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REPORT OF THE

WORKING GROUP ON SEABIRD ECOLOGY

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International Council for the Exploration of the Sea

Conseil International pour l'Exploration de la Mer

Palægade 2–4 DK–1261 Copenhagen K Denmark

Section **Page**

1 INTRODUCTION

1.1 Participation

The following nominated members of the Working Group participated in the meeting:

Peter H. Becker	Germany
Gilles Chapdelaine	Canada
Petter Fossum	Norway
Bob Furness	UK
Mark Tasker (Chair)	UK

1.2 Terms of Reference

At the 85th Statutory meeting, it was agreed that the Working Group on Seabird Ecology should produce a Report and that the Working Group should meet at ICES headquarters in Copenhagen from 22 – 26 March 1999 (5 days) (C. Res. 1998/2:10). The terms of reference were:

a) assess food consumption by seabirds in the ICES area, focusing primarily on areas other than the North Sea;

b) review the data available for describing interannual to interdecadal variation in seabird distribution at sea, in connection to both their reproductive performance and winter survival, and in relation to variation in diet;

c) review contents of the database of seabird diet composition;

d) compare seabird community structure in the eastern and western Atlantic, in relation to differences in fish stocks and fisheries practices of these regions;

e) review the usefulness of seabirds as monitors of pollutants in marine ecosystems;

f) propose tactics, activities, and products in support of the Oceanography Committee's Five Year Plan Objectives.

In addition, C.RES 1997/1:6 requested the preparation of a *Cooperative Research Report* based on ICES CM 1997/L:3 (the 1997 Working Group on Seabird Ecology report). This was not prepared in 1998 owing to lack of time. Instead, a *Cooperative Research Report* was requested based on a combination of the 1997 and 1998 reports (C.Res. 1998/1:3).

1.3 Overview

The Working Group on Seabird Ecology met for 5 days (22-26 March 1999), and was attended by five nominated representatives from four countries. We were unable, with resources and knowledge available, to address Terms of Reference b), c) d). Term of Reference a) was addressed, but not in the depth that would be possible with more resources. Terms of Reference a) and e) were reviewed and are reported here. The *Cooperative Research Report* was prepared.

1.4 Acknowledgements

The Working Group wishes to thank ICES and their staff for providing rooms for our meetings, computing and photocopying facilities. We wish particularly to thank those staff who helped us overcome difficulties with computing facilities. Professor Becker wishes to thank Neidersaechsische Wattenmeerstiftung for their support that enabled him to attend the meeting.

2 FOOD CONSUMPTION OF SEABIRDS IN THE ICES AREA, FOCUSED ON AREAS OTHER THAN THE NORTH SEA

2.1 Introduction

The Working Group constructed a model of food consumption by seabirds (not including seaducks or waders) in the North Sea at its meeting in 1994 (Tasker and Furness, 1996). This model used information on seabird densities in six sections of the North Sea, along with calculated energy requirements, and available information on diet. Total annual seabird energy requirement was 3.9 x 10^{12}kJ, which was the equivalent of 600,000 tonnes of food. The outputs of this model indicated that two species, guillemot and fulmar were together responsible for more than 50% of the total seabird energy requirements. The energy demand was not homogenous in time or space – most food was required in ICES Division IVa (west); and the second and third quarters of the year having the greatest demands. About one-third of food requirement was met by sandeels, with another third deriving from the waste products of fisheries (12% offal, 18% discards).

This approach is possible only where there is information on densities of birds at sea, and on their diet. Such information is available for waters to the west and south of the United Kingdom, in addition to the North Sea. In other areas, numbers of birds at colonies provide some indication of food consumption in the vicinity during the breeding season, but cannot account for immigration or emigration during the non-breeding period. In this section, calculations of food consumption are made, based on breeding numbers, for five sections of the Atlantic outside the North Sea. The North Sea model was applied to one further area of sea also.

2.2 Studies off eastern Canada

Previous models of energy use by seabirds in eastern and Arctic Canada (Diamond *et al.*, 1993; Cairns *et al.*, 1991) allowed estimation energy requirement in differing oceanographic areas and comparison between these areas. For example, Diamond *et al.* (1993)'s model demonstrated that year-round energy demand by seabirds in the Northwest Atlantic (NWA) was mainly from non-breeding birds, especially populations breeding in the Northeast Atlantic and in the southern hemisphere. However in the Gulf of St. Lawrence the year-round energy consumption was close to an estimate already based on breeding birds alone (Cairns *et al.*,1991), illustrating the relatively small impact of the few number of trans-oceanic and trans-equatorial migrants in this area (Brown, 1986). At the time that Diamond and colleagues produced their model, dietary information was sparse, both geographically and temporally, and much of it was presented as number of prey items or frequency of occurrence, so neither form allows a direct prey type harvest assessment by each species of seabirds for each oceanographic area. Their approach was mainly aimed at understanding the dynamics of large-scale marine ecosystems. In contrast, the model of Cairns *et al.* (1991) for the Gulf of St. Lawrence provided more specific seabird dietary information from studies within the Gulf and nearby waters. It allowed the estimation of removals of prey type by seabirds in tonnes, a more familiar unit to make comparison with the commercial fisheries landings.

In this section, the breeding populations of the major seabird species in the Gulf of St. Lawrence and Northwest Atlantic (NWA), together with data on energy expenditure and diet, provide the basis for estimating food consumption by these populations. For the NWA, trans-oceanic and trans-equatorial migrants are also considered in the estimate of energy demands. We would like to stress that the numerous assumptions made in our estimates of prey consumption may be questionable. There are uncertainties regarding the size of the breeding populations, particularly for gulls species in the Gulf and NWA. The estimates of the total numbers of seabirds other than breeders are speculative, but reasonable, because they have been based on the population dynamics of the species involved. The residence time or occupation dates by the seabird populations is another parameter liable to introduce errors in the calculation.

2.2.1 Gulf of St. Lawrence (NAFO Areas TSR)

The Gulf of St. Lawrence is 214 000 km^2 in extent (Steven, 1975) (Figure 2.1). The breeding populations were taken from BIOMQ (Banque Informatisée des Oiseaux Marins du Québec) and from Chapdelaine and Brousseau (1992), Lock *et al.* (1994), Chapdelaine (1995), and Chapdelaine (1996). To estimate numbers of nestlings and pre-breeders, seabirds were classified as inshore or offshore species and the following empirical calculation based on breeding pairs (bp) was adopted for both areas (Cairns *et al.*, 1986; Montevecchi, unpubl.): offshore species = (bp x 0.6) + (bp x 0.8); inshore species = (bp x 0.6) + (bp x 1.0). Approximate occupation dates, population estimate in pairs and number of birds (breeders, nestlings and nonbreeders) identified as total population using the breeding areas (TPA) are presented in Tables 2.2.

Estimates of daily energy expenditure were obtained from measurements of field metabolic rate (FMR) determined by Birt-Friesen *et al.* (1989) or by using allometric equations given by the same authors. Estimates of seabird biomass were based on the body-mass values of the birds from this FMR study. In subsequent calculations we assumed that energy requirements of the birds were stable throughout their respective occupation dates or season. In order to calculate the prey consumption by a seabird we used an average energy density of the prey of 6 kJ/g fresh mass and an assimilation efficiency of 0.75 (Tasker and Furness, 1996).

In order to assess the prey type biomass harvested by seabird species, we used the dietary information available through the literature related to the Gulf of St.Lawrence. Most of it comes from studies at breeding colonies during summer and little is known of the diets outside this period. The partitioning of prey type consumed by seabird is strongly bias toward the summer period and should be interpreted cautiously when these partitions are applied to the complete period in which the species occupies the area. The assessment seabird diet by numbers of prey items or by frequency of occurrence, as is comments in dietary papers makes it difficult to estimate the biomass of prey consumed by seabird (Tasker and Furness, 1996). We tried to avoid such information in the model but in some cases this was the only information available. The assumptions made and literature used for input parameters to the model are listed in Table 2.2.

2.2.1.1 Seabird populations

The estimate of the total number of seabird breeding pairs in the Gulf of St. Lawrence is about 368 669 and we estimated at 1.2 x 10^6 individuals as the total population of birds using the area. The seabird guild is dominated by black-legged kittiwake (22.5% of total TPA) but their total biomass represents only 9.2 %. The northern gannet dominates the seabird biomass total with 33.6% and represents 11.2% of total TPA. Herring gulls, common guillemots and double-crested cormorants are the next most important consumers with 13,5%, 11.4% and 11.9% of total TPA and represent 14.2%, 11% and 16.2% of the total seabird biomass respectively.

2.2.1.2 Consumption of food and energy uptake

The northern gannet is the major seabird consumer among the species in the Gulf of St. Lawrence, taking 30.2 % of the food biomass (Table 2.3). The herring gull, guillemot and double-crested cormorant follow with 21.2% , 11.8% and 8.2% of the food biomass consumed annually by all seabirds. The annual total prey biomass consumed by the breeding population, nestlings and nonbreeders is estimated at 108 419 tonnes. This is the equivalent of 6.5 x 10^{11} kJ of energy required by seabirds in the Gulf or 0.5g/m^2 (1g/m^2 = 1t/km^2 and entire area is 214 000 km^2). Because marine birds are not evenly distributed at sea, the value given for average prey consumption per unit area is not representative of every sectors of the gulf. Cairns *et al* (1991) for their bioenergetics model subdivided prey type harvest by NAFO Unit Area for the Gulf of St. Lawrence. They showed that in general the distribution of seabird harvest followed the pattern of breeding colonies.

2.2.1.3 Estimated prey harvest

Fish accounts for 93.4% of the prey consumption of this community. Capelin and sandeel are consumed by all seabird and represent the largest prey components, comprising 36.7% (39 776 tonnes) and 22.9% (24 844 tonnes) respectively of the total consumption (Table 2.3). Larid and alcid species are the most important consumers of these small pelagic and schooling fish. Mackerel are preyed only by northern gannet and account for 17.5% (19 012 tonnes). The total benthic and estuarine fish (mainly represented by flatfish, cunner and sculpins) are consumed mostly by great and double-crested cormorant and comprise 2.2% of the annual prey harvest by seabirds.

2.2.2 Northwest Atlantic (NAFO Areas 2J3KLNO)

The area of the Northwest Atlantic (Figure 2.1) considered in this section is estimated to 409 766 km^2 (Diamond *et al.* 1986). For breeding populations of NWA most information is provided by Nettleship and Evans (1985), Montevecchi and Tuck (1987), Nettleship and Chapdelaine (1988) and unpubl, Cairns *et al.* (1989), Lock *et al.* (1994), Diamond *et al.* (1986, 1993), Sklepkovych and Montevecchi (1989), Storey and Lien (1990); Stenhouse and Montevecchi (1998), Montevecchi (unpubl.). We used the same assumptions as used for the Gulf of St.Lawrence to allow for the extra numbers of nestlings and pre-breeders, for FMR, for average energy density of the prey and for assimilation efficiency. The waters of the open NWA coast are frequented by large numbers of trans-oceanic and trans-equatorial migrants so an estimate of energy use by this group of seabird was done separately. Information on their numbers is derived from Brown (1986), Diamond *et al.* (1986, 1993) and Montevecchi (unpubl.) (Table 2.4).

2.2.3 Seabird populations

The 18 nesting seabird species within the NAFO Unit Areas 2J3KLNOPs number about 5.6 million of pairs. We estimated the total population at 1.8 x 10^7 individual seabirds liken assessing the food consumption of this group. Most are Leach's storm-petrel (81%), guillemot (10%) and Atlantic puffin (5,4%) breeding at colonies at Baccalieu Island, Funk Island and Witless Bay Islands (Montevecchi and Tuck 1987; Cairns *et al.* 1989; Lock *et al.* 1994). Gulls and terns (2.7%), northern gannet (0.3%), black guillemot, thick-billed murre, razorbill (0.7%), double-crested cormorant, great cormorant, Manx shearwater and northern fulmar (0.1%) comprise the remainder of the nesting total. Biomass densities of nesting seabird in this area represent 9 kg km^{-2} during the breeding season.

In contrast to the Gulf of St. Lawrence, this area supports large numbers of non-breeding migrant seabirds. Their population sizes are poorly known, but the migrants probably outnumber the breeding species here in summer and possibly at all times of the year (Diamond *et al.*, 1993; Lock *et al.*, 1994; Montevecchi, unpubl.). Nine species are considered as occurring within and breeding mostly or completely outside of NAFO Areas 2J3KLNOPs. The Banks offshore of Newfoundland are the chief wintering area for little auks which represent about 70 % of the migrants group estimated at 14.3 millions of birds (Table 2.5). Brunnich's guillemot (10.5 %), great shearwater (10.5 %), black-legged kittiwake (3.5%), northern fulmar (2.1%), sooty shearwater (2.1%), Iceland gull, glaucous gull and Wilson's petrel (1.3%) complete the list. Biomass densities by these migrants represent a potential of 12 kg km^{-2} through the year. Thus seabird biomass of migrant seabirds exceeds that of the breeders.

2.2.4 Consumption of food and energy uptake

The total biomass consumed annually by the breeders (including nestlings and non-breeders) is estimated at 318 351 tonnes. This is the equivalent to energy consumption of 1.9 kJ x 10^{12} and corresponds to 0.8 g/m^2 (entire area is 409 766 km^2). But this estimate excludes populations breeding in other oceanographic regions present through the year. Guillemot dominates consumption by breeders, with 50.6% of the total biomass taken in one year. Leach's storm-petrel, Atlantic puffin, herring gull and northern gannet consume with 17.4%, 15.1%, 6.4% and 3.5% of the total respectively (Table 2.5). Northern fulmar, Manx shearwater, great and double-crested cormorants, black-headed, ring-billed and great black-backed gulls, Caspian, common and arctic terns, Brünnich's guillemot, razorbill and black guillemot comprise the remainder with 7%.

The bioenergetics model estimates that the migrants group remove about 388 933 tonnes/year of living prey from Northwest Atlantic (Table 2.6). Little auk and Brünnich's guillemot take 63.2%, great shearwater 16.3%, northern fulmar 9.2%, black-legged kittiwake 4.8%, sooty shearwater 3.0% and Wilson's petrel, Iceland and glaucous gull complete with 3.6%. The annual energy consumption requirement for migrants is 2.3 kJ x 10^{12} or 0.8 g/m^2.

Combining the annual consumption of breeders and migrants gives 707 284 tonnes of fish and invertebrates consumed by seabird in the Northwest Atlantic. This is equivalent to 4.2 kJ x 10^{12} or 1.7 g/m^2 which is essentially identical to the estimate of Diamond *et al.* (1993) using an energy modelling approach for the same area.

2.2.5 Estimated prey harvest

The partitioning of prey type harvest in function of different seabird species shows that capelin is the most important prey consumed by breeders in NWA with 201 474 tonnes. It represents 63.3% of the total annual prey type harvested by seabirds. Guillemot is the most important predator with 138 452 tonnes or 68.7% of capelin taken annually by seabirds. Sandeel represents the second most important type of prey fish but yields only 5.1% (16 158 tonnes) of the total annual harvest. It is mainly consumed by common guillemot and Atlantic puffin but its availability does not appear to be the same as in the North Sea where sandeel constitute the staple food of most of the seabird community (Tasker and Furness, 1996). Mackerel and herring are consumed only by northern gannet and represent a merely 1.9% of the total biomass harvested. Invertebrates are mostly consumed by the abundant Leach's storm-petrel that breed in NWA. More specifically, myctophids, amphipods, euphausiids as well as decapods, copepods and isopods constituted their diet but owing to small body size and metabolic efficiency, they account for comparatively little of the energy that flows through the avian assemblage of the NWA (Montevecchi, 1992).

Migrants have certainly an important impact on pelagic fish species as the removals by northern fulmar, great and sooty shearwater, kittiwake and Brünnich's guillemot represents 67.2% of the total seabird removal of this group. They also consume pelagic fish such as capelin in the NWA area (Rice, 1992; Elliot *et al.*, 1990 ; Montevecchi and Myers, unpublished data). But having no more details of prey type proportions in their diet we cannot speculate beyond the available information.

Table 2.1. Summary of diets (% mass) for seabirds in the Gulf of St. Lawrence.

Species	Diets assumed for the model	References
Leach's storm-petrel	100% invertebrates	1
Northern gannet	58% mackerel, 4% herring, 10% capelin, 22% sandeel, 6% others	2, 3, 4
Great cormorant	20% sandeel, 40% flatfish, 30% cunner, 7% sculpins, 3% others	5
Double-crested cormorant	6% herring, 18% capelin, 25% sandeel, 15% flatfish, 11% cunner, 10% sculpins, 15% others	5, 6, 7, 8
Black-headed gull	n.a.	n.a.
Ring-billed gull	n.a.	n.a.
Herring gull	1% herring, 58% capelin, 3% sandeel, 9% invertebrates, 29% others	2, 9
Great black-backed gull	19% herring, 57% capelin, 1% sandeel, 1% invertebrates, 1% sculpins, 21% others	2, 10
Black-legged kittiwake	27% capelin, 66% sandeel, 7% invertebrates	10, 11
Caspian tern	n.a.	n.a.
Common tern	33% capelin, 31% sandeel, 5% invertebrates, 31% others	12, 13
Arctic tern	17% capelin, 73% sandeel, 10% invertebrates	12
Guillemot	97% capelin, 3% sandeel	10
Brunnich's guillemot	n.a.	n.a.
Razorbill	58% capelin, 42% sandeel	10, 14
Black guillemot	8% sandeel, 1% invertebrates, 33% gadidae, 28% daubed shanny, 30% others	15
Atlantic puffin	37% capelin, 63% sandeel	10

(1) Montevecchi *et al.* (1992); (2) Rail *et al.* 1996; (3) Burton and Pilon (1978); (4) Taylor and Nettleship (1974); (5) Pilon *et al.* (1983); (6) Rail and Chapdelaine (1998); (7) Gallant (1988); (8) Léger and Burton (1979); (9) Rail *et al.* (in prep.); (10) Chapdelaine and Rail (unpubl.); (11) Chapdelaine and Brousseau (1989); (12) Chapdelaine *et al.* (1985); (13) Chalifour (1982); (14) Chapdelaine and Brousseau (1996); (15) Cairns (1981)

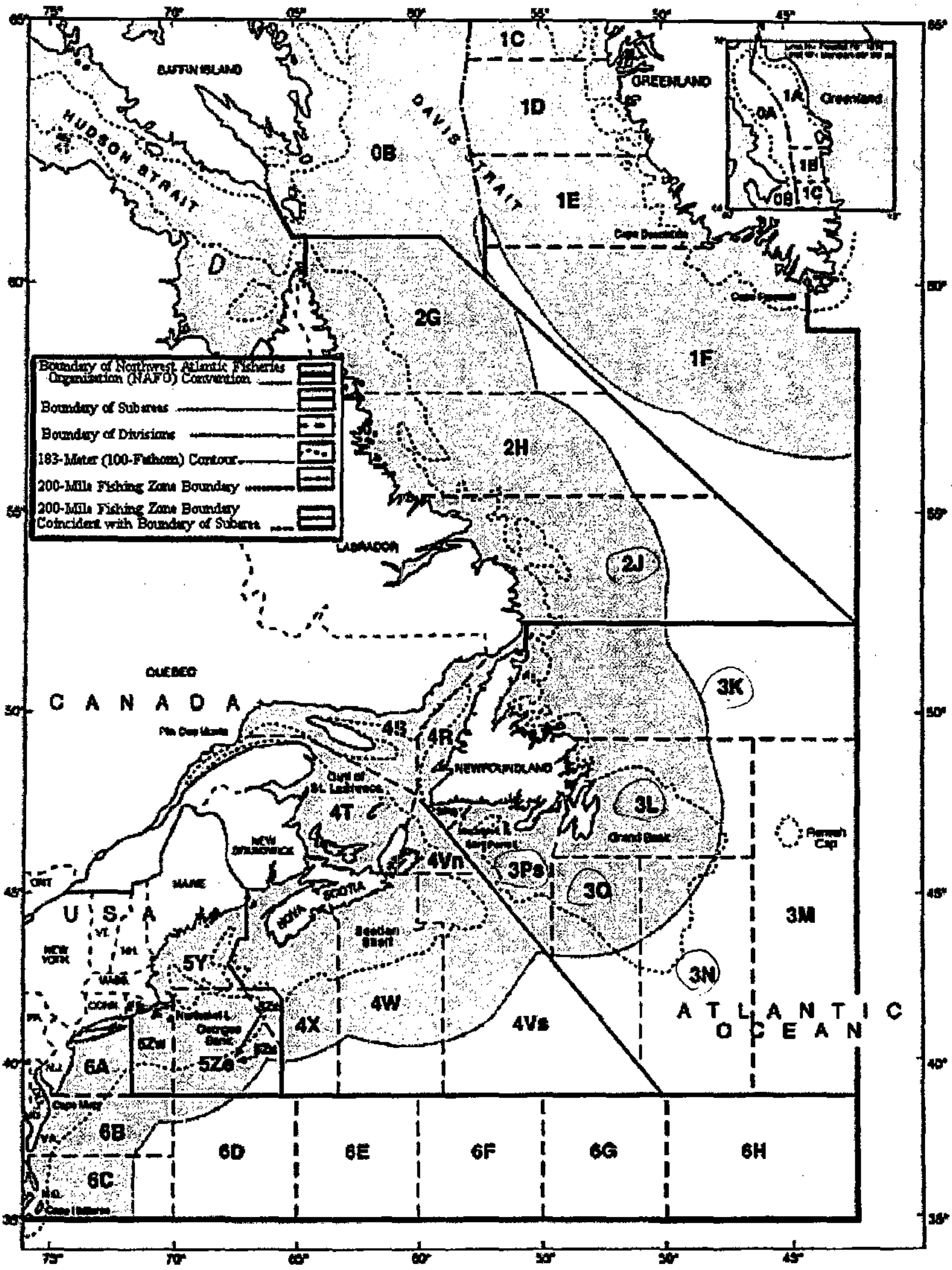

Figure 2.1 The NAFO Areas used to describe the Gulf of St. Lawrence and the North West Atlantic.

Table 2.2. Seabird species that breed within NAFO AREAS 4RST, Gulf of St. Lawrence

Species	Population estimate (pairs)	Occupation dates	TPA	Individual mass (kg)	Biomass (kg)	%	FMR (kJ/day)	Ref. FMR data*	Consumption (tonnes/day)	%	tonnes/year	%
Leach's storm-petrel	518	May-Oct	1761	0.05	88	0.0	89	1	0.0	0.0	6.4	0.0
Northern gannet	42124	Apr-Oct	143222	3.2	458309	33.6	4 865	1	154.8	32.8	32779.3	30.2
Great cormorant	2484	Apr-Oct	8446	2.25	19003	1.4	1761	1b	3.3	0.7	699.7	0.6
Double-crested cormorant	39000	Apr-Oct	132600	1.67	221442	16.2	1419	1b	41.8	8.9	8851.9	8.2
Black-headed gull	10	Apr-Oct	36	0.28		0.0	473	1a	0.0	0.0	0.8	0.0
Ring-billed gull	33392	Apr-Oct	120211	0.5	60106	4.4	1049	1a	28.0	5.9	5932.4	5.5
Herring gull	47887	Mar-Dec	172393	1.12	193080	14.2	1984	1a	76.0	16.1	23026.1	21.2
Great black-backed gull	9736	Mar-Dec	35050	1.68	58883	4.3	2533	1a	19.7	4.2	5976.9	5.5
Black-legged kittiwake	84376	Apr-Oct	286878	0.44	126226	9.3	794	1	50.6	10.7	10715.9	9.9
Caspian tern	11	May-Sep	40	0.61	24	0.0	1213	1a	0.0	0.0	1.6	0.0
Common tern	26268	May-Sep	94565	0.12	11348	0.8	372	1a	7.8	1.7	1169.9	1.1
Arctic tern	1005	May-Sep	3618	0.11	398	0.0	349	1a	0.3	0.1	42.0	0.0
Guillemot	44660	Apr-Oct	151844	0.99	150326	11.0	1789	1	60.4	12.8	12779.6	11.8
Brunnich's guillemot	12	Apr-Oct	41	0.93	38	0.0	1420	1	0.0	0.0	2.7	0.0
Razorbill	8250	Apr-Oct	28050	0.72	20196	1.5	1368	1a	8.5	1.8	1805.2	1.7
Black guillemot	4762	Jan-Dec	16191	0.4	6476	0.5	616	1	2.2	0.5	809.0	0.7
Atlantic puffin	24174	Apr-Oct	82192	0.46	37808	2.8	988	1a	18.0	3.8	3820.3	3.5
										Total	108419.4	

*1 After Birt-Friesen *et al.* (1989)
(1a) cold water flappers FMR= 11.455 $M^{0.727}$ after Birt-Friesen *et al.* (1989), mass in g
(1b) other seabirds FMR= 6.441 $M^{0.727}$ after Birt-Friesen *et al.* (1989), mass in g
(1c) cold water seabirds FMR= 8.892 $M^{0.646}$ after Birt-Friesen *et al.* (1989), mass in g

Table 2.3. Estimated prey harvest by seabirds in the Gulf of St. Lawrence

	Pelagic fish					Benthic and estuarine fish					
Species	Mackerel	Herring	Capelin	Sandeel	Invertebrates	Cunner	Sculpins	Gadidae	Flatfish	Daubed Shanny	Others
Leach's storm-petrel					6.4						
Northern gannet	19012.0	1311.2	3277.9	7211.4							1966.8
Great cormorant				139.9		209.9	49.0		279.9		21.0
Double-crested cormorant		531.1	1593.3	2213.0		973.7	885.2		1327.8		1327.8
Black-headed gull	n.a.										
Ring-billed gull	n.a.										
Herring gull		230.3	13355.1	690.8	2072.3						6677.6
Great black-backed gull		1135.6	3406.8	59.8	59.8		59.8				1255.2
Black-legged kittiwake			2893.3	7072.5	750.1						
Caspian tern	n.a.										
Common tern			386.1	362.7	58.5						362.7
Arctic tern			7.1	30.7	4.2						
Guillemot			12396.2	3833.9							
Brunnich's guillemot	n.a.										
Razorbill			1047.0	758.2							
Black guillemot				64.7	8.1			267.0		226.5	242.7
Atlantic puffin			1413.5	2406.8							
Total prey harvest	19012.0	3208.2	39776.4	24844.2	2959.4	1184	993.9	267.0	1607.6	226.5	11853.6
% of tonnes/year	17.5	3.0	36.7	22.9	2.7	1.1	0.9	0.2	1.5	0.2	10.9

Table 2.4. Summary of diets (% mass) for seabirds in the Northwest Atlantic.

Species	Diets assumed for the model	References
Northern fulmar	n.a.	n.a.
Manx shearwater	n.a.	n.a.
Leach's storm-petrel	100% invertebrates	1
Northern gannet	41% mackerel, 14% herring, 28% capelin, 2% sandeel, 10% saury, 3% squid, 1% gadoids, 1% others	2
Great cormorant	2% invertebrates, 5% flatfish, 53% cunner, 12% sculpins, 1% gadoids, 27% others	3, 4
Double-crested cormorant	6% sandeel, 10% flatfish, 27% cunner, 16% sculpins, 41% others	3, 4, 5
Black-headed gull	n.a.	n.a.
Ring-billed gull	n.a.	n.a.
Herring gull	51% capelin, 1% squid, 9% invertebrates, 2% gadoids, 37% others	6, 7, 8, 9
Great black-backed gull	n.a.	n.a.
Black-legged kittiwake	75% capelin, 25% others	6, 10
Caspian tern	n.a.	n.a.
Common tern	33% capelin, 31% sandeel, 5% invertebrates, 31% others	11
Arctic tern	17% capelin, 73% sandeel, 10% invertebrates	11
Guillemot	86% capelin, 5% sandeel, 2% gadoids, 5% daubed shanny, 2% others	12, 13, 14
Brünnich's guillemot	29% capelin, 2% sandeel, 2% gadoids, 66% daubed shanny, 1% others	14
Razorbill	62% capelin, 33% sandeel, 5% others	13, 15
Black guillemot	8% sandeel, 1% invertebrates, 33% gadoids, 28% daubed shanny, 30% others	16
Atlantic puffin	81% capelin, 14% sandeel, 5% gadoids	9, 13, 17

(1) Montevecchi *et al.* (1992); (2) Montevecchi and Myers (1997); (3) Milton and Austin-Smith (1983); (4) Ross (1976); (5) Lewis (1957); (6) Threlfall (1968); (7) Haycock and Threlfall (1975); (8) Pierotti (1983); (9) Brown and Nettleship (1984); (10) Regehr (1994); (11) Chapdelaine *et al.* (1985); (12) Cairns *et al.* (1990); (13) Birkhead and Nettleship (1983) (14) Birkhead and Nettleship (1987); (15) Chapdelaine and Brousseau (1996); (16) Cairns (1981); (17) Rodway and Montevecchi (1996)

Table 2.5. Seabird species that breed within NAFO AREAS 2J3KLNO, Northwest Atlantic (NWA)

Species	Population estimate (pairs)	Occupation dates	TPA	Individual mass (kg)	Biomass	%	FMR (kJ/day)	Ref. FMR data*	Consumption tonnes/day	%	tonnes/year	%
Northern fulmar	53	Jan-Dec	181	0.8	144.8	0.0	1477	1a	0.1	0.0	14.3	0.0
Manx shearwater	100	Mar-Nov	340	0.48	163.2	0.0	573	1b	0.0	0.0	9.2	0.0
Leach's storm-petrel	4511952	Apr-Oct	15340636	0.05	767031.8	20.6	89	1	303.4	20.1	55371.2	17.4
Northern gannet	14355	Apr-Oct	48806	3.2	156179.2	4.2	4 865	1	52.8	3.5	11170.3	3.5
Great cormorant	167	Mar-Nov	601	2.25	1352.25	0.0	1761	1b	0.2	0.0	49.8	0.0
Double-crested cormorant	291	Mar-Nov	1048	1.67	1750.16	0.0	1419	1b	0.3	0.0	70.0	0.0
Black-headed gull	7	Jan-Dec	25	0.28	7	0.0	473	1a	0.0	0.0	0.6	0.0
Ring-billed gull	6406	Apr-Oct	23062	0.5	11531	0.3	1049	1a	5.4	0.4	1138.1	0.4
Herring gull	42163	Jan-Dec	151787	1.12	170001.4	4.6	1984	1a	66.9	4.4	20273.8	6.4
Great black-backed gull	3461	Jan-Dec	12460	1.68	20932.8	0.6	2533	1a	7.0	0.5	2124.8	0.7
Black-legged kittiwake	81617	Jan-Dec	293822	0.44	129281.7	3.5	794	1	51.8	3.4	10975.2	3.4
Caspian tern	30	May-Oct	108	0.61	65.88	0.0	1213	1a	0.0	0.0	4.4	0.0
Common tern	3091	Jan-Dec	11128	0.12	1335.36	0.0	372	1a	0.9	0.1	137.7	0.0
Arctic tern	4544	May-Oct	16358	0.11	1799.38	0.0	349	1a	1.3	0.1	189.9	0.1
Guillemot	562605	Jan-Dec	1912857	0.99	1893728	51.0	1789	1	760.5	50.4	160990.8	50.6
Brünnich's guillemot	12000	Jan-Dec	40800	0.93	37944	1.0	1420	1	12.9	0.9	2725.6	0.9
Razorbill	10972	Jan-Dec	37305	0.72	26859.6	0.7	1368	1a	11.3	0.8	2400.8	0.8
Black guillemot	15000	Jan-Dec	54000	0.4	21600	0.6	616	1	7.4	0.5	2698.1	0.8
Atlantic puffin	303781	Jan-Dec	1032855	0.46	475113.3	12.8	988	1a	226.8	15.0	48007.0	15.1
										Total	318351.3	

*1 After Birt-Friesen *et al.* (1989)

(1a) cold water flappers FMR= 11.455 $M^{0.727}$ after Birt-Friesen *et al.* (1989), mass in g

(1b) other seabirds FMR= 6.441 $M^{0.727}$ after Birt-Friesen *et al.* (1989), mass in g

(1c) cold water seabirds FMR= 8.892 $M^{0.646}$ after Birt-Friesen *et al.* (1989), mass in g

Table 2.6. Seabird species that occur within and breed outside of NAFO AREAS 2J3KLNO, Northwest Atlantic

Species	TPA	Individual mass (kg)	Biomass(kg)	%	FMR (kJ/day)	Ref. FMR data*	tonnes/day	%	tonnes/year	%
Wilson's storm-petrel	50000	0.04	2000	0.0	119	1	1.3	0.1	279.9	0.1
Northern fulmar	300000	0.8	240000	4.7	1477	1a	98.5	4.8	35940.3	9.2
Greater shearwater	1500000	0.89	1335000	26.2	897	1b	299.0	14.6	63298.3	16.3
Sooty shearwater	300000	0.79	237000	4.6	823	1b	54.9	2.7	11615.3	3.0
Iceland gull	100000	0.86	86000	1.7	1557	1a	34.6	1.7	7324.8	1.9
Glaucous gull	50000	1.7	85000	1.7	2664	1a	29.6	1.4	6266.3	1.6
Black-legged kittiwake	500000	0.44	220000	4.3	794	1	88.2	4.3	18676.6	4.8
Brünnich's guillemot	1500000	0.93	1395000	27.4	1420	1	473.3	23.1	100204.7	25.8
Little auk	10000000	0.15	1500000	29.4	437	1a	971.1	47.4	145326.8	37.4
								Total	388933.1	

*1 After Birt-Friesen *et al.* (1989)
(1a) cold water flappers FMR= 11.455 $M^{0.727}$ after Birt-Friesen *et al.* (1989), mass in g
(1b) other seabirds FMR= 6.441 $M^{0.727}$ after Birt-Friesen *et al.* (1989), mass in g
(1c) cold water seabirds FMR= 8.892 $M^{0.646}$ after Birt-Friesen *et al.* (1989), mass in g

Table 2.7. Estimated prey harvest by seabirds in the Northwest Atlantic

Species	Pelagic fish and squid						Inver-tebrates	Benthic and estuarine fish					Others
	Mackerel	Herring	Capelin	Sandeel	Atlantic Saury	Squid		Flatfish	Cunner	Sculpins	Gadoids	Daubed Shanny	
Northern fulmar								n. a.					
													---
								n. a.					
													--
							55371.2						5.0
Northern gannet	4579.8	1563.8	3127.7	223.4	1117.0	335.1					111.7		111.7
Great cormorant							1.0	2.5	26.4	6.0	0.5		13.4
Double-crested cormorant				4.2				7.0	18.9	11.2			28.7
Black-headed gull								n. a.					

Ring-billed gull								n. a.					

Herring gull			10339.6			202.7	1824.6				405.5		7501.3
Great black-backed gull								n. a.					

Black-legged Kittiwake			8231.4										2743.8
Caspian tern								n. a.					
													--
Common tern			45.4	42.7			6.9						42.7
Arctic tern			32.3	138.6			19.0						
Guillemot			138452.1	8049.5							3219.8	8049.5	3219.8
Brünnich guillemot			790.4	54.5								1798.9	27.3
Razorbill			1488.5	792.3									120.0
Black guillemot				215.8			27.0				890.4	755.5	809.4
Atlantic puffin			38885.7	6721.0							2400.4		
Total prey harvest	4579.8	1563.8	201393.2	16242.0	1117.0	537.8	57249.7	9.5	45.3	17.2	7028.2	16603.9	14618.1
% of tonnes/year	1.4	0.5	63.3	5.1	0.4	0.2	18.0	0.0	0.0	0.0	2.2	3.5	4.6

2.3 Icelandic waters (ICES Area Va)

Seabird numbers for Icelandic waters were obtained from the mid ranges of the figures used by Lloyd *et al.* (1991). To estimate numbers of nestlings and pre-breeders we adopted the same empirical calculation applied in Northwest Atlantic. An FMR of 3.9 BMR (see Tasker and Furness, 1996) was used to assess daily energy expenditure and food consumption was estimated for 90 days corresponding to the summer period. We validated our estimate by applying the data of Lilliendahl and Solmundsson (1997) in order to the food requirements of six seabird species in Iceland. The discrepancy between the two model output was less than 0.01%, so we assume that our results for the 21 species breeding in Iceland are broadly similar to other studies analysing the food consumption by seabirds in other ICES and NAFO oceanographic areas. The total area used by seabird around Iceland was assumed at 225 000 km^2.

Assessment of prey type biomass harvested by seabird species is available for the six most numerous species found in Icelandic waters (Lilliendahl and Solmundsson, 1997).

2.3.1 Seabird populations

The 21 species of seabird nesting in Iceland number about 12.2 millions pairs (Table 2.8). Northern fulmar and Atlantic puffin represent 77.6% of this total. Common and Brünnich's guillemots are the next most important species and account for 13.5% of the seabird breeding population.

2.3.2 Consumption of food and energy uptake

Not unexpectedly northern fulmar and Atlantic puffin dominate the consumption of the seabird guild in Iceland, accounting for 69.3 % of the total biomass taken. Common and Brünnich's guillemot are the two next most important consumers with 21.6 % of total food consumed. The annual total prey biomass consumed by the breeding population, including nestling and non-breeders, in Iceland is estimated at 986 196 tonnes of fish and invertebrates (Table 2.8). This is the equivalent to 4.9 x 10^{12} kJ or 4.4 g/m^2.

2.3.3 Consumption of prey type and energy uptake for 6 seabird species

The following analysis is based on Lilliendahl and Solmundsson (1997). Atlantic puffin is the major consumer among this group of seabirds taking 33 % of the 441 700 tonnes of foods harvested over the summer period (Table 2.9). Common guillemot, northern fulmar and Brunnich's guillemot are the next most important consumers with 23%, 17% and 16% of the biomass harvested. Black-legged kittiwake and razorbill take 8% and 5% respectively. The total biomass of fish and invertebrates consumed is the equivalent of 2.2 x 10^{12} kJ of energy required by these 6 seabird species or 1.96 g/m^2 (assuming 225 000 km^2 for entire area used by seabirds in Iceland).

2.3.4 Estimated prey harvest for 6 seabird species

Sandeel is the primary prey, constituting 42% of the total food consumption or 184 400 tonnes while capelin is the second most important with 38% or170 700 tonnes. Sandeel are mainly eaten by Atlantic puffin, consuming 59.5% of the total sandeel take by seabirds and common guillemot is the most important consumer of capelin with 39.7% of the total biomass consumed by seabirds. Euphausiids are mainly preyed upon by Brunnich's guillemot, which consume 42.1% of the total euphausiids eaten by seabirds, however capelin remains prey of this species.

Table 2.8 Estimated annual summer food consumption of all seabird species breeding in Iceland (see assumptions for Iceland)

	Pairs	FMR (kJ/day)	Tonnes/year
Northern fulmar	5000000	1005	384413
Manx shearwater	5000	573	219
Leach's storm-petrel	5000	89	34
Storm petrel	5000	119	46
Northern gannet	25000	4865	9304
Shag	6600	2882	1541
Great cormorant	3000	3467	842
Arctic skua	4000	2117	686
Black-headed gull	10000	733	594
Common gull	100	783	6
Herring gull	10000	1669	1352
Glaucous gull	3500	2760	745
Great black-backed gull	2500	2710	549
Lesser black-backed gull	10000	1583	1282
Black-legged kittiwake	400000	794	25726
Arctic tern	100000	308	2495
Guillemot	1200000	1789	164230
Brünnich's guillemot	450000	1420	48308
Razorbill	450000	1213	41758
Black guillemot	50000	1022	3909
Atlantic puffin	4500000	866	298121
		Total	986196

Table 2.9. Food consumption in tonnes of six seabird species breeding on Icelandic coastal waters (adapted from Lilliendahl and Solmondsson (1997).

Species	Population estimate (individuals)	FMR (kJ/day)	tonnes/annual summer
Northern fulmar	4352000	821	73400
Black-legged kittiwake	1363000	795	19600
Common guillemot	2590000	2034	102700
Brunnich's guillemot	1512000	2402	71600
Razorbill	988000	1245	26500
Atlantic puffin	7342000	1065	147900

Table 2.9. Estimated annual summer food consumption in tonnes of six species breeding in Iceland in 1994 and 1995. Divided between bird species and by major food items (adapted from Lilliendahl and Solmundson (1997))

Species	Capelin	Sandeel	Euphausiids	Others
Northern fulmar	8500	21300	4000	39600
Black-legged kittiwake	15700	3100	400	400
Common guillemot	67800	27900	4600	2400
Brunnich's guillemot	41900	10000	14400	5300
Razorbill	13100	12200	1100	100
Atlantic puffin	23700	109900	9700	4600
Total	170700	184400	34200	52400

2.4 Barents Sea (ICES Area I and eastern parts of IIa,b)

This section is based on the work of Mehlum and Gabrielsen (1995)

Mehlum and Gabrielsen (1995) describe the breeding populations of the major seabird species in the Barents Sea region, together with data on energy expenditure and diet. These figures were used to provide the basis for estimating food consumption by these populations and fluxes of energy through the seabirds. In the Barents Sea year-round energy consumption by sea birds is close to an estimate based on breeding birds alone.

Estimates of breeding population sizes and the assumption that the number of nonbreeding adults, chicks and immature is equal to the number of breeders were used to calculate the average densities of marine birds. The total Barents Sea area is approx 1.4 x 10^6 km^2 (Figure 2.2). Measurements of field metabolic rate of breeding adult during the chick-rearing period with double marked water were made in several colonies. The mean residency time in the sea was estimated at of 250 days of the year. An average energy density and an assimilation efficiency of 5kJ/g fresh mass and 0.75 were used respectively.

The estimate of total number of breeding pairs in the Barents Sea region is about 3.7 x 10^6, dominated by Brunnich's guillemot. The Brunnich's guillemot is also the major consumer taking 63% of the food biomass (Table 2.10). The other major species are kittiwake, common guillemot, puffin and little auk. The annual total prey biomass consumed by the breeding population of marine birds in the entire Barents Sea is estimated at 690 000 tonnes (Table 2.10). Including the nonbreeding population and nestlings the total annual food consumption by birds is estimated at 1,400,000 tonnes. The mean consumption of seabirds in the whole Barents Sea is 1.0 g/m^2/year. There are large differences within this huge area and an example of this is that at a daily basis during the breeding season the energy flux to the seabirds breeding at Bear Island is five times the average for the whole Barents Sea.

Table 2.10. Seabird biomass and food consumption in the Barents Sea

Species	Total pairs	Mass (g)	Biomass(kg)	%	FMR (kJ/day)	Consumption (tonnes/year
Fulmar	27100	650	35230	0.8	1005	3625
Kittiwake	759000	350	561660	13.3	788	79750
Glaucous gull	12000	1800	43200	11.0	2760	4500
Common guillemot	266000	800	425600	10.1	1871	66350
Brunnich's guillemot	1567000	820	2569880	60.7	2080	434575
Razorbill	16100	600	19320	0.5	1400	3000
Puffin	412800	460	379776	9.0	848	46650
Black guillemot	16200	360	11664	0.3	887	1925
Little auk	580000	160	185600	4.4	696	53825
					Total	694200

2.5 Norwegian Sea (part of IIa)

2.5.1 Seabird consumption in the Norwegian Sea

Piscivorous seabirds use the Norwegian Sea for foraging. Table 2.11 shows estimates of regional population sizes of breeding seabirds fully or partly dependent on fish prey taken from Anker-Nilssen (unpublished data) and the Norwegian Seabird Registry at NINA.

Table 2.11. Regional population sizes of breeding seabirds on the Norwegian coastline between Stadt and Lopphavet.

Species	Population estimates
Gannet	5500
Cormorant	30000
Shag	25000
Red-breasted merganser	30000
Great skua	50
Arctic skua	10000
Common gull	150000
Herring gull	25000
Lesser black-backed gull	3500
Great black-backed gull	65000
Kittiwake	325000
Common tern	6000
Arctic tern	50000
Razorbill	30000
Common guillemot	10000
Black guillemot	30000
Puffin	3250000

Obviously, among seabirds, puffins are by far the most numerous of the species, and are the important consumer of fish in this region, constituting 77% of the seabird numbers (94% when excluding the more omnivorous gulls and skuas).

Some preliminary calculations for puffin consumption are made in the report by Anker-Nilssen and Øyan (1995). They were based on the following parameters:

1. Daily energy expenditure (DEE) per adult puffin in the chick period: 848 kJ (G.W. Gabrielsen, unpublished data from Hornøy, Finnmark in 1992);
2. DEE outside chick period and by non-breeders assumed reduced by 20%;
3. Assumed metabolic efficiency of adults: 70% (Tasker and Furness, 1996);
4. Daily energy demand (DED) per puffin chick: 400 kJ (Anker-Nilssen and Øyan, 1996);
5. Energy value of 0-group herring (mean length 60 mm): 3.7 kJ/g fresh weight (Anker-Nilssen and Øyan, 1995).

Setting the breeding success to a modest average of 0.6 chicks per pair, and extending the calculations to cover for 3,25 million breeders and (conservatively) an additional 0.75 million immature present in the area (as a seasonal average), then the daily energy consumption of Norwegian Sea puffins may be calculated:

Table 2.12 Daily energy consumption of Norwegian Sea puffins

Breeders within chick period	3937 GJ
Nestlings	390 GJ
Breeders outside chick period	3150 GJ
Non-breeding immatures	727 GJ

In total, the puffin population in the Norwegian Sea would consume 5054 GJ per day within the chick period, and 3877 GJ per day prior to the chick period. The adults attend their colonies for ca 3 months prior to hatching (1 April to 30

June) and another 1.5 months during the chick rearing period (1 July to 15 August). Given the calculations and assumptions above, the puffin's total consumption in this 4.5 months long breeding season amounts to (3877 x 91) + (5054 x 45) = ca 580,000 GJ or 156,820 tonnes of herring equivalent prey (i.e. assuming 3.7 kJ/g, see above).

It is no straightforward task to produce a realistic estimate of the proportion of a herring year-class consumed by these puffins. An attempt to calculate the consumption was made by Anker-Nilssen, Fossum and Gabrielsen (in prep.). A 60 mm long herring (which is the mean size in puffin loads at Røst in good years) weighs ca 0.93 g (Anker-Nilssen and Øyan, 1995). Thus 157,000 tonnes amounts to 157 billion individual herring. Although the puffins also feed on several other prey, the actual 'predation pressure' on herring may actually be many times larger. Than this is because the average herring (in good years) grows from less than 0.1 g in April to 5-7 g in July/August. The energy value of herring increases with fish size: 3.5 kJ/g for 41-50 mm fish, 3.6 kJ/g for 51-60 mm, 3.8 kJ/g for 61-70 mm, 4.4 kJ/g for 71-80 mm, 4.8 kJ/g for 81-90 mm and 4.9 kJ/g for 91-100 mm (Anker-Nilssen and Øyan, 1995), but these data suggest it is relatively constant (ca 3.4-3.7 kJ/g) for fish in the normal size range available to puffins in the Norwegian Sea during the breeding season (average usually less than 60 mm).

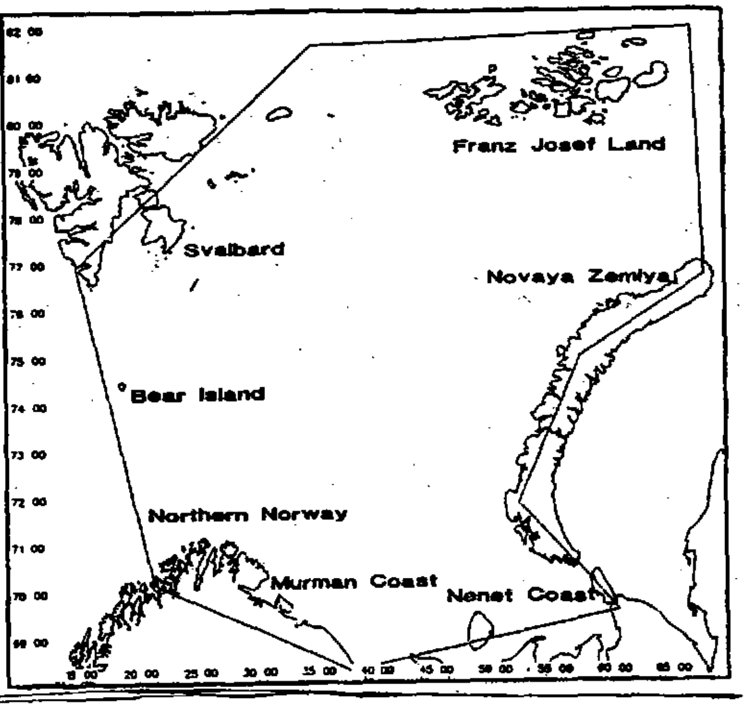

Figure 2.2. Boundaries of the Barents Sea used in this report

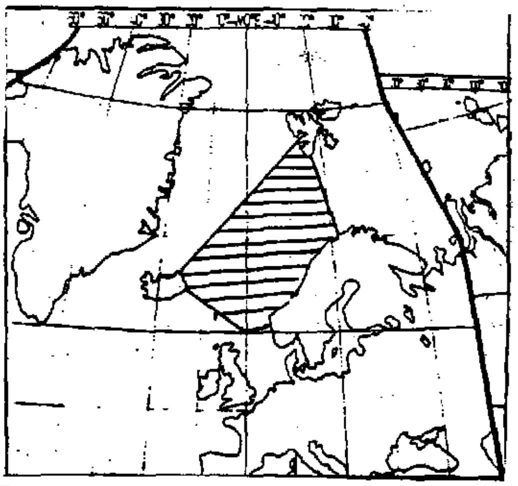

Figure 2.3. The extent of the Norwegian Sea used in this report (hatched area)

2.6 Discussion

Capelin have a prominent position in the ecosystem of the Gulf of St. Lawrence as a prey species. Many species of fish, marine mammals and seabirds are dependent on capelin for their survival. Commercial fishery removes only a small proportion of the total biomass because of fluctuating market demand. Prior to 1977, annual landings were stable at under 2 000 tonnes. The emergence of a Japanese market for roe-bearing females has attracted the attention of Canadian fishers. Japanese demand is responsible for the sharp increase in landings which stood at about 10 000 tonnes in 1978 and 1979 and also between 1989 and 1993. Capelin landings totalled 6 786 t and 7 451 t in 1996 and 1997 respectively (Anon., 1998a). So, it is widely recognised that the fishery in divisions 4RST removes only a small portion of the total biomass, compared to cod in northern Gulf, as well as many other species like seals and summer visitors such as whales and seabirds (Anon., 1998b).

In NWA breeding seabirds are taken annually 201 393 tonnes of capelin which is much more important than the consumption in the Gulf. But this harvesting by seabirds is quite small comparatively to the mass of capelin taken by the main predatory fish and mammals in NWA. Harp seals are estimated to have consumed about 800 000 tonnes of capelin in the NAFO divisions 2J3KL in 1996 (Anon., 1998c). Also, previous estimates for cod consumption of capelin indicated that during the early 1980,s, cod were consuming 1 to 3 millions tonnes of capelin annually. During the same time period, a minimum of 100 000-200 000 tonnes of capelin were estimated to have been consumed by Greenland halibut (Anon., 1998c). Annual harvest by the fisheries is estimated at about 25 000 tonnes annually (Anon., 1998c).

Capelin are also an important prey in Icelandic waters, but quantities consumed in summer are equalled in order of magnitude by the take of sandeels. Given that sandeels are unavailable in winter, capelin are probably the principle year-round prey. Food consumption in the Norwegian and Bering Seas has not been fully partitioned by prey species, but capelin are likely to be important in both systems.

Table 2.15 Food consumption by marine birds in different oceanographic areas

Area	Birds	Prey sp.	Residence time days	Consumption KJ	Energy required g/m2
Gulf of St. Lawrence	gannet, herring gull, common guillemot	capelin,sandeel, mackerel	summer	0,65x10^{12}	0,5
Northwest Atlantic (breeders)	common guillemot, Leach's storm-petrel, puffin	capelin,sand-eel, invertebrates	summer	1,9x10^{12}	0,8
Northwest (migrants)	little auk, Brunnich's guillemot, great shearwater	?	summer/winter	2,3x10^{12}	0,8
Iceland	Puffin, common guillemot, fulmar	sandeel, capelin, invertebrates	90 days	4,9x10^{12}	4,4
Barents Sea	Brünnich's guillemot,kittiwake, common guillemot	capelin,polar cod, invertebrates	250 d.	6,9x10^{12}	1
Norwegian Sea	Puffin, kittiwake, herring gull, common guillemot	herring	135 d.	0,58x10^{12}	?

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Appendix. Scientific names of species mentioned in Chapter 2.

Common name	*Scientific name*
Birds	
Northern fulmar	*Fularus glacialis*
Great shearwater	*Puffinus gravis*
Sooty shearwater	*Puffinus griseus*
Wilson's storm-petrel	*Oceanites oceanicus*
Leach's storm-petrel	*Oceanodroma leucorhoa*
Northern gannet	*Sula bassanus*
Great cormorant	*Phalacrocorax carbo*
Double-crested cormorant	*Phalacrocorax auritus*
Ring-billed gull	*Larus delawarensis*
Herring gull	*Larus argentatus*
Iceland gull	*Larus glaucoides*
Glaucus gull	*Larus hyperboreus*
Great-black-backed gull	*Larus marinus*
Black-legged kittiwake	*Rissa tridactyla*
Caspian tern	*Sterna caspia*
Roseate tern	*Sterna dougallii*
Common tern	*Sterna hirundo*
Arctic tern	*Sterna paradisaea*
Guillemot	*Uria aalge*
Brunnich's guillemot	*Uria lomvia*
Razorbill	*Alca torda*
Little auk	*Alle alle*
Black guillemot	*Cepphus grylle*
Atlantic puffin	*Fratercula arctica*
Fish	
Atlantic herring	*Clupea harengus*
Capelin	*Mallootus villosus*
Atlantic cod	*Gadus morhua*
Cunner	*Tautogolabrus adspersus*
Sand lance	*Ammodytes sp.*
Atlantic mackerel	*Scomber scombrus*
Saury	
Sculpin	*Myoxocephalus sp.*
Daubed shanny	*Sticheeus sp.*

3 SEABIRDS AS MONITORS OF MARINE POLLUTION

3.1 Introduction

The oceans are the ultimate sink for many pollutants transported by rivers or through the atmosphere. Especially in the case of atmospheric transport, pollutants can be deposited many thousands of kilometres from their source of discharge. Thus there is a clear need to monitor pollution of marine ecosystems. Many national, and several international programmes exist, especially to provide surveillance of pollutant concentrations in marine resources that are harvested for human consumption. For example, MAFF report annually on concentrations of pollutants in fish muscle sampled from commercially caught fish at markets around the United Kingdom (Franklin and Jones, 1995; Jones and Franklin, 1997). This sampling programme is well designed to provide information relevant to concerns about pollutant exposure of people consuming fish. However, it does not satisfy the need to understand the dynamics of pollutants in marine ecosystems as it provides little insight into the sources of the pollutants, into the distribution of the pollutants through the food web, or into variations in pollutant burdens related to season, fish size or behaviour. Since many pollutants are stored in specific tissues and may occur only at very low concentrations in muscle tissues, the sampling exclusively of muscle provides little information on pollutants found predominantly in other tissues. Some other programmes of pollutant surveillance focus on a particular indicator species, such as the blue mussel *Mytilus edulis* (Goldberg, 1978), grey seal *Halichoerus grypus* (Addison *et al.*, 1984), or cod *Gadus morhua* (Scott *et al.*, 1981). The use of seabirds as monitors of marine pollution has been advocated many times (Chapdelaine *et al.*, 1987, Furness, 1987, 1993, Gilbertson *et al.*, 1987; Becker, 1989, 1991, Walsh, 1990, Furness *et al.*, 1995, Monteiro and Furness, 1995, Barrett *et al.*, 1996, Elliott *et al.*, 1996, Becker *et al.*, 1998). In this review we consider the usefulness of seabirds as a means of monitoring pollutants in marine ecosystems, and highlight particular situations where monitoring of pollutants in seabirds is highly desirable as an especially cost-effective and informative procedure.

3.2 Reasons for selecting biomonitors rather than physical samples

Measuring concentrations of pollutants in seawater and sediment can be technically demanding because of the low concentrations of most pollutants found, and the problems of avoiding contamination of samples during storage or during preparation for analysis. Pollutants in seawater or in sediments may not be available to be taken up by biota due to their chemical form or due to being bound to surfaces or to macromolecules. Indeed, concentrations of many pollutants in seawater show positive correlations with concentrations of nutrients in the water, indicating that the concentration of dissolved pollutant in the water is a reflection of primary productivity (with higher primary production leading to a greater uptake of the pollutant from the water into the biota). Then the concentration of the pollutant in the water is not a measure of the amount of the pollutant reaching the water mass. With regard to risks to human health, concentrations of pollutants in marine sediments or in seawater may be much less relevant than the measurement of amounts of pollutant in fish or other marine organisms of high trophic positions. In particular, the ability of biota to 'integrate pollutant signals over space and over time' by bioaccumulating pollutants in tissues, allows an equivalent level of measurement accuracy to be obtained from a smaller number of samples of animals than for samples of seawater or sediment. Essentially, the variance in measurements in biota is usually much less than the variance in measurements of physical samples (Furness and Greenwood, 1993) therefore increasing power for trend analysis. Together with the biomagnification of chemicals this lower variance has the consequence that animals and especially seabirds show intersite differences in contamination more distinctly than water or sediment (Table 3.1). In general, the sampling, handling and chemical analysis of samples of water, sediment or of marine invertebrates are much more complex and expensive than that of vertebrates.

3.3 Seabirds as biomonitors of marine pollution

3.3.1 Oil pollution

The use of seabirds as monitors of oil pollution at sea has been reviewed in a number of recent publications (Camphuysen and Van Franeker, 1992, Dahlmann *et al.*, 1994, Camphuysen, 1995, 1998, Wiens *et al.*, 1996, Furness and Camphuysen, 1997). Beached bird surveys carried out predominantly by amateurs with organisation and data interpretation by professional staff (usually from NGOs) provide clear evidence of long term trends in oiling rates of seabirds (Figure 3.1) and differences in oil impacts between regions (Figure 3.2). There is evidence to show that oiling indices based on proportions with oil of beached seabirds gives a reasonable measure of the numbers of oil slicks at sea, although factors such as wind direction and numbers of seabirds dying from starvation or disease can confound the picture (Stowe, 1982). Recent development of fingerprinting oil from carcasses permits identification of the source of oil on birds and can be used in prosecutions for discharge of oil at sea (Dahlmann *et al.*, 1994). Toxic effects of oil ingested by seabirds have been reviewed several times (e.g. Briggs *et al.*, 1996), but are unlikely to provide a useful monitor of oil impact on seabirds. We do not consider seabirds as monitors of oil pollution further in this review, but refer those interested in this topic to the papers listed above.

Table 3.1: Average concentrations of environmental chemicals in different species of the food chain of the Wadden Sea 1986-1992 at three areas of different degree of contamination (Elbe estuary: high; East- and North Frisian Islands: low). dw = dry weight; fw = fresh weight; fatw = fat weight; ~ values taken from figures.

Contaminant and matrix		**Wadden Sea area**	
	East Frisian Islands	**Elbe estuary**	**North Frisian Islands**
mercury			
water (ng/l)[1]	40	50	11
sediment (mg/kg)[5]	0.4	0.5	0.3
Mytilus edulis (mg/kg dw)[2]	~ 0.2	~ 0.4	~ 0.0
Platichthys flesus (muscle, mg/kg fw)[3]	0.12-0.28	0.14-0.60	0.03-0.09
Haematopus ostralegus (egg, mg/kg fw)[4]	0.3	0.5	0.2
Sterna hirundo (egg, mg/kg fw)[4]	1.0	7.6	0.5
PCBs			
sediment (µg/kg/C-org)[5]	192-1491	421	26-318
Mytilus edulis (mg/kg dw)[2]	~ 0.07	~ 0.07	~ 0.05
Platichthys flesus (liver, mg/kg fatw)[6]	5.0	8.0-9.2	4.0-4.6
Haematopus ostralegus (egg, mg/kg fw)[4]	2.3	2.0	1.9
Sterna hirundo (egg, mg/kg fw)[4]	2.1	7.1	2.8
ppDDE			
Platichthys flesus (liver, mg/kg fatw)[6]	0.26	0.71-0.85	0.18-0.19
Haematopus ostralegus (egg, mg/kg fw)[4]	0.11	0.27	0.15
Sterna hirundo (egg, mg/kg fw)[4]	0.14	0.91	0.20
HCB			
Platichthys flesus (liver, mg/kg fatw)[6]	0.05	0.34-0.55	0.02-0.04
Haematopus ostralegus (egg, mg/kg fw)[4]	0.01	0.06	0.01
Sterna hirundo (egg, mg/kg fw)[4]	0.02	0.30	0.03

1) Haarich (1994), values from 1986-1991; 2) QSR (1999), 1990; 3) Harms (1994); 4) Becker *et al.* (1991), 1989; 5) Koopmann *et al.* (1993), 1989-1992; 6) v. Westernhagen (1994), 1989

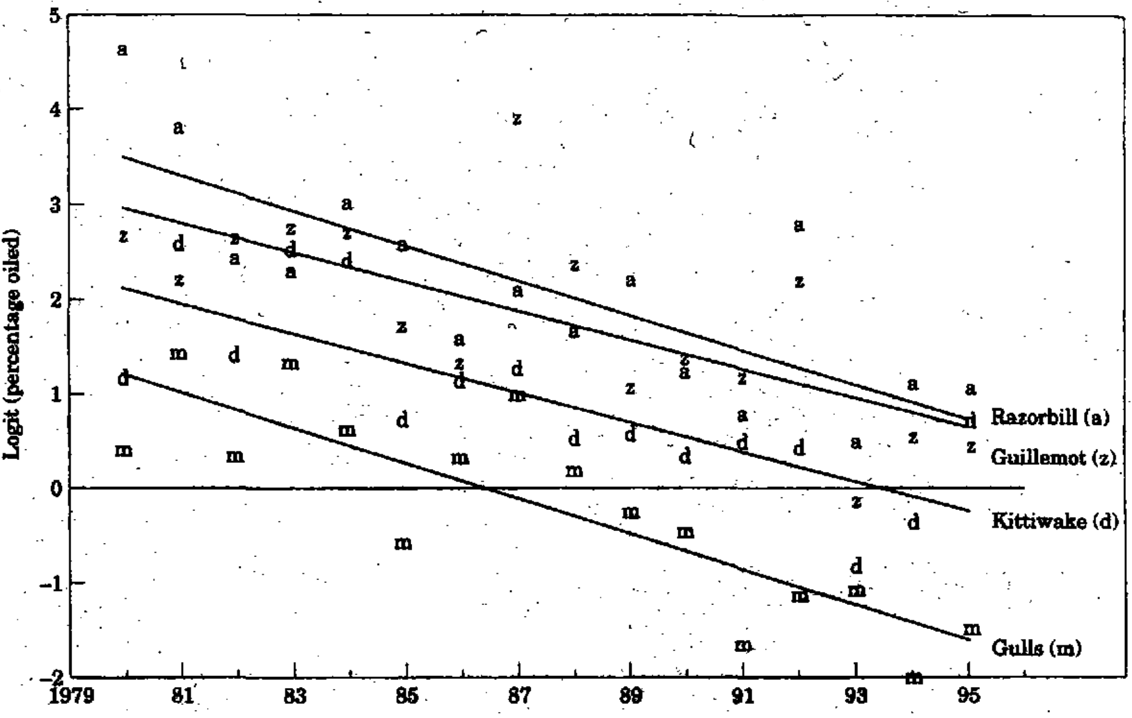

Figure 3.1. Trends in oil rates in razorbills, guillemots, kittiwakes and *Larus* gulls stranded at the mainland coast in The Netherlands, 1979-1995. Data from Camphuysen (1995).

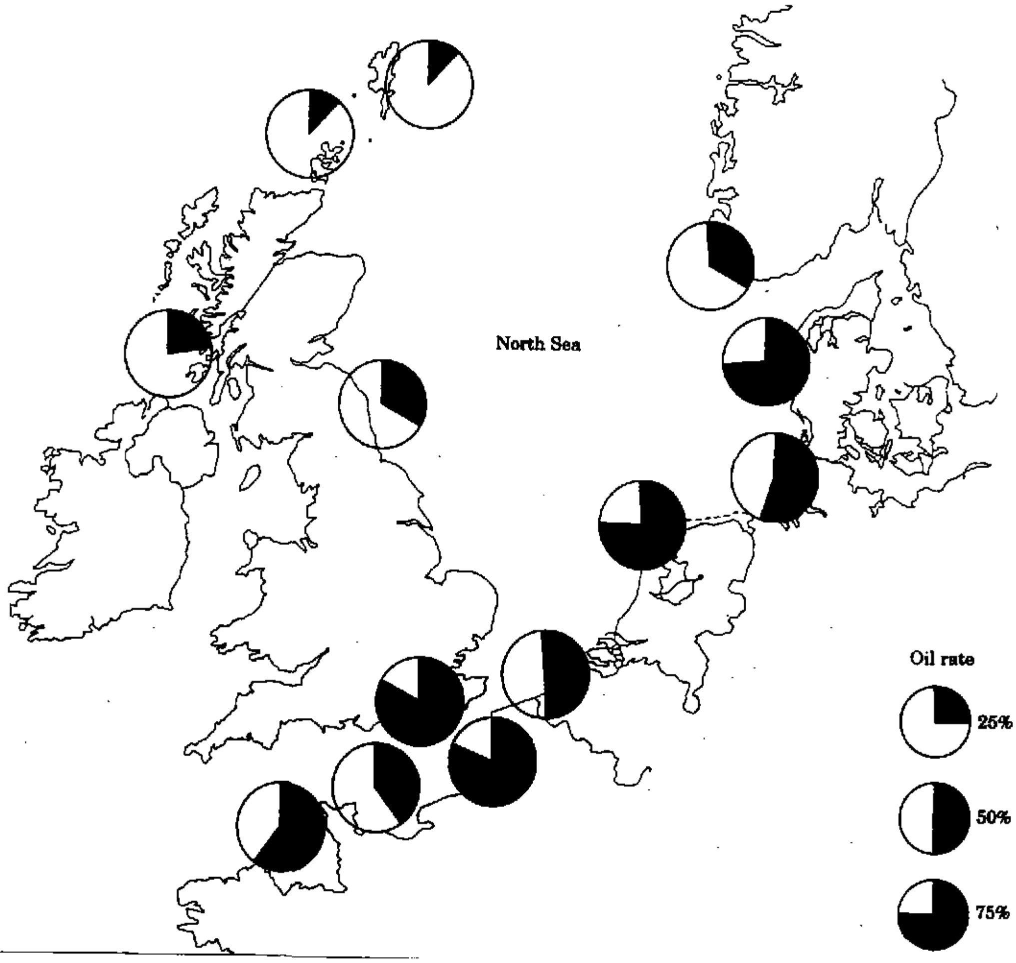

Figure 3.2. Differences in oil rates of guillemots in western Europe. Data from Camphuysen (1995).

3.3.2 Plastic particle pollution

Use of seabirds as monitors of plastic particle pollution on the ocean surface has been suggested by a number of authors (Furness, 1985, 1993, Ryan, 1987, Spear *et al.*, 1995, Blight and Burger, 1997) because some seabirds, especially petrels, accumulate large numbers of plastic particles in their gizzard, and may suffer harmful effects on their ability to process food (Ryan 1988). Sampling seabirds to measure quantities of ingested plastic requires obtaining dead birds or killing birds since the stomach contents must be obtained. Procedures that offload the proventriculus contents by 'stomach-pumping' or 'wet-offloading' do not extract material from the gizzard, which is where the vast majority of plastic is stored. Thus sampling proventriculus contents from live seabirds provides very little data on plastic ingestion and is unlikely to be an effective means of monitoring plastic ingestion. Killing seabirds as a means of monitoring pollution is undesirable. However, there are two possible sources of seabird gizzards that do not require killing of healthy birds. It may be possible to monitor plastic ingestion by sampling from petrels obtained from beached bird surveys (e.g. fulmars *Fulmarus glacialis* on the European beaches). However, this runs the risk that the birds washed up on beaches do not represent the population as a whole. Beached birds are likely to be predominantly juveniles rather than adults, and birds that have died slowly may have ingested plastic more or less than birds that are healthy and feeding well. Such biases may be difficult to quantify. Another possible source of gizzards from petrels may be from colonies where birds are killed in numbers by predators or accidents. At some colonies petrels form the main prey of skuas and gizzards may be obtained from some of the birds killed by skuas before the skuas have eaten them. At other colonies, birds may be killed by cats or rats or due to specific hazards. For example, shearwater fledglings at some colonies die when attracted to lights; prions at some colonies become tangled in vegetation. Sampling on a regular basis over years at such sites might provide indications of long term trends in plastic particle pollution. There is evidence that plastic particle burdens in pelagic seabirds are increasing and that this is a problem that needs further attention, but this topic will also not be considered further here, since we assume that the main focus of interest is in pollution by chemicals.

3.3.3 Organochlorines

Organochlorine concentrations have been measured in the physical environment (e.g. Bignert *et al.*, 1998), in marine invertebrates (e.g. Johansen *et al.*, 1996, Mattig *et al.*, 1997), in fish (e.g. von Westernhagen, 1994, Jones and Franklin, 1997, Kennish and Ruppel, 1998, Mattig *et al.*, 1997), and in various populations of marine mammals (e.g. Addison *et al.*, 1984, Jarman *et al.*, 1997) and seabirds (e.g. Mehlum and Daelemans, 1995, Savinova *et al.*, 1995, Focardi *et al.*, 1996, Jones *et al.*, 1996, Joiris *et al.*, 1997, Van Den Brink, 1997, Van Den Brink *et al.*, 1997).

Being lipid-soluble, organochlorines tend to accumulate in the lipid-rich tissues of animals, and biomagnify through the food chain, so that animals high in marine food chains tend to carry the largest body burdens and have the highest tissue concentrations (Figure 3.3, Table 3.2, Table 3.3). The variation of organochlorines within the seabird samples, however, is similar or even lower compared with that of their food (Table 3.2.).

Table 3.2. Mean concentrations (µg g^{-1} wet weight) and coefficients of variation for DDE and PCBs in marine organisms:

Species	Site	Age	Tissue	n	mean and CV-PCBs	mean and CV-DDE	Ref.
Herring	Nova Scotia	4 years	Muscle	29	0.25, 108%	0.06, 490%	1
Herring	Gulf of St. Lawrence	-	Muscle	26	0.44, 98%	0.09, 506%	1
Herring	Wadden Sea	2-3 years	Whole	7	0.03, 25%	0.005,1) 29%	2
Sandeel	Wadden Sea	2-3 years	Whole	8	0.04, 40%	0.002,1) 83%	2
Plaice	Wadden Sea	2 years	Whole	7	0.02, 30%	0.002,1) 28%	2
Flounder	Norway	-	Liver	10	0.03, 63%	0.06, 116%	1
Cod	Norway	-	Liver	18	0.45, 57%	0.70, 79%	1
Cod	Nova Scotia	5 years	liver	38	1.81, 49%	0.28, 50%	1
Cod	Nova Scotia	2-9 yrs	Liver	100	1.71, 53%	0.28, 54%	1
Grey seal	Nova Scotia	imm.	Blubber	8	5.00 70%	1.50, 40%	1
Grey seal	Nova Scotia	adult	Blubber	8	15.7, 37%	2.50, 32%	1
Leach's petrel	Newfoundland 1984	eggs	Egg	5	1.16, 24%	0.40, 28%	1
Leach's petrel	Bay of Fundy 1984	eggs	Egg	5	3.44, 36%	1.05, 39%	1
Puffin	Newfoundland 1984	eggs	Egg	5	0.99, 12%	0.30, 19%	1
Puffin	Bay of Fundy 1984	eggs	Egg	5	3.20, 20%	0.74, 24%	1
Common Tern	Wadden Sea	egg	Egg	10	4.65, 33%	0.39, 60%	3
Herring Gull	Wadden Sea	egg	Egg	10	1.45, 40%	0.39, 60%	3
Oyster-catcher	Wadden Sea	egg	Egg	10	2.66, 48%	0.11, 46%	3

1) ? DDT ; References: 1 Gilbertson *et al.* (1987) 2 Mattig *et al.* (1996) (year 1992)
3 Becker *et al.* (1991) (year 1987; islands Mellum, Minsener Oldeoog)

Table 3.3. Biomagnification factors between organochlorines in food and eggs of oystercatcher, herring gull and common tern from Spiekeroog, German Wadden Sea in 1993 (Mattig *et al.*, 1996). See Fig. 5.3 for PCB- concentrations

		Biomagnification factors		
Species	food	PCBs	DDTs	HCB
Oystercatcher	Benthic animals1)	4-14	3-23	12-21
Herring gull	Benthic animals1)	5-19	6-46	17-30
	Fish 2)	2-3	2	2-3
Common tern	Fish 2)	3	3	3-5

Cardium, Mytilus; 2) Herring, Plaice

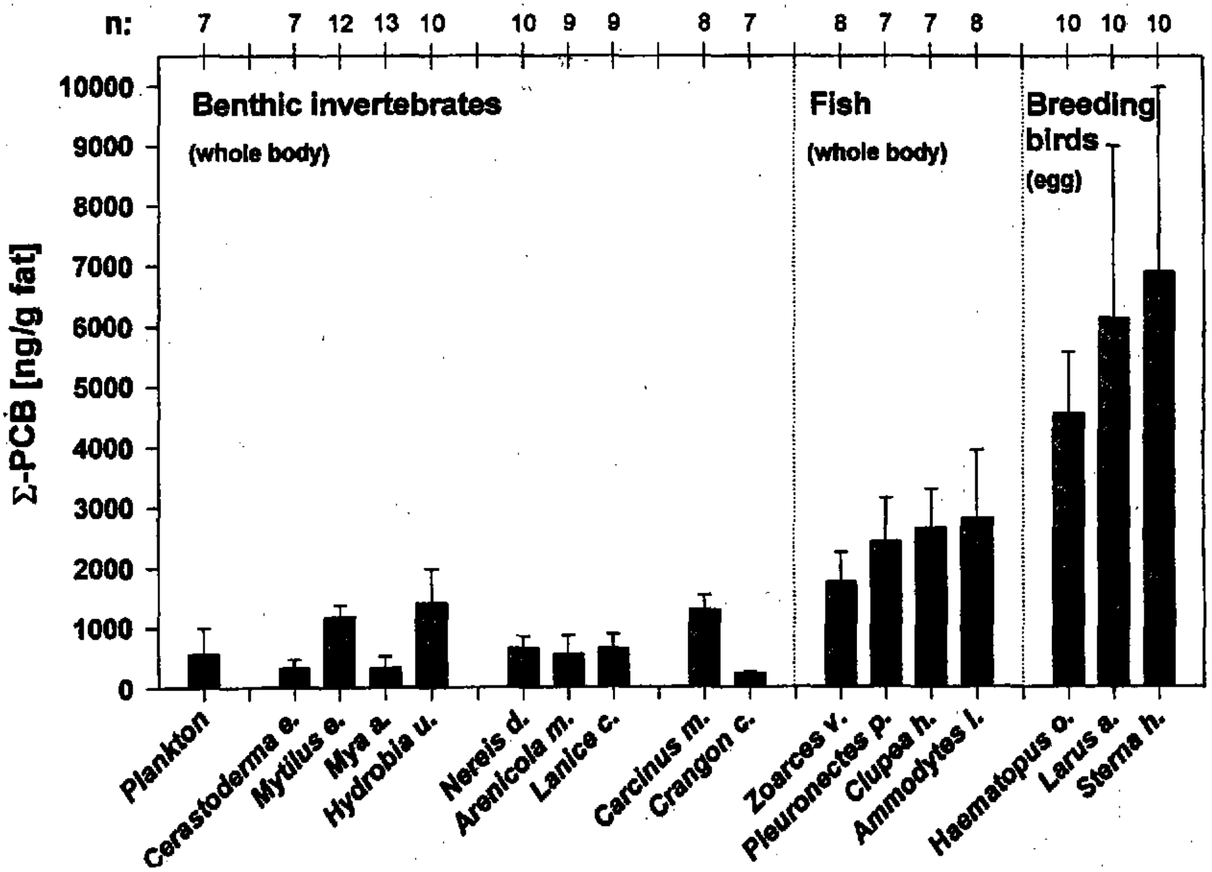

Figure 3.3. Biomagnification of PCBs in the food web of the Wadden Sea. Sum of the concentrations of 8 PCB-congeners on fat weight basis is presented for plankton, for 9 benthic invertebrate, 4 fish (juvenile stages) and 3 seabird species. Means + 1 standard deviation (Mattig *et al.*, 1996).

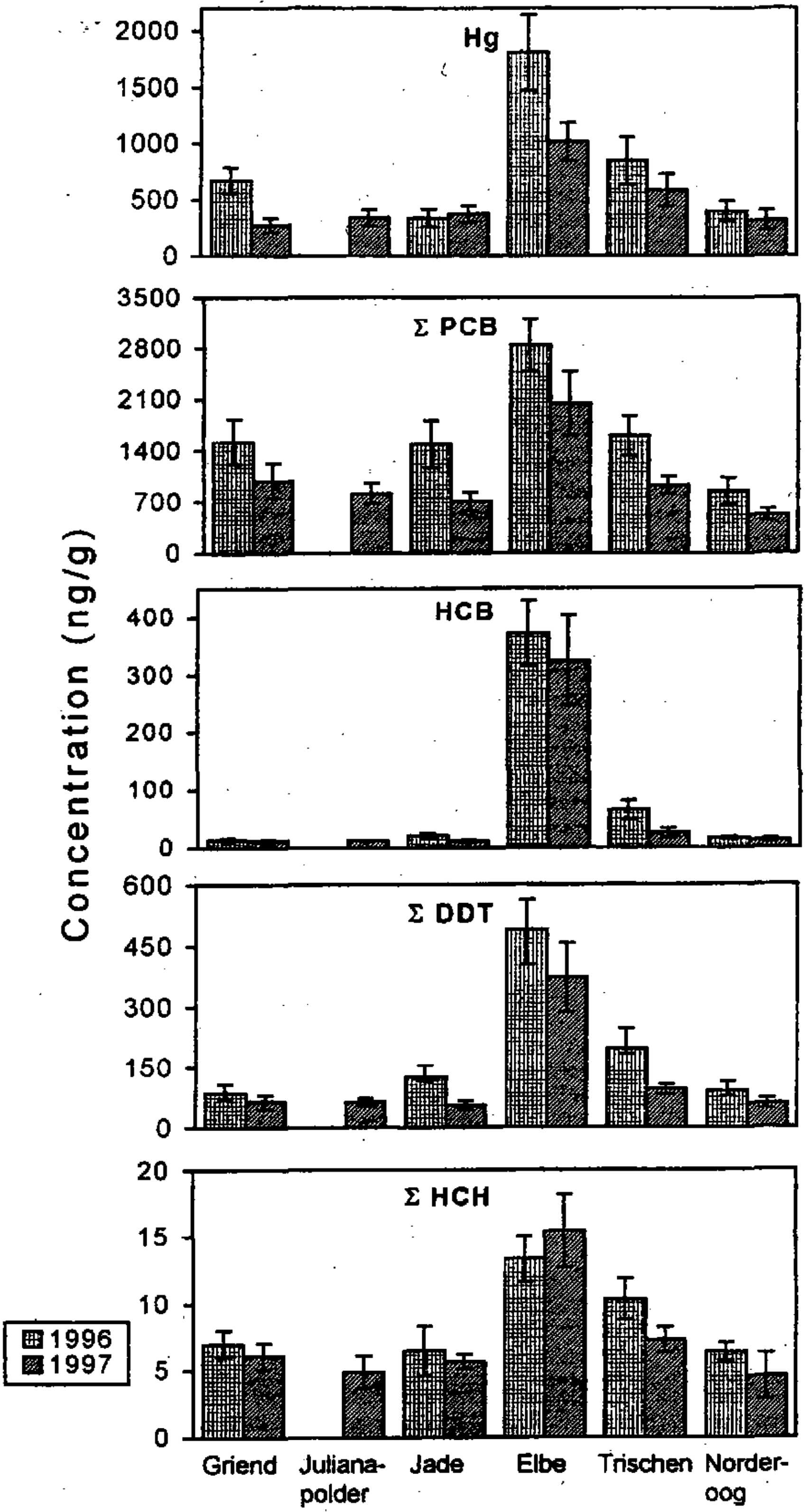

Figure 3.4. Geographical patterns of mercury and organochlorine pollution of common tern eggs in the Wadden Sea in 1996 and 1997 (six sites; from Becker *et al.*, 1998). Mean values ± 95% coefficients of variation, n = 10 eggs each.

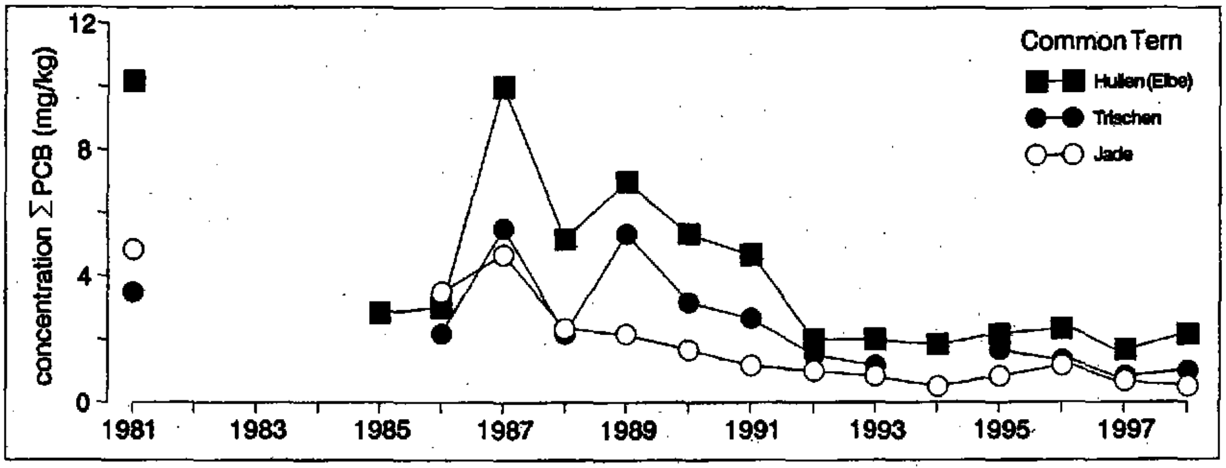

Figure 3.5. Temporal trends of PCB-concentration in eggs of common terns from three selected breeding sites in the Wadden Sea from 1981-1997 (Becker *et al.* 1998).

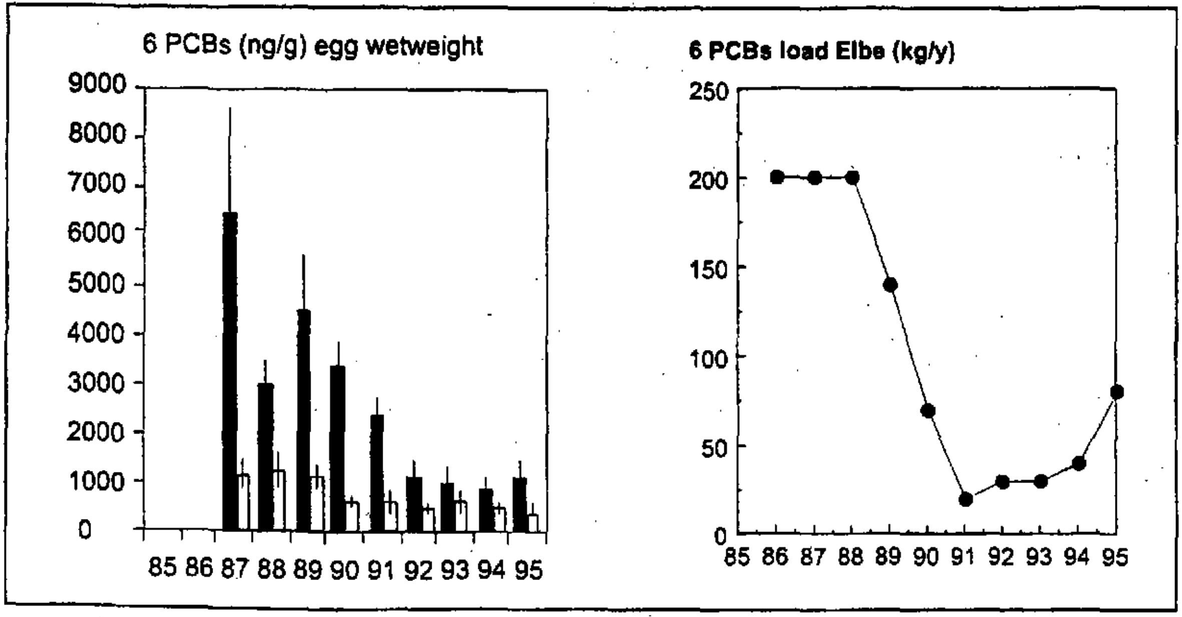

Figure 3.6. Temporal trend in PCB-loads of the Elbe river compared to the trend in PCB-concentration in eggs of common terns (black columns) and oystercatchers (white columns) breeding at the Elbe estuary (Bakker *et al.*, 1997).

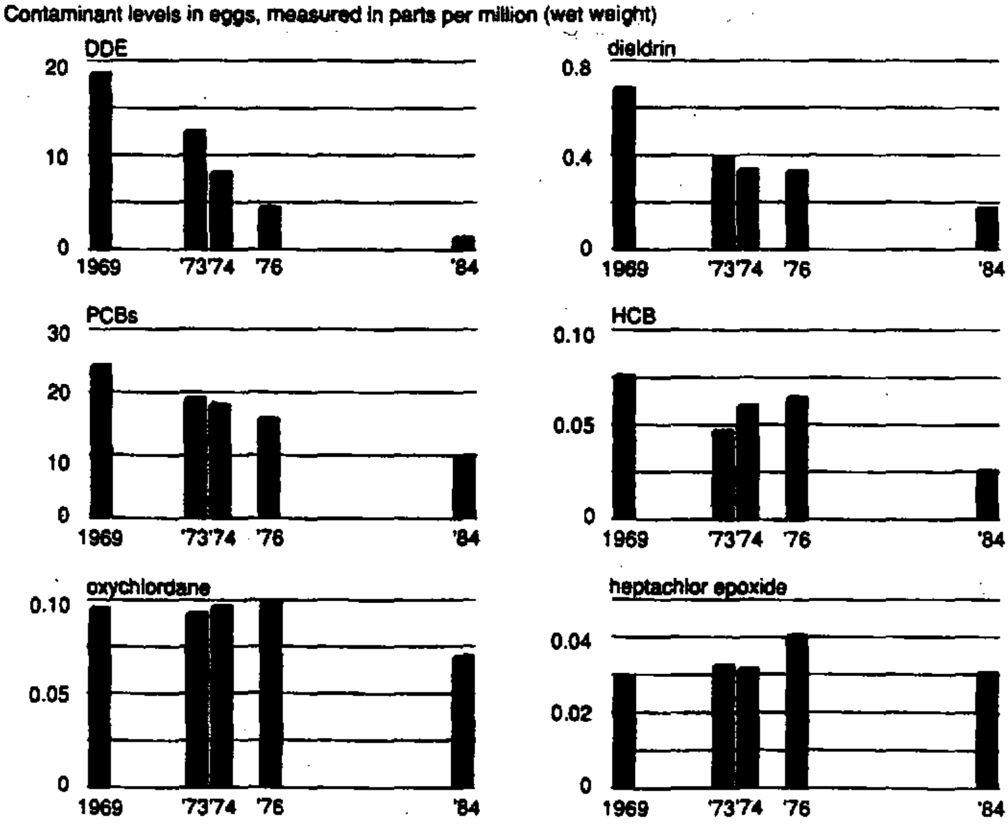

Figure 3.7. Temporal trends in organochlorine levels in gannet eggs from Quebec, Canada, from 1969-1984 (Chapdelaine *et al.*, 1987, Elliott *et al.*, 1988).

PCBs are industrial chemicals and consist of up to 209 congeners. The degree of metabolization of the PCB-mixture in seabirds depends on the species, on the level of PCB-pollution in its environment as well as on the length of the time of year the birds spend there (Beyerbach *et al.*, 1993, Denker *et al.*, 1994).

Different organochlorines, and even different congeners of PCBs differ considerably in toxicity (Niimi, 1996) and the toxicity varies considerably between different groups of animals. As a broad generalisation, seabirds tend to be less sensitive to toxicity of organochlorines than are marine mammals or terrestrial birds. Almost all sampling of adult birds and mammals for monitoring of organochlorine concentrations has been sampling of liver or muscle tissues, so that animals have to be killed or samples taken opportunistically from drowned or wrecked samples. These may introduce bias due to starvation and consequent mobilisation of lipid reserves, and so organochlorines. High tissue (especially liver) concentrations of organochlorines can indicate tissue wastage rather than high body burdens of the pollutants.

Seabird eggs have been sampled to provide more reliable monitoring of organochlorines, and this permits an assessment of geographical patterns of organochlorine pollution (Becker *et al.*, 1998) (Figure 3.4) as well as long term trend analysis (Chapdelaine *et al.*, 1987, Elliott *et al.*, 1988, 1996, Bignert *et al.*, 1995, Becker *et al.*, 1998) (Figures 5.5 to 5.7). The change in loads of organochlorines in the aquatic environment, e.g. of PCBs in the Elbe river, is reflected immediately by the seabird egg concentrations (Figure 3.6). While levels of many organochlorines like DDE, dieldrin, HCB and PCBs have been shown to have decreased since the 1970s (e.g. Figures 5.5 to 5.7), levels of some other organochlorines have shown no trend (Figure 3.7) and a few have increased (e.g. Becker *et al.*, 1998). Analysis of organochlorines in seabirds resident at high latitudes (Arctic and Antarctic) has provided evidence of the global transport of these pollutants, although concentrations in resident seabird species tend to be low, and less than in seabirds that breed in these regions but migrate to lower latitudes in winter (Lønne *et al.*, 1997, Van den Brink, 1997).

While eggs tend to be sampled at a very clearly defined and consistent time of year, avoiding problems of interseasonal variation, long term trends in organochlorine concentrations in tissues of adult seabirds can be obscured where there are pronounced seasonal variations and sampling across years is not limited to a short period (Joiris *et al.*, 1997).

It is worth emphasising that the organochlorine concentrations in seabird eggs reflect local pollution in the vicinity of each breeding colony, even in seabird species that are transequatorial migrants such as common tern *Sterna hirundo* (see Figure 3.4). After arrival in the breeding area terns and other seabirds need high amounts of supplementary food presented by the males during the short prelaying period, enabling females to raise weight and produce eggs (common tern: up to 50% weight increase during 10 days, Wendeln and Becker, 1996). Thus eggs provide a measure of pollution on a scale set by the foraging range of birds from their breeding colony. Exposure to these pollutants in the wintering area apparently has little or no influence on the amounts put into the egg. This may not be so in all seabird species but does appear to be a general pattern.

3.3.4 Mercury

Mercury is the heavy metal most likely to present a toxic hazard in marine foods. Particularly high concentrations occur in long-lived predatory and deep-sea fish. It is readily converted by bacteria from inorganic forms into methylmercury in low-oxygen environments (deep water or in anoxic sediments). Methylmercury is not only much more toxic to vertebrates, but also is lipid-soluble so tends to biomagnify through food chains and is accumulated in lipid-rich tissues of vertebrates in a similar way to organochlorines (Tables 5.4–5.6.). As in case of organochlorines the within-seabird-sample variation is in the same order as variation in fish, the main prey (Tables 5.4–5.5.). Furthermore, while the assimilation efficiency of inorganic mercury from digested food is very low, assimilation efficiency of methylmercury is around 95%. Thus most of the mercury taken into the tissues of fish, marine mammals and seabirds is methylmercury. However, at least some marine mammals and probably some seabirds can demethylate methylmercury in order to store it in a relatively nontoxic, and non-labile, inorganic form in the liver.

Mercury concentrations increase with age in fish, and in marine mammals, but not in seabirds (Furness *et al.*, 1990, 1993). Seabirds lose their mercury into growing feathers. All mercury in feathers is methylmercury (Thompson and Furness, 1989a), even in seabirds where the bulk of the mercury in the liver is inorganic (Thompson and Furness, 1989b). Concentrations of mercury in feathers vary according to the moult pattern. Feathers renewed first in the major autumn moult have highest concentrations, and these decrease as the moult progresses as the body pool of mercury is depleted (Furness *et al.*, 1986, Braune, 1987, Braune and Gaskin, 1987). A sample of several small body feathers provides a good measure of the mercury level in an individual bird, and is the most appropriate way of using feathers from live birds or museum skins for mercury monitoring. Female seabirds may have slightly lower concentrations of mercury than found in males because they put some mercury into the eggs (Becker, 1992) but differences between the sexes tend to be small (Lewis *et al.*, 1993). Both laboratory experiment and oral dosing of wild birds in the field with mercury has shown that mercury concentrations in blood and internal organs relates closely to the ingested dose, and that concentrations in feathers are dependent on the mercury level in blood during feather growth, which itself is a function of mercury level in the diet.

Mercury concentrations in seabirds can be related to mercury levels in their prey (Monteiro *et al.*, 1995, 1998; Figure 3.8), and in particular show that seabirds feeding on mesopelagic prey have much higher mercury burdens than seabirds feeding in other food chains (Tables 5.5, 5.6). This reflects a trend for mercury levels to be higher in fish from deeper water (Monteiro *et al.*, 1996), presumably due to methylation of mercury in deep low-oxygen water permitting greater assimilation of mercury into biota.

Table 3.4. Mean concentrations (µg g^{-1} wet weight) and coefficients of variation for mercury in marine organisms in Shetland. Median values are given for each group.

Group	Species	Tissue	n	mean µg g^{-1} wet weight	CV	ref
Fish	sandeel	whole	18	0.04	25%	1
	cod	whole	79	0.05	40%	1
	whiting	whole	20	0.07	29%	1
	plaice	whole	25	0.03	33%	1
		MEDIANS		**0.045**	**31%**	
Seabirds	guillemot	chick down	29	1.24	22%	2
	kittiwake	chick down	12	1.43	26%	2
	Arctic tern	chick down	24	2.03	32%	2
	Arctic skua	chick down	36	2.00	45%	2
	great skua	chick down	58	4.15	34%	2
		MEDIANS		**2.0**	**32%**	
	kittiwake	chick feathers	26	0.37	32%	2
	Arctic tern	chick feathers	15	0.69	20%	2
	Arctic skua	chick feathers	30	0.46	47%	2
	great skua	chick feathers	28	1.22	31%	2
		MEDIANS		**0.55**	**32%**	
	fulmar	adult body feathers	12	1.1	27%	1
	kittiwake	adult body feathers	14	2.4	25%	1
	kittiwake	adult body feathers	21	3.31	36%	2
	razorbill	adult body feathers	16	2.1	14%	1
	guillemot	adult body feathers	17	1.5	27%	1
	guillemot	adult body feathers	34	0.99	34%	2
	puffin	adult body feathers	10	5.2	52%	1
	great skua	adult body feathers	197	7.0	73%	1
	great skua	adult body feathers	54	6.34	41%	2
	Arctic tern	adult body feathers	23	0.86	27%	2
	Arctic skua	adult body feathers	28	2.52	88%	2
		MEDIANS		**2.4**	**34%**	

References: 1 Thompson *et al.* 1991, 2 Stewart *et al.* 1997

Table 3.5. Mean concentrations (µg g^{-1} wet weight) and coefficients of variation for mercury in marine organisms in Azores. Median values are given for each group.

Group	Species	Tissue	n	mean µg g^{-1} wet weight	CV	Ref
Fish	*Macroramphosus scolopax*	Whole	42	0.16	34%	1
	Scomber japonicus	Whole	4	0.27	26%	1
	Capros aper	Whole	19	0.44	71%	1
	Trachurus picturatus	Whole	20	0.45	81%	1
	Maurolicus muelleri	Whole	11	1.03	22%	1
	Electrona rissoi	Whole	10	0.97	44%	1
	Myctophum punctatum	Whole	6	0.96	27%	1
	Ceratoscopelus maderensis	Whole	14	1.20	9%	1
		MEDIANS		**0.7**	**30%**	
Seabirds	Bulwer's petrel	Egg	16	1.60	41%	3
	Cory's shearwater	Egg	23	0.51	21%	3
	Common tern	Egg	20	0.32	50%	3
	Roseate tern	Egg	17	0.45	43%	3
		MEDIANS		**0.5**	**42%**	
	Cory's shearwater	Chick feathers	7	4.2	18%	2
	Yellow-legged gull	Chick feathers	5	4.0	38%	2
	Common tern	Chick feathers	42	1.6	41%	2
	Roseate tern	Chick feathers	13	1.2	47%	2
		MEDIANS		**2.5**	**40%**	
	Bulwer's petrel	Adult body feathers	24	22.4	22%	2
	Cory's shearwater	Adult body feathers	40	6.3	33%	2
	Little shearwater	Adult body feathers	4	2.4	48%	2
	Madeiran storm petrel (June breeders)	Adult body feathers	25	9.5	23%	2
	Madeiran storm petrel (November breeders)	Adult body feathers	27	16.0	27%	2
	Common tern	Adult body feathers	28	2.4	28%	2
	Roseate tern	Adult body feathers	21	2.2	36%	2
		MEDIANS		**6.3**	**28%**	

References: 1 Monteiro *et al.* 1996, 2 Monteiro *et al.* 1995, 3 Monteiro *et al.* 1998

Table 3.6. Biomagnification factors between mercury in food and in seabird feathers for populations in Azores. From Monteiro *et al.* 1998.

Species	Mercury in food ($\mu g\ g^{-1}$, dry weight)	Mercury in adult body feathers ($\mu g\ g^{-1}$ fresh weight)	Biomagnification factor (fresh weight to fresh weight)
Bulwer's petrel	0.318	22.3	225
Madeiran storm petrel (hot season)	0.243	11.1	146
Madeiran storm petrel (cool season)	0.432	17.4	129
Cory's shearwater	0.131	5.4	132
Little shearwater	0.72	3.1	138
Common tern	0.54	2.1	125

Geographic variations in mercury contamination can be seen from sampling seabird feathers from different colonies, or from sampling eggs or chick down or feathers. For example, Renzoni *et al.* (1986) showed higher levels of mercury in Cory's shearwaters *Calonectris diomedea* in Mediterranean colonies than in Atlantic colonies. Becker *et al.* (1993) showed that feathers from tern and gull chicks indicated local patterns of mercury pollution of the German North Sea coast attributable to river inputs of mercury into the southern North Sea. Also eggs clearly indicate spatial variation (Figure 3.4) and temporal trends of mercury in the marine environment (Becker *et al.*, 1998).

Joiris *et al.* (1997) found a strong increase in the mercury levels in guillemots in the southern North Sea through the winter, where these birds spend the summer in areas with much lower mercury exposure (the northwestern North Sea) (Figure 3.9).

Body feathers from adult seabirds can be used to show long term trends in mercury contamination since museums hold material dating back to the 1850s. Inorganic mercury contaminating study skins can be separated from the methylmercury put into feathers by the birds by making a simple biochemical fractionation, so that only the mercury of biological relevance is measured. Such studies have shown approximately 400% increases in mercury in seabirds from the UK coast (Thompson *et al.*, 1992; Figure 3.10), and in the Azores region (Monteiro and Furness, 1997; Figure 3.11), but not in southern hemisphere seabirds (Thompson *et al.*, 1993b). These patterns match closely with predictions from modelling of atmospheric transport of mercury from industrial sources (Mason *et al.*, 1994, Fitzgerald, 1995), which predict a 4-fold increase in mercury in northern hemisphere ecosystems but little increase in the southern hemisphere. On the southern North Sea coast the pattern of mercury levels in herring gull *Larus argentatus* feathers from 1880 -1990 showed an about 300% increase during the second world war and a second wave of increase during the 1960s and 70s owing to the industrial development in central Europe (Thompson *et al.*, 1993a). So far as we are aware, only seabird feathers permit retrospective monitoring of mercury contamination in marine food webs over the last 150 years, whereas in terrestrial systems it is possible to monitor mercury concentrations in ice cores, peat layers and lake sediment columns (Swain *et al.*, 1992).

Whereas feathers reflect the bird's body burden with mercury only during the time of feather growth, bird blood can be used indicating the present-day mercury contamination all throughout the year (Kahle and Becker in press).

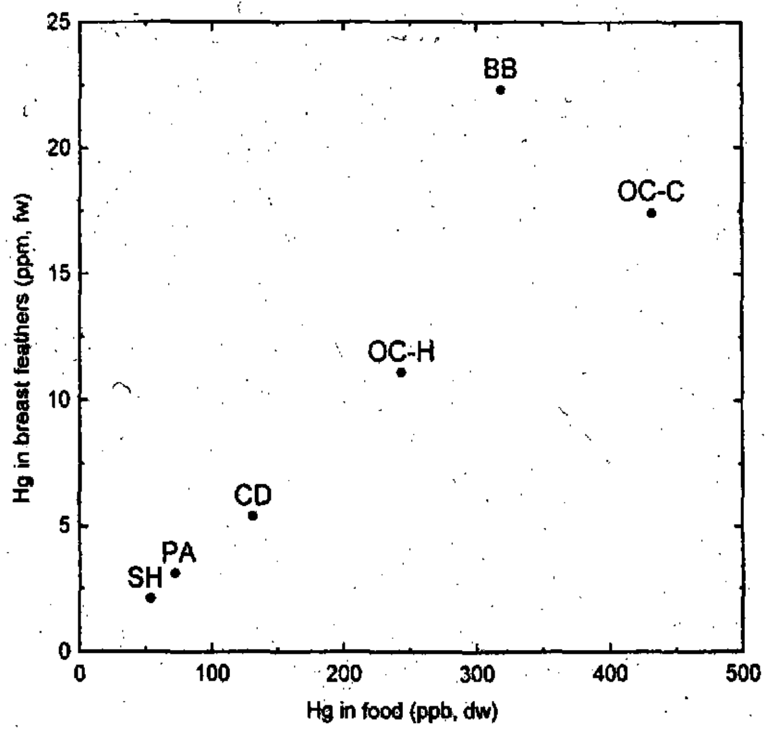

Figure 3.8. Relationship between mean mercury concentrations in breast feathers of seabirds from the Azores and in the food of these birds sampled during the breeding season at the colony. BB: *Bulweria bulweria*; CD; *Calonectris diomedea*; OC: *Oceanodroma* castro, H=June breeders, C=November breeders; PA: *Puffinus assimilis*; SH; *Sterna hirundo*. From Monteiro *et al.* (1998).

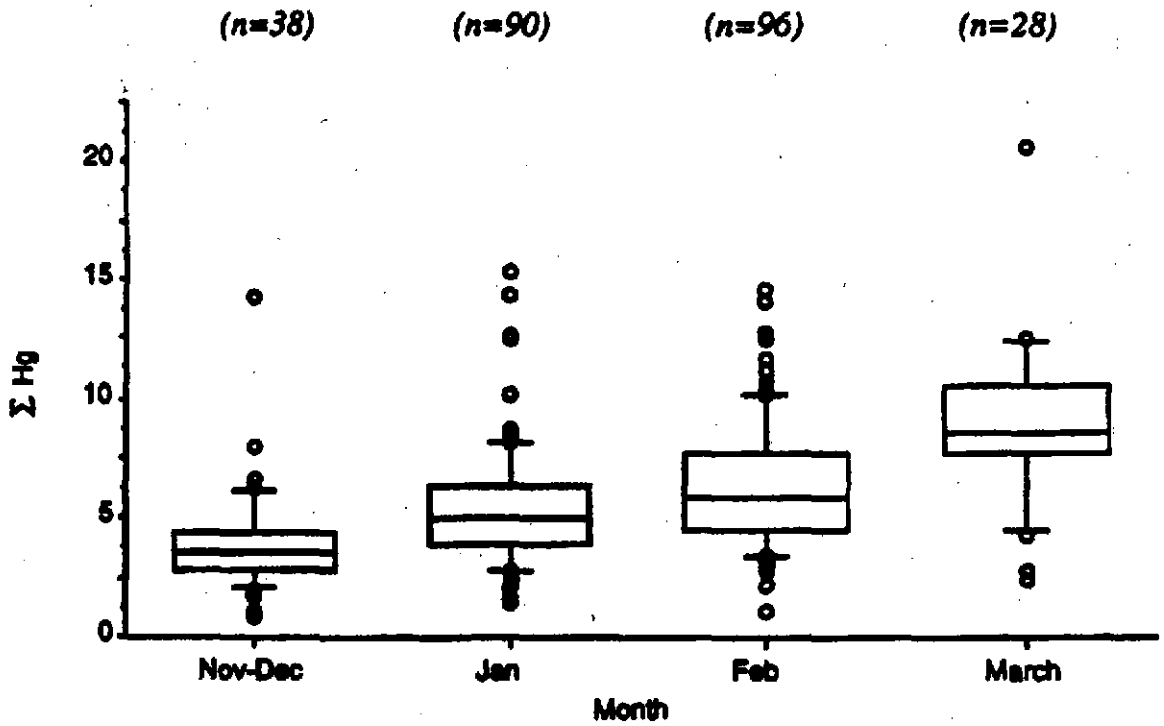

Figure 3.9. Mercury in common guillemot liver samples as a function of collection date (μg g^{-1} dw; Joiris *et al.*, 1998)

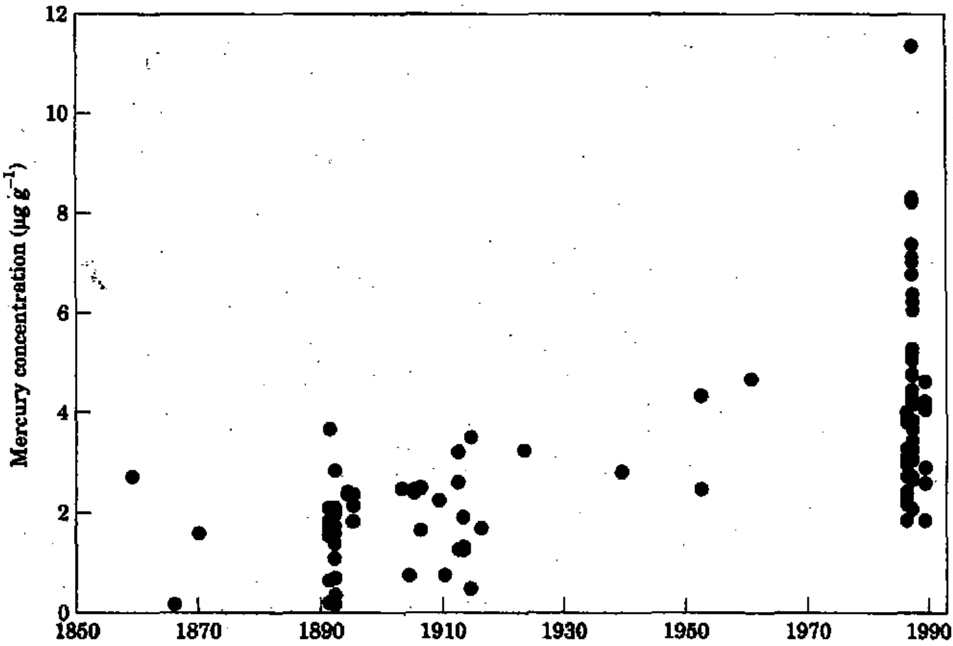

Figure 3.10. Mercury concentrations in body feathers of Atlantic puffins from south-west Britain and Ireland from 1850 to 1990. From Thompson *et al.* (1992).

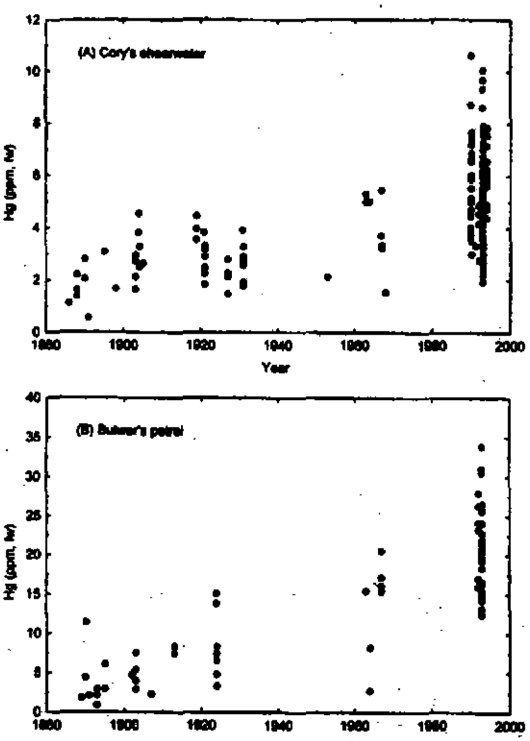

Figure 3.11. Mercury concentrations in body feathers of (A) Cory's shearwaters (which feed on epipelagic fish and squids) and (B) Bulwer's petrels (which feed on mesopelagic fish) in the Azores, from 1880 to 1995. From Monteiro and Furness (1997).

3.3.5 Organotin

Although organotin (butyltin, TBT) has mostly been monitored in molluscs (Morcillo *et al.*, 1997, Harino *et al.*, 1998), and with particular regard to imposex in whelks and developmental abnormalities in oysters, recently there has been a considerable increase of interest in the pronounced bioaccumulation (especially in the liver) of organotin in marine mammals (Lee, 1991, Iwata *et al.*, 1997, Tanabe *et al.*, 1998) and in seabirds (Guruge *et al.*, 1997, Kannan *et al.*, 1998). Factors resulting in high concentrations of organotin in particular species or populations of seabirds are not yet known, and there is a need for further work on the patterns of accumulation of organotin by seabirds and the toxic implications. It is as yet unclear whether organotin pollution can be monitored by sampling seabirds. So far, organotin levels have been measured in liver and kidney tissues of seabirds and marine mammals, requiring sampling of dead animals or the killing of animals. Guruge *et al.* (1996, 1997), however, show elevated TBT levels in feathers suggesting that birds excrete TBT, as mercury during moult, and that feathers could be used as an indicator for TBT contamination in wild birds.

3.3.6 Other metals

Cadmium is concentrated to high levels in the kidney of birds and mammals. Lead is concentrated particularly in bones but can also be measured in blood. These elements enter eggs or feathers from the blood only in minute amounts, but cadmium and lead can be deposited onto feather surfaces from the atmosphere (Hahn, 1991), and so using feathers to attempt to monitor amounts of these metals in the food chains of birds is confounded by problems of low concentrations and high likelihood of external contamination. Nevertheless, feathers have been used to assess pollution by a wide range of elements (Burger, 1993). New techniques permitting the location of atoms within or on the surface of feathers may permit this use to be developed with greater reliability. Several papers published in the 1970s-80s contain measurements of improbably high levels of metals in seabird feathers or eggs that must now be considered unreliable data.

Several papers provide details of concentrations of a range of elements in seabird tissues (e.g. Honda *et al.*, 1990, Elliott *et al.*, 1992, Wenzel and Gabrielsen, 1995, Kim *et al.*, 1996, 1998). This requires either killing of birds to obtain samples or the use of chance sampling opportunities. Wenzel and Adelung (1996) examined the possible use of oiled birds as a means of sampling for heavy metal monitoring.

3.3.7 Radionuclides

Seabirds are probably not very useful in radionuclide monitoring because levels do not tend to increase up food chains and assimilation efficiency of most radionuclides through the digestive system of seabirds is poor (Brisbin, 1993). Matishov *et al.* (1996) reported on Caesium-137 in seabirds in the Barents Sea, but very few data on radionuclide levels in seabirds are available. One might anticipate that levels in mollusc-eating shorebirds and sea ducks could be elevated in areas such as the Cumbrian coast, but this seems not to have been investigated.

3.4 Advantages of seabirds as biomonitors of pollution

Below we consider in turn each of the particular advantages that seabirds can provide as tool for monitoring particular marine pollutants. Disadvantages are considered separately in section 3.5.

3.4.1 Well known taxonomy and biology

The phylogeny of seabirds has been the subject of very detailed research. There still remain some minor uncertainties, such as the numbers of taxa within certain groups. For example molecular data suggest that some albatross species could be split into several closely-related but genetically distinct species (Robertson and Gales, 1998). The Madeiran storm petrel *Oceanodroma castro* may consist of sibling species with seasonally distinct breeding (Monteiro and Furness, 1998). Nevertheless, such examples are aspects of detail, and it is unlikely that significant changes to the phylogeny of seabirds will arise as a result of further research. Thus studies of pollutant levels can be based on a stable and well described phylogeny. Furthermore, the huge amount of research on the biology of seabirds means that the migration patterns, seasonal distribution, feeding ecology, breeding biology and physiology of seabirds is very well known. Of course, the amount of detail known about populations varies. There are some seabirds that have been little studied, whereas there are huge numbers of publications on the biology of some species such as herring gull, common guillemot *Uria aalge*, black-legged kittiwake *Rissa tridactyla* and common tern. It is likely that widespread and well studied species would also be most suitable as biomonitors of pollutants because a prerequisite for a biomonitor would be availability of satisfactory sample sizes and ease of sampling. The detailed knowledge of seabird ecology provides a good background for interpretation of patterns of pollutant levels in seabirds, whereas for many other groups of marine animals, too little is known of the ecology of the organisms to permit such interpretation. Thus, for example, knowledge of the seasonal pattern of moult permits the selection of particular feathers to assess mercury contamination in different food webs in which the same individual bird is feeding at different times of year (Thompson *et al.*, 1998a).

3.4.2 Tendency to accumulate high concentrations

Seabirds tend to feed at high trophic levels in marine food chains, and so pollutants that accumulate up food chains will be well represented in seabirds. These include organochlorines and methylmercury, which are lipid soluble pollutants with low solubility in water. Seabirds thus provide a potentially good biomonitor for lipid soluble organic pollutants, since concentrations in seabirds are likely to be relatively high, and careful choice of seabird species and sampling tissue should allow an appropriate spatial and temporal scale integration of the pollutant signal as well as giving an indication of the likely risk of toxic effects to animals high in the food chain (including man through harvesting of fin-fish and shell-fish stocks). In contrast, many water soluble pollutants with low lipid affinities, such as inorganic metals, show no trend of increased concentration with trophic level. In such cases, concentrations may be lower in seabirds than in some biota at low trophic levels. This is particularly true for large radionuclides such as uranium and plutonium, where molluscs or algae provide a more appropriate biomonitor than do seabirds (Brisbin, 1993). Nevertheless, certain metals accumulate to high concentrations in particular avian tissues. For example, cadmium concentrations are particularly high in seabird kidneys (Stewart *et al.*, 1996).

As biomagnification factors do not only increase with the kind of food of a species but also with the environmental burden by a chemical, seabirds indicate intersite or interyear differences in pollution more distinctly than other animal or physical samples (e.g. Table 3.1, Figure 3.4).

3.4.3 Ease of sampling

Almost all species of seabirds are colonial breeders, and so sampling large numbers of birds is often possible at selected colonies. Most seabirds breed at traditional sites every year, with the same adults usually nesting in the same territory each year, so that locations where seabird samples can conveniently be collected are highly predictable. When incubating, many adult seabirds are relatively easy to catch, and adults of some species are easy to catch while rearing chicks, but catching adults away from the nest and at times of year when the birds are not breeding can be difficult. Eggs and chicks can be sampled at appropriate dates during the breeding season. Seabird timing of breeding tends to be consistent from year to year, so that optimal dates for sampling are predictable. Behaviour of seabirds at the colony in response to human activity is highly variable from species to species. Birds of certain species panic and human disturbance can cause mortality of eggs or chicks, whereas other species are highly tolerant of disturbance. Choice of monitoring species and sites should take this into account. For example, cormorants tend to lose eggs or chicks when people enter their colony and are not ideal as a choice of monitoring species for this reason. In contrast, kittiwakes tend to remain on the nest and egg or chick losses due to human disturbance are very rare. Responses can also vary between colonies. Adult gannets *Sula bassana* on the Bass Rock are easily caught at the nest with little disturbance, whereas gannets at Grassholm or St Kilda tend to panic when a human approaches. At the latter sites, gannets very rarely see humans at their colony, whereas at the Bass Rock human visitors are numerous and regular and the birds have learned to adapt to them.

Responses of particular species of seabirds to human intrusions are well known, as are the locations and accessibility of colonies, so that it is very easily possible to plan, timetable and cost a sampling programme.

By contrast, marine mammals are very difficult to sample, and most studies of pollutants in marine mammals have been based on small sample sizes of animals found stranded or entrapped in fishing gear (Addison *et al.*, 1984, Lee, 1991, Kannan *et al.*, 1994, Becker *et al.*, 1997, Fossi *et al.*, 1997, Iwata *et al.*, 1997, Krahn *et al.*, 1997, Moessner and Ballschmiter, 1997, Tanabe *et al.*, 1998). The concentrations of pollutants in marine mammals may be of interest because they give an indication of exposure that humans would experience from a marine diet, or from consumption of marine mammal meat (Weihe *et al.*, 1996), and they may reach levels that are toxic to marine mammals and so are of concern in terms of marine mammal conservation (Fossi *et al.*, 1997). However, in terms of monitoring marine ecosystems, sampling of marine mammals is difficult to achieve regularly and reliably. Seabirds are much more amenable to sampling in sufficient quantity.

3.4.4 Choice of sampling tissues

The ideal tissues to sample depend on the pollutant of interest, but the selection of several sampling tissues can often provide a much greater depth of information than taking a single monitoring tissue. For example, mercury concentrations vary between feathers of an individual seabird in a way that reflects the pattern of moult (Furness *et al.*, 1986, Braune, 1987, Braune and Gaskin, 1987), and so sampling feathers grown at different times of year can indicate seasonal variation in mercury burdens of seabirds, and hence indicate seasonal patterns of mercury assimilation.

Adult seabirds tend to be long-lived, and may range widely between breeding seasons so may be exposed to pollutants far distant from the breeding colony. Migrations and diets may vary between individuals, between the sexes, and between age classes, so that pollutant exposures may be highly variable between birds of differing status. With knowledge of these patterns, sampling can be planned to minimise the variance due to differences within populations. As a broad generalisation, pollutant concentrations in chicks tend to be much less variable than those in adults. This at least in part reflects the fact that pollutant burdens in chicks are largely derived from food fed to chicks during their growth, besides the amounts receiving from the egg (Becker *et al.*, 1993). Chick diet tends to be rich in energy-dense food, whereas adults may take a more varied diet, and with greater variation in diet among individuals. Secondly, the food for the chicks is taken from a relatively small area over which parents forage during the chick rearing period. In contrast, adults may range over much longer distances from the colony during the pre-laying and incubation periods, and may carry stored pollutants that they assimilated from food eaten during the nonbreeding period when they were widely dispersed away from their colony. Sampling chicks can therefore provide indications of the amount of pollution within the defined foraging range of the parents during chick-rearing and permits comparisons between colonies so that geographical variation in pollutant concentrations can be determined.

For some pollutants, samples of chick feathers or down (mercury) or blood (mercury, organochlorines, butyltin) provide satisfactory monitoring information. For others (e.g. cadmium) concentrations in feathers or blood may be too low to quantify, since the pollutant is strongly bound in a particular tissue and is not free to circulate in the blood. Monitoring of such pollutants might require killing of chicks to obtain the necessary tissue (e.g. kidney for cadmium analysis).

Since killing of chicks may be unacceptable, sampling eggs has attractions, particularly since many species of seabirds can replace a clutch that is removed. Taking a single egg from a clutch of several may have very little effect on breeding success as the survival of the chicks from the remaining eggs may be increased due to the reduction in sibling competition. Sampling eggs takes little time, and eggs are easy to handle and to store. Pollutant burdens in eggs of a specific area and year tend to reflect pollutant uptake of the female (healthy and reproductive members of the population) in the period shortly prior to egg laying (Becker, 1989; Dietrich *et al.*, 1997). So eggs can be used to measure contamination of the food web in the area around the colony over which food is gathered in the pre-laying period. Being restricted to the breeding season, the seasonal variability in chemicals' levels is reduced (see 5.3.3, 5.3.4). Compared to tissues the matrix egg has a consistent composition with high lipid contents accumulating persistent compounds to high concentrations, simplifying the chemical analysis.

3.4.5 Known foraging range

Although details of the foraging range of breeding seabirds are not known for every species, the information is available for many, and can be inferred for others from knowledge of closely related species or from other aspects of breeding biology (e.g. duration of the alternating periods spent on and off the egg during incubation). Foraging ranges may vary between different colonies or according to food abundance, but there is enough information to permit sampling seabirds at breeding colonies selected to provide fairly accurate estimation of the geographical variation in pollutant concentration. Foraging ranges of breeding seabirds vary from a few km in the case of terns and shags, up to thousands of km in the case of albatrosses and some shearwaters and petrels. Knowing the scale of foraging ranges of particular species may assist in selecting species that would provide the appropriate scale for a study. Terns, for example, can provide evidence of differences in pollutant levels resulting from local river discharges, whereas certain large albatrosses may provide data representative of the entire Southern Ocean.

3.4.6 Diet can be quantified or estimated

Pollutant uptake will vary to some extent according to the variability of the diet, both between individuals and across years. Selection of appropriate seabird species with narrow and consistent diets can avoid the noise that might otherwise be introduced by such variation in diet. For example, common guillemots and shags *Phalacrocorax aristotelis* have diets of fish that vary relatively little, whereas herring gulls are opportunists that may switch between highly differing diets. On this basis, herring gulls may be less suitable as biomonitors than common guillemots or shags. However, there are methods that can be used to investigate diet so that effects of change in diet can be assessed. These include both the conventional sampling of food regurgitates, fishes observed to be carried into the colony, contents of pellets regurgitated by adults, samples offloaded from chicks by 'stomach-pumping', or indirect methods of diet assessment such as analysis of stable isotope ratios. Stable isotopes of carbon and of nitrogen have been widely used as indirect measures of diet, and especially of trophic status, and have recently been used in combination with analysis of pollutants in the same samples to provide an aid to the interpretation of differences in pollutant levels between samples (Hobson *et al.*, 1994, Jarman *et al.*, 1996, 1997, Atwell *et al.*, 1998). Since stable isotope analysis is based on analysis of protein, it has the advantage that it can be used with feather material from study skins in museums so that even historical samples can be examined for dietary variation detectable by isotope analysis (Thompson and Furness, 1995, Thompson *et al.*, 1998a).

3.4.7 Historical samples available

Although there are few, and only rather recent, tissue banks that can provide material to examine temporal trends in pollutant burdens in biota (Elliott, 1985, Schladot *et al.*, 1993, Becker *et al.*, 1997, Krahn *et al.*, 1997), museum material can be of use as a means of examining long term trends. Eggshells in museum collections provided clear evidence of the effects of DDT poisoning through eggshell thinning effects. Eggshells may also provide an opportunity to investigate trends in contaminant levels through chemical analysis of shell or membrane composition, especially for some heavy metals (Burger, 1994, Burger and Gochfeld, 1996). Similarly, skeletal material might be used to examine trends in contamination, particularly for lead but possibly also for other contaminants. Feathers from study skins can be used to measure methylmercury contamination. Mercury concentrations in feathers reflect mercury levels in blood at the time of feather growth and these in turn correlate with the amount of mercury in the diet (Monteiro and Furness, 1995, Monteiro *et al.*, 1998). All of the mercury assimilated by seabirds and subsequently excreted into growing feathers is in the form of methylmercury and so any later contamination of the feathers with inorganic mercury from dust or preservatives can be removed by a biochemical separation (Thompson and Furness, 1989a). As a result, it has been possible to quantify the increase in mercury contamination of marine food webs over the last 150 years by analysis of mercury concentrations in selected feathers from seabird skins (Thompson *et al.*, 1992, 1993a, b, 1998b, Monteiro and Furness, 1997). Such an analysis is not possible for fish since museum collections of fish from many decades ago are very limited, and fish are stored in preservative solutions that can affect concentrations of metals in the tissues. It might be possible to investigate long term trends in concentrations of other heavy metals in seabird feathers (Burger, 1993), but this would require an analytical facility that can discriminate between metal incorporated into the feather structure from the bird's blood and metal that has been deposited onto the feather surface, either during the life of the bird or during storage (cf. 5.3.6.).

3.4.8 Low variance within population

Pollutant concentrations in samples of seabird chicks may be less variable than in other biota, so that the sample sizes required to detect a particular magnitude of increase would be less using seabirds than using other biota (5.3.3, 5.3.4; Gilbertson *et al.* , 1987, Fryer and Nicholson, 1993). Similarly, selecting adult seabirds, or the chicks of seabirds with larger foraging ranges, may permit more cost-effective monitoring of long-term trends where spatial resolution of pollutant variation is not the objective. Where the aim is to examine spatial variation, seabirds cannot provide as small-scale resolution as could be obtained using sedentary animals such as blue mussels, but for large spatial scales (> 10 km) seabirds may integrate spatial variation that would be noise in an analysis based on sedentary animals and may provide a better means of assessing large spatial scale pattern.

3.4.9 High public interest

The fact that birds are of considerable public interest can be very helpful in a monitoring programme. Many amateur ornithologists, reserve wardens and conservation staff are able to provide data or collect samples within a monitoring programme, and coordination of such work can be achieved through existing specialists groups such as the Seabird Group, Royal Society for the Protection of Birds, scientific institutions or through wardens in nature reserves or national parks, and others. For example, in the U.K., the Joint Nature Conservation Committee administers the seabird populations and productivity monitoring programme, with assistance from the Seabird Group, RSPB, English Nature, Scottish Natural Heritage, Countryside Council for Wales and others, to which over 100 people contribute data of a standardised format throughout the British Isles (Thompson *et al.*, 1997).

3.4.10 Resistance to toxic effects

As a broad generalisation, seabirds appear to be more resistant to toxic effects of most pollutants than are mammals or terrestrial birds (Beyer *et al.*, 1996). High concentrations of mercury in apparently healthy breeding birds are found in many seabird species, well above levels that would cause toxic effects in terrestrial or freshwater birds (Thompson, 1996). PCBs can occur in concentrations in apparently healthy seabirds that would certainly have toxic effects at the same concentrations in mammals (Barron *et al.*, 1995, Guruge and Tanabe, 1997). On the other hand, during ontogeny seabirds are vulnerable to toxic chemicals like PCBs (e.g. Becker *et al.*, 1993). There is no evidence that TBT at moderately high levels in seabirds has harmful effects (Guruge *et al.*, 1997, Kannan *et al.*, 1998).

The tendency for seabirds to be able to carry high concentrations of pollutants without displaying impaired reproduction or survival means that concentrations of pollutants in samples of seabirds should be a true reflection of exposure and not one that is biased by loss from the population of individuals carrying toxic doses. Especially choosing the egg as matrix avoids such problems, as eggs originate from the healthy, reproductive part of the population.

3.5 Drawbacks of using seabirds as biomonitors of pollution

3.5.1 Complex physiology

The more complex physiology of vertebrates in some respects makes them less suitable than invertebrates as biomonitors. Seabirds regulate tissue concentrations of essential metals and partly regulate the concentrations of some non-essential metals. For example, the coefficient of variation for cadmium in seabirds is much less than for mercury. For monitoring purposes, seabirds would be of little or no use as monitors of iron, zinc or copper pollution, and may be less suitable than invertebrates as monitors of cadmium. Moult, seasonal variation in organ size, adaptation to season, fat deposition, anorexia, and other processes, can affect pollutant concentrations in tissues, making changes between samples difficult to interpret as due to changes in pollution load rather than changes in physiology (Van Den Brink *et al.*, 1998).

Sex differences can occur, especially where females can excrete a pollutant into developing eggs, but such sex differences in pollutant burdens tend to be small (Furness *et al.*, 1990, Lewis *et al.*, 1993, Stewart *et al.*, 1994, 1997, Burger, 1995).

Eggs may be formed directly from recently assimilated food, or from materials drawn from stores within tissues. The relative importance of these two sources of material may vary between species, and often varies within a female through the laying sequence of egg production. As a result, since body stores and current diet may differ in pollutant content, egg mercury concentrations in terns and gulls decline with laying sequence (Becker, 1992). Levels of organochlorines also vary systematically with egg laying sequence (Mineau, 1982, Becker and Sperveslage, 1989).

3.5.2 Uncertain provenance

Seabirds sampled at sea are unlikely to be all from a single local population but may include birds of differing status from a variety of breeding areas. Seabirds sampled at a colony may be more homogeneous, but their previous movements during the nonbreeding season may have exposed them to various different sources of pollution and these may continue to be represented in the body burden through to the breeding season, possibly causing confusion.

3.5.3 Need to avoid killing birds

In most countries a licence is required to kill adults or chicks, to collect samples of eggs or to draw blood samples, or indeed to catch and handle live seabirds. However, such requirements should not hinder pollutant monitoring that is based on non-lethal sampling. In many countries in Europe, sampling by killing birds for pollutant analyses would now be considered to be unacceptable in most situations. The trend towards greater protection for wildlife is likely to continue. This could especially affect any programme of pollutant monitoring in countries where killing is currently an acceptable approach but may not be in the future, and any new programme of pollutant monitoring should be designed with such trends in public attitude and legislative control in mind.

3.5.4 Diet switching and diet specialisation

Many seabirds will switch diet according to relative abundance of preferred prey, and such diet switching can affect pollutant burdens in seabirds, especially if the switch is between vertebrate and invertebrate prey types, or between prey at different trophic levels. Within populations, diet specialisation can lead to increased variance of pollutant levels among individuals. Although seabird species can be selected as biomonitors on the basis of their having a stenophagous diet, even the most specialised seabirds may switch from one prey species to another if food availability changes enough. Such changes can be detected by monitoring diet or by analysis of stable isotopes as indicators, but this adds to the cost and complexity of a monitoring programme.

3.5.5 Difficulties to monitor toxicity

Since seabirds tend to show higher tolerance of many pollutants than do other animal groups, the opportunity to use breeding performance as a means of monitoring pollutant levels is of limited value. This possibility should not be discounted. Fox and Weseloh (1987) and Fox *et al.* (1991) suggest that breeding performance of gulls on the Great Lakes may be a useful indicator of pollutant exposure in this highly polluted region. They suggest the possibility that low gull breeding success might indicate toxic effects of a complex mixture of chemical pollutants that it would be extremely difficult and expensive to monitor by chemical analysis of gull samples or of other biota or physical samples. Thyen *et al.* (1998) propose a program for monitoring breeding success of coastal birds in the Wadden Sea, among other aims also to indicate pollution. However, seabird breeding failures can be caused by a wide variety of environmental factors, including food shortage, adverse weather, predators and human disturbance, and so one should be cautious about the possibility of detecting a relatively weak signal due to pollutants from the considerable and often unpredictable noise caused by a wide range of other factors. One reproductive parameter which may indicate shell thinning or embryotoxicity by chemicals is hatching success, in case of its reduction after external causes have been excluded (Becker *et al.*, 1993).

It is possible that specific biomarkers of toxicity might be useful, either at the biochemical level (Peakall, 1992) or at the level of specific effects on reproduction. Sex ratio distortion as a result of feminisation of genetically male embryos, for example, provides a fairly specific effect of oestrogenically active pollutants that is unlikely to be mimicked by other environmental influences. Similarly, teratogenic effects of particular pollutants may be evident in embryos or recently hatched chicks, while in unpolluted populations, even those stressed by various natural environmental factors, such abnormalities are exceedingly rare.

3.6 Criteria for selecting seabird biomonitors

A good candidate as a seabird biomonitor of pollutants should have the following attributes:

a) accumulation of the pollutant to high concentrations;
b) resistance to toxic effects due to the pollutant (unless these are what is being monitored);
c) known, or preferably no, migratory habits;
d) a foraging range consistent with the spatial scale over which the pollutant is to be monitored;
e) a large population size with known breeding biology and ecology, and with large numbers of colonies throughout the area where pollutant monitoring is required;
f) be easy to collect without major disturbance to the breeding colony, and have easily identifiable life-stages if a particular category is to be sampled;
g) have known physiology;
h) have a narrowly defined and consistent diet;
i) feed predominantly or exclusively on prey in the food web under investigation.

Based implicitly or explicitly on criteria similar to these, the Institute of Terrestrial Ecology sampled the eggs of common guillemots and gannets to monitor organochlorine pollution of marine ecosystems around the United Kingdom. Gilbertson *et al.* (1987) proposed the monitoring of pollutants in the North Atlantic by the sampling of eggs of Atlantic puffin *Fratercula arctica* and/or common guillemot (pelagic fish food web), and Leach's storm petrel (plankton food web, west Atlantic). For the Wadden Sea, Becker (1989) and Becker *et al.* (1991) proposed common tern (fish) and oystercatcher (benthic animals) as monitor species of the parameter „Pollutants in coastal bird eggs“. This parameter of high priority within the TMAP (Trilateral Monitoring and Assessment Program) is studied from 1996 on every year in the Wadden Sea (Becker *et al.*, 1998). Chosing more than one seabird species feeding on different prey, contamination of different parts of the food web can be indicated.

In practice, most published studies reporting pollutant concentrations in seabirds, or even reporting spatial or temporal patterns of pollutant levels in seabirds, have been based on data apparently collected adventitiously rather than as a planned monitoring programme.

3.7 Recommendations for monitoring pollutants using seabirds

3.7.1 Oil

Ongoing programmes of monitoring the proportions of dead seabirds found on shorelines ('Beached Bird Surveys') should be encouraged as a cost effective means (most are carried out by amateurs at no cost and are organised by NGOs) of determining long term trends and geographical patterns of oil pollution at sea. Such monitoring is of greater interest to seabird conservation than to fisheries.

3.7.2 Plastic particles

Given that this pollution appears to be increasing there is a need for monitoring of the amounts of plastic ingested by seabirds, especially petrels. Whether ingestion of plastic pellets by fish results in harm to fish is unclear. The evidence from seabirds suggests that the plastic is directly ingested by seabirds and not obtained indirectly inside prey that they consume. Such monitoring is of greater interest to seabird conservation than to fisheries, but would help to increase public awareness and concern about plastic pollution of the seas.

3.7.3 Organochlorines

Sampling of seabird eggs as a means of monitoring local contamination with organochlorines (advantages see 5.4.4) should be developed into integrated marine pollution monitoring programmes, with the selection of appropriate locally common and internationally widespread monitoring species. Table 3.7 presents seabird species suggested as monitors. In the Wadden Sea, besides the common tern the benthivorous oystercatcher *Haematopus ostralegus* was selected as monitor species since 1996 within the international "Trilateral Monitoring and Assessment Program".

Table 3.7: Seabird species suggested as monitors of marine pollution by organochlorines and mercury in the North East Atlantic and adjacent seas. Information on population size and trend in Europe, clutch size, diets, feeding range as well as on distribution is presented.

Fulmar: * 1 egg, not replaced if taken; 3 million pairs; populations increasing
* wide-ranging pelagic: zooplankton, offal, discards, fish, squid
* Norway, Iceland, Faeroe, UK (all coasts), Ireland, France; North America, Greenland

Gannet: * 1 egg; 230,000 pairs; populations increasing
* wide-ranging: fish, sandeel, sprat, herring, mackerel, discards
* Norway, Iceland, Faeroe, UK (all coasts), Ireland, France; North America

Shag: * 3-4 eggs, 86,000 pairs; populations mostly stable
* coastal, short range: sandeel, sprat
* Norway, Iceland, Faeroe, UK (all coasts), Ireland, France, Mediterranean countries

Kittiwake: * 2 eggs, 2-3 million pairs; populations mostly increasing or stable
* wide ranging: small fish, zooplankton
* Norway, Iceland, Faeroe, UK (all coasts), Ireland, France, Helgoland, North America, Greenland

Common tern: * 2-3 eggs, 208,000 pairs; some populations increasing, some stable, some decreasing
* coastal: small fish
* all European coasts (except Ireland and Faeroe); North America

Guillemot: * 1 egg, 2 million pairs; most populations increasing
* inshore: fish, especially sandeel, sprat
* Norway, Iceland, Faeroe, UK (all coasts), Ireland, France, Sweden, Helgoland, North America

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3.7.4 Mercury

Developed methods to monitor mercury contamination in marine food chains by sampling chick down or feathers from chicks or adults, or from blood samples or egg samples, should be applied to areas where there is concern about possible contamination of marine food chains with mercury. Sampling eggs from colonies located close to rivers carrying mercury pollution can be used as a means of monitoring trends in river mercury loadings reaching the sea. Such monitoring provides useful evidence of the successful reduction in mercury pollution where technical measures have been effected to reduce discharges. The same monitor species as for organchlorines are suggested to be integrated in monitoring programmes (Table 3.7).

3.7.5 Organotin

There is a need for research into organotin levels in seabirds to determine whether these may have toxic effects on seabirds, and whether seabirds may be used as a means of monitoring organotin pollution on large scales.

3.7.6 Other metals

There is a need for research into the possible use of eggshells, egg contents or feathers for monitoring cadmium, lead and other elemental concentrations to avoid the need to kill birds for liver, kidney or bone sampling. In particular, if methods can be developed to measure elemental concentrations within feather keratins separately from contaminants on feather surfaces, this would permit retrospective monitoring of long term trends in elemental contamination of marine food chains as has been done successfully for mercury.

3.7.7 Radionuclides

Seabirds probably have no role to play in monitoring of radionuclide pollution.

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Appendix: Scientific names of bird species mentioned in chapter 3

Arctic skua	*Stercorarius parasiticus*
Arctic tern	*Sterna paradisaea*
Atlantic puffin:see puffin	*Fratercula arctica*
Bulwer's petrel	*Bulweria bulweria*
Common guillemot:see guillemot	*Uria aalge*
Common tern	*Sterna hirundo*
Cory's shearwater	*Calonectris diomedea*
Fulmar	*Fulmarus glacialis*
Gannet	*Sula bassana*
Great skua	*Catharacta skua*
Guillemot	*Uria aalge*
Herring gull	*Larus argentatus*
Kittiwake	*Rissa tridactyla*
Leach's petrel	*Oceanodroma leucorhoa*
Little shearwater	*Puffinus assimilis*
Madeiran storm petrel	*Oceanodroma castro*
Oystercatcher	*Haematopus ostralegus*
Puffin	*Fratercula arctica*
Razorbill	*Alca torda*
Roseate tern	*Sterna dougallii*
Shag	*Phalacrocorax aristotelis*
Yellow-legged gull	*Larus cachinnans*

4 PROPOSALS IN SUPPORT OF THE DRAFT ICES 5-YEAR WORK PLAN

Term of Reference f) for the 1999 meeting of the Working Group asked that it propose tactics, activities, and products in support of the Oceanography Committee's Five-Year Plan Objectives. The Group learned at the meeting that the Objectives had been superseded and were now included in an overall draft ICES Five-Year Work Plan which was presented to us by Harry Dooley, the ICES Oceanographer. The Group therefore decided to make suggestions in relation to all of these objectives, especially in view of the need to integrate activities across the work of ICES.

In making these suggestions, WGSE would like to point out that it is reliant on the participation of a range of scientists from a number of institutions. Many of these institutions are not funded directly by the Governments of Member Countries, or are not funded for participation in the work of ICES. The capacity of the Group (and therefore of ICES) would be considerably enhanced if further Member Governments could find ways of providing funding for participation in the Group. We note also that there will be a need to work closely with scientists from other specialisms/Working Groups in order to undertake many of these tasks. Both Member Governments and ICES will need to examine ways by which this integration may be achieved.

As a further tactic to ensure the integration of ICES advice, we will examine ways of holding joint meetings with other Groups within ICES in order that we might benefit from interdisciplinary working. Greater integration with the wider scientific community will be furthered through the participation in and or organisation of scientific meetings. An example of one such meeting is that planned on capelin to be held in Iceland in 2001.

	Objective	**WGSE can:**
1 acme1	Provide timely, peer reviewed, integrated scientific advice requested by Member Countries and partner organisations on the management of the marine environment to maintain or restore its quality, thereby safeguarding the sustainable use of marine resources in the ICES area	- review the status and trends of seabird populations - review the effects of human use of the marine environment on seabirds - peer review in relation to seabird issues
2 acfm1	Provide sound, credible, timely, peer reviewed and integrated scientific advice on fishery management requested by client Commissions, Member Countries, and partner organisations	- help widen fisheries management perspectives to take account of fishery impact on seabirds, and the seabird impact on fish stocks
3 acme2	Be proactive by maintaining a dialogue with clients to improve ICES understanding of customer needs and to publicise new developments in science which will assist in the husbandry of the marine environment and its resources.	- help in developing monitoring programmes using seabirds and their eggs as indicators
4 acme3	To publicise the work of ICES and the contributions that ICES can make for its stakeholders, and for the wider public audience, regarding the understanding and the management of the marine environment	- participate in the development of the ICES web site, by adding and helping to maintain a section on seabirds -write/edit ICES publications, such as CRR
5 o1	Describe, understand and quantify the variability and state of the marine environment in terms of its biological, physical and chemical components.	- review and analyse trends in seabird populations and their life-history parameters, comparing them with other trend information where available
6 o3	To understand and quantify the impacts of climatic variability on the dynamics of marine ecosystems	- continue to review the effects of climatic variability on seabirds
7 o6	To promote the development of tools for the incorporation of environmental information into fisheries and ecosystem management.	
8 rm1	Improve the scientific basis for the Precautionary Approach and its application in ICES advice	
9 rm2	Define and develop the scientific basis for an "ecosystem approach to management" to the point that it may become operational.	- help widen the current perspective on the "ecosystem approach" in order to move it from being solely related to fish stock assessment and management via TACs to one that incorporates the use of technical measures
10 rm4	Establish a framework for evaluation of management regimes and a programme to investigate alternative management strategies	
11 ft2	Quantify and determine the main factors affecting gear selectivity and its role in fishery management	- review the risks that various gears provide to seabirds
12	Promote development of methods of	- help develop the use of seabirds as indicators of

rm5	fish stock assessment, particularly those which address issues of uncertainty, risk and sustainability.	recruitment
13 lr4	Investigate trophic relationships in marine ecosystems and develop multispecies models suited to management issues.	- assess food consumption by seabirds, and provide output in a form suitable for input to multispecies models.
14 mh1	Development of a toolbox to assess marine habitat quality.	- assess usefulness of seabirds as an indicator of the state of marine habitats
15 mh2	Development of a classification system for marine habitats of coastal areas, continental shelves and slopes, and the open ocean; including subsequent habitat mapping	- analyse seabird distribution data to provide a way of classifying open sea habitat
16 mh3	Development of knowledge on the importance of biological diversity to the functioning of marine ecosystems.	
17 mh4	Development of knowledge on the effects of anthropogenic contaminants on habitats and dependent living resources	- continue to review the effects of contaminants on seabird populations
18 mh5	Develop knowledge of the impact of (non-contaminant related) human-induced change on habitats and dependent living resources including the effects due to fishing gears and bycatch of non-target species.	- review effects of fishing activities on seabird populations
19 o4	To understand and quantify the impact of human activities on marine ecosystems, in relation to natural variability.	- review effects of fishing activities on seabird populations - continue to review the effects of contaminants on seabird populations
20 mh6	Develop the science of biological and contaminant monitoring methodology in relation to of marine habitat quality	- promote the use of seabirds and their eggs as indicators of marine habitat quality and to integrate these approaches in marine monitoring programmes
21 lh1	Develop our knowledge of the life history and population dynamics of living resource populations.	- review knowledge of key life history parameters of seabirds and evaluate their variability, and the population effects of such variation
22 ft1	Understand, describe and quantify the behaviour of fish in relation to the fish capture process.	
23 lr2	Co-ordinate national programmes aimed at monitoring the abundance and distribution of marine populations.	- provide a forum for integration of seabird survey and monitoring programmes
24 ft3	Describe and quantify the characteristics of survey gears in order to improve fishery independent surveys of stock abundance and distribution.	
25 ft5	To develop the theory and practice of acoustic methods in the marine environment	
26 b1	Develop an integrated approach to marine science in the Baltic Sea.	- review information on seabirds in the Baltic

27 mc1	Development of sustainable mariculture through diversification of species, and improvement of breeding and reproductive techniques, nutrition, and genetic approaches.	
28 mc2	Consideration of ecological, social, and economic interactions as the introduction and transfer of non-indigenous species, environmental interactions, competition with other users, economic feasibility, and the development of industry partners.	- review effects of mariculture on seabirds
29 mc3	Development of intensive and extensive mariculture systems to operate in an environmentally sound manner, with consideration of best animal welfare practices and disease prevention	- review effects of mariculture on seabirds

5 RECOMMENDATIONS

5.1 Proposals

The Working Group on Seabird Ecology makes the following proposals:

1. That the Working Group on Seabird Ecology should meet at the Institut für Vogelforschung, Wilhelmshaven, Germany from 20-23 March 2000 to:

a) review the sensitivity of seabird populations to changes in life history parameters;

b) review the extent to which fisheries have altered the composition of seabird communities;

c) continue to assess food consumption by seabirds in the ICES area;

d) review the contents of the database on seabird diet composition.

e) establish the means to develop awareness of the relevance of Seabird Ecology to ICES science and advice

WGSE will report to ACME before its May/June 2000 meeting and to the Oceanography and Marine Habitat Committees at the 2000 Annual Science meeting.

5.2 Justification

The meeting will be hosted by Working Group member Peter Becker at his home institute over four days immediately following the sixth International Seabird Group conference, to be held in Wilhelmshaven from 17-19 March 2000. This arrangement could help reduce travel costs for Group members.

a) At present monitoring of seabird populations is carried out primarily using counts of numbers and assessments of breeding success. Changes in food supply may affect other life history parameters. These other parameters may be of greater importance in driving population dynamics. The review should examine the desirability, feasibility and practicality of monitoring other parameters. The meeting is planned in the immediate aftermath of a conference on seabird reproduction to be held in Wilhelmshaven, so a wider range of knowledge than might usually be available may be called upon for the review.

b) It is known that fisheries have changed the size spectrum of fish populations in a way that is likely to have increased potential foods for seabirds. Fisheries have also provided large quantities of waste that are consumed by seabirds. It is not clear how these new foods and increased food supply has changed the overall seabird community. The review will make comparisons worldwide, but will focus on the ICES area.

c) The Working Group started work on modelling food consumption in the North Sea at their first meeting. Work continued for areas outside the North Sea in 1999. Data for further areas to the west of the British Isles are available and may be forthcoming elsewhere. This information should be of interest to other ICES Working Groups, and potentially to OSPAR and HELCOM.

d) This database was established prior to the March 1998 WGSE meeting and has been added to since. It is though still incomplete. It provides a useful and detailed summary of data on seabird diet by species and size of prey, by season and by location. WGSE were unable to review it in an updated version at the 1999 meeting. It will be further updated by the 2000 meeting, and is a vital source of information for WGSE.

e) the Group feels that its products and science could be made better use of within ICES. The Group will consider the usefulness of mechanisms such as a section in the ICES web site for promoting products such as the seabird Diet database, or as a source of other relevant information.

WHEN COMPLETE, PLEASE RETURN THIS LIST TO CLAIRE WELLING

WORKING GROUP ON SEABIRD ECOLOGY

ICES, Headquarters, 22–26 March 1999

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