moriarty et al. 1986, Furness 1993). Becker et al. (1991) and Becker et al. (1993) have not found differences in the shell-thickness and strength of Common tern eggs neither between highly nor low DDT polluted sites: 670 $ng \cdot g^{-1}$ in eggs from the Elbe and 230 $ng \cdot g^{-1}$ in eggs sampled at the Jade Bay (both concentration are given in fresh weight of egg content), nor between unhatched eggs and eggs sampled at random at the Elbe (17,500 ng and 20,300 ng total amount in eggs, respectively). In the present study, parameters of shell quality of eggs (eggshell weight and thickness) of all considered species was not impaired by the p,p'-DDE levels (unpublished data). The threshold range of p,p'-DDE in bird eggs associated with impairment of reproduction varies between 500 to more than 6,000 $ng \cdot g^{-1}$, and in Herring Gulls breeding at the Elbe, p,p'-DDE levels found in their eggs were within this range, which might explain the lower overall reproductive success in nests with higher levels of this metabolite. Consequently, negative effects cannot be ruled out, and further studies are recommended in order to assess the impact of DDT on Herring Gulls at the Elbe.

Furthermore, DDT levels (determined mainly by the isomer p,p'-DDE) possibly affected the hatching success of Common Gulls, as well as chicks' growth of Herring Gulls and Common Terns. DDT and its metabolites were banned in West Europe during the 1970s but was still used in several countries of East Europe during the 1980s. The presence of p,p'-DDE has been associated usually to "old" DDT contamination (Streit 1991), which could explain the higher proportions of this metabolite – in comparison to the other metabolites – found in the eggs. A reduction in the early post-hatching survival of chicks after oral exposures to DDT or DDE in maternal birds has been the most consistently reported developmental effect (Logcore et al. 1971). While the mechanism of DDT-induced reduced chick survival has not been thoroughly studied, investigators have hypothesized that increased body burden of DDT in chicks may cause direct toxicity, or that reduction in parental care of treated birds may result in chick malnutrition and poor survival (Keith & Mitchell 1993). Other developmental effects in birds included a decreased ability to thermo regulate and behavioral alterations in chicks of treated parental birds (Vangilder & Peterle 1980).

Mercury levels of 0.5–6 ppm in eggs have been associated with decreased egg weight, malformations, lowered hatchability, and/or altered behavior in various species (Eisler 1987, Burger & Gochfeld 1997). Although the mercury levels found in Common Tern and Herring Gull eggs from the Elbe were within this range, no relationship between mercury and reproductive parameters or chick development was observed. Furthermore, although mercury pollution has been historically high, especially at the Elbe (Haarich 1996, Becker et al. 2001), effects of this heavy metal on bird reproduction have been not observed (Becker et al. 1993). The results of this study coincide with these results: at the Elbe as well as at the Jade Bay the relationship between mercury levels and bird reproduction were not observed.

4.3 Confounding Factors that Affect the Overall Reproductive Success

Because of confounding factors that affect reproduction of birds, as predation, food availability, and weather, etc., it is difficult to recognize and discriminate the effects of chemical contaminants on reproduction. Predators were an important factor determining the overall reproductive success in Herring and Common Gulls breeding at the Elbe. Common Gull nests were mainly concentrated in a relatively small area of the island Pionier Island, being the distance among nests not larger than 2 m, whereas Herring Gull nests were distributed all over the island (although concentrated at the northwest side and not where Common Gulls breed). The distance among Herring Gull nests varied between 10–15m, being smaller at the edges of the island. Several authors have suggested that nest distance may be related to a large body size of the birds: e.g. in Great Black-backed Gulls

(*Larus marinus*) and Glaucous Gulls (*Larus hyperboreus*), low nest densities reduce the risk of nest predation by other birds as well as the intraspecific killing of chicks by cannibalistic neighbors (Butler & Trivelpiece 1981, Cramp & Simmons 1983, Götmark 1982). Also in Herring Gulls on Mellum Island (Jade Bay), Wilkens & Exo (1998) found that the reproductive success decreased with increasing population density, because high nest density increased the predation risk of chicks by conspecifics. On the other hand, several studies have shown that an increasing numbers of defenders reduce predator success in colonially-breeding birds (Kruuk 1964, Götmark & Andersson 1984, Conover 1987; Arroyo et al. 2001). But as ground breeders, seabirds are very vulnerable to predation by ground predators such as rats (*Rattus norvegicus*) or foxes. In contrast to effective antipredator behavior against aerial predators, colony sites affected regularly by fox predation as on the Pionier Island, colonial gulls do not exhibit behavior that effectively deters or distracts foxes from the nests (Southern et al. 1985). That explains the heavy eggs and chick losses in the colonies on Pionier Island.

Also the overall reproductive success of Black-headed Gulls breeding at the Jade Bay was possibly affected by ground predators. Numerous egg losses were observed as in 1995 as in 1996 (approximately 35%), and also chicks have been predated. Thyen et al. (1998) found that in 1996 foxes were presumably responsible for total egg losses in some places at the eastern Jade Bay. In the case of the Common Tern, the predation on eggs and chicks was not important in determining its overall reproductive success. On Minsener Oog Island, where ground predators did not occur, the predation pressure on Common Terns was low, and at the Elbe Estuary, predation was also unimportant. Here, the other important factor – food availability – might have positively influenced the reproductive success by reducing the time for foraging so that the parents can more intensively care and defend the clutch or chicks, as has been suggested for Herring Gulls and Oystercatcher (*Haematopus ostralegus*, Ens et al. 1992, Brouwer & Spaans 1994). The terns breeding at the Jade Bay (on Minsener Oog Island) are more dependent on the tide to acquire food (Frank & Becker 1992, Becker et al. 1993), since tides regulate the accessibility to marine organisms, whereas at the Elbe, the terns can use limnetic food sources, which are known to be constantly available (Becker et al. 1997) and might explain the differences in the chick growth rates between both sites. The relatively high proportion of chicks dead by starvation, hypothermia or diseases in all studied colonies suggests that besides food availability weather conditions had affected chick survival (Becker & Fink 1985, Becker & Specht 1991).

5. Conclusions

Herring Gull (Photo: Rolf Nagel)

The contaminants' levels found in the 1990s were low and they did not clearly affect the birds' reproduction, with the exception of the hatching and overall reproductive success of Common Gull, which were related to HCB, p,p'-DDE, and β-HCH. Although in Common Gull eggs the levels of these contaminants were lower than in Common Tern and Herring Gull eggs, this species was especially sensitive to them. Therefore, the Common Gull may be studied to supplement the monitoring carried out with less sensitive species – as the Common Tern and the Herring Gull – giving information about the lowest levels that could affect the reproduction of birds within the coastal bird community. The Common Tern and the Herring Gull accumulate contaminants to high body levels, being suitable to show temporal as well as intersite variation in environmental pollution.

In general, the levels of chemicals in bird eggs were low. However owing to the long-term exposition and additive and synergistic effects of the single compounds, chronic effects cannot be ruled out. In the case of the Common Tern, the fledging success was probably affected by ΣHCH, and for the Herring Gull, ΣDDT and ΣOHa seemed to play an important role determining the overall reproductive success. The chick development of both species was at the Elbe estuary possibly injured by HCB, p,p'-DDE, and β-HCH. On the other hand, correlations observed between chick growth rates and egg concentrations of ΣPCB, ΣDDT and ΣOHa of Herring Gulls breeding at the Jade Bay were not so coherent, therefore these results must be interpreted carefully. Although the Common Tern is considered a sensitive species, ten times more sensitive to chlorinated hydrocarbons than Herring Gulls (Neuman & Blokpoel 1996), which accumulate high pollutant levels, clear effects on its reproduction were not identified, probably owing to the low pollutant levels in eggs found at the Elbe Estuary in the mid 1990s. Also the Herring Gull accumulates and magnifies contaminants to high levels, but it is not as sensitive to organochlorine compounds as some other fish-eating waterbird species (Ryckman et al. 1997). In general, in the case of the Herring Gull, contaminant effects on reproduction were difficult to recognize because contaminant levels were low and because other factors influencing the reproductive success. Nevertheless, DDT concentrations found in Herring Gull eggs were within the range associated with reproductive failure for wildlife mentioned in the literature. For this reason and because TEQ levels determined in the Common Tern and the Herring Gull were within the limits associated with embryo toxicity and impaired hatching success in fish-eating birds, further studies are recommended in order to assess the impact of chemicals on the populations of these species. The Black-headed Gull was not affected by environmental chemicals during the 1990s.

In order to recognize effects of chemical contaminants on the overall reproductive success of birds, effects of other environmental factors on reproduction must be identified, such as food supply and availability, disturbance by man or predators, and weather. Considering the necessary compromise between getting "reproducible and exact results" and "nature conservation" (Thyen et al. 1998), I suggest the following approaches for further studies aiming to use seabirds as suitable indicators of the environmental contamination in the Wadden Sea:

1. Both, the "Monitoring Pollutants in Coastal Bird Eggs in the Wadden Sea" using birds as accumulative indicators of environmental chemicals (Becker et al. 2001) and the proposed TMAP-parameter "Breeding Success" (Thyen et al. 1998) should be combined and carried out long-term in order to reveal temporal trends in the contaminant levels as well as population dynamics, and to discriminate possible chronic effects induced by pollution from changes caused by environmental factors;
2. Breeding colonies located at high and low polluted areas should be selected in order to compare effects of different environmental levels of pollutants on reproduction;
3. Field methods have to be used and to be optimized which allow to determine with accuracy the fate of chicks, the fledging success and the body mass development of chicks;
4. Species should be selected, which accumulate large quantities of pollutants, such as the fish-feeding Common Tern and Herring Gull, and/or which are sensitive to pollutants, as the Common Tern and the Common Gull, in order to investigate the relation between pollutants and reproduction;
5. Large breeding colonies should be chosen to obtain a statistically adequate number of samples; and
6. Besides the "sample egg technique", pollutant levels between unhatched eggs and eggs taken at random could be compared to evaluate the effects of chemicals on hatching success (e.g. Becker et al. 1993).

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