Organochlorine contaminants in albatross from the South Pacific Ocean

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Summary

1. Albatross eggs and embryos were collected in field seasons from 1996 to 1998 by Department of Conservation field staff. Species collected were the Northern Royal albatross *(Diomedea sanfordi)*, Northern Buller's mollymawk *(Thalassarche (platei)* (nova sp.)) and Chatham Islands mollymawk *(Thalassarche eremita)*.

2. Tissues were submitted to ESR for chemical analysis. Chemicals of particular interest were polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF), polychlorinated biphenyls (PCBs) and a range of persistent organochlorine pesticides, including DDT group compounds.

3. Some PCDD, PCDF and PCB congeners were detected in all samples analysed. Total International Dioxin Equivalents (I-TEQ) ranged from 3.03 to 6.32 pg/g wet weight while PCB concentrations (sum of 25 conge ners) ranged from 18.0 to 66.7 ng/g wet weight. PCB congeners contributed between 73.3 and 86.5 % of the total I-TEQ.

4. Concentrations detected in these Southern Ocean albatrosses were considerably lower than in North Pacific albatrosses.

5. The profile of PCDD, PCDF and PCB congeners present in the Southern Ocean albatrosses was very similar to that found in the North Pacific. This probably indicates that the major source of contaminants in both locations is general atmospheric deposition of contaminants.

6. Some organochlorine pesticide residues were also detected in all samples analysed, the most prevalent being p,p'-DDT and p,p'-DDE and heptachlor-epoxide. p,p'-DDT and p,p'-DDE concentrations ranged from 15.8 to 79.8 ng/g wet weight.

7. The p,p-DDT concentration ranged from 5.6 to 33.6% that of the p,p-DDE concentration. This would normally indicate that the birds had been exposed to relatively `fresh' sources of DDT, but the low absolute concentrations of these residues may require further interpretation.

8. One sub-group of samples collected showed markedly thin egg shells. There was a positive correlation between contaminant concentrations and egg shell thickness for some contaminants. This suggests that the contaminants are not the cause of the observed shell thinning.

9. A risk analysis of the results suggests that, as in North Pacific albatrosses, PCBs and I-TEQ pose the greatest threat to the southern ocean birds. Margins of safety for effects of these contaminants on the birds are discussed.

1. Introduction

Over the past decade there has been considerable concern raised over the occurrence of persistent organic pollutants (POPS) in open ocean marine ecosystems. These concerns have been demonstrated by the high accumulation of these contaminants in marine mammal species from around the globe (Tanabe 1994). Considerable effort has been placed on assessing the possible adverse effects of this contamination (Jones *et al.,* 1996; O'Shea & Brownell 1994).

The major source of contamination to the world's remote marine environments appears to be the atmospheric transport and deposition of contaminants from areas of higher contamination (Wania & MacKay 1996). For this reason we have been investigating the accumulation of organic contaminants in southern ocean marine mammals (Jones *et al.,* 1998).

The accumulation of high concentrations of POPs, particularly PCBs and dioxins, in North Pacific albatrosses is cause for considerable concern (Jones *et al.* 1996). The levels of these contaminants in one species of albatross have been demonstrated to be sufficient to cause a measurable adverse reproductive impact (Auman *et al.* 1997). It appears that the major source of contaminants in this region is again atmospheric deposition.

This study was designed to investigate the concentrations of POPs in Southern Ocean albatrosses compared to the North Pacific. In addition we hoped to test whether accumulated POPS could be causing some of the reproductive deficiencies recently observed in the Southern Ocean albatrosses (Chris Robertson, Department of Conservation, personal communication).

2. Methods

2.1 SAMPLING

All field sampling was carried out by DOC staff during regular summer visits to the Chatham Islands. Samples consisted of dead or abandoned eggs at various stages of development, and in some cases the age of the parent birds was known from previous leg banding. Unfortunately, only 4 of these known age birds were identified so comparison of contaminant burdens with adult age could not be carried out. Species collected were Northern Royal albatross *(Diomedea sanfordi),* Northern Buller's mollymawk *(Thalassarche (platei)* (nova sp.)), and Chatham Island mollymawk *(Thalassarche eremita).* Samples were preserved either in formalin (January 1996 collection) or in ethanol (all other 1996-1997 collections). Pre-cleaned glass jars were used for all sample collections, and preservative volumes added were noted in the field. Details of each sample collected are provided in Table 1.

2.2 ANALYTICAL PROCEDURES

For analysis in the laboratory, egg/embryo and preservative were extracted to provide the total concentration of contaminants in the original sample. Samples were analysed by standard isotope dilution procedures (Jones *et al.* 1996). Analytes of interest were polychlorinated dibenzo-p-dioxins (PCDD), dibenzofurans (PCDF), biphenyls (PCBs) and a range of organochlorine pesticides. Before extraction a range of isotopically labelled internal standards was added to each sample. The samples were then subjected to a range of chemical and chromatography clean-up procedures to remove interfering substances and to isolate the most toxic co-planar PCBs from other PCB congeners.

After clean-up, analytes were determined by high-resolution gas chromatography with high-resolution mass spectrometry for identification and quantification of compounds of interest.

In addition to determination of target analytes, some samples were subjected to both low- and high-resolution mass spectrometry screening procedure to identify any non-polar organic analytes present at high concentrations but not determined in the targeted analytical procedures. Results for the high-resolution analysis have been delayed to allow time for the acquisition of additional analytical standards. This will permit unequivocal determination of additional organic contaminants.

Full analytical details are available on request, as are details of the extensive quality assurance procedures used in the laboratory. All analyses were performed under the laboratory's IANZ (formerly Telarc) accreditation.

3. Results

A variety of organochlorine residues were detected in the samples analysed (Table 2). p,p'-DDE was the most abundant compound in all samples, followed by PCBs (sum of 25 congeners). Low-resolution mass spectrometry scanning of the crude extracts did not reveal the presence of significant concentrations of other non-polar organic contaminants.

3.1 APPARENT INTER-ANNUAL VARIATIONS

Concentrations of most POPS appear to be considerably lower in samples collected in the 1995/96 field season than in subsequent years. This was particularly the case for PCBs in Northern Royal albatross. In the 1995/96 PCBs, concentrations averaged 8.48 µg/g as compared with 33.73 µg/g in samples collected in 1996. We presume this is because the analytical laboratory extracted only the solid tissue and not the formalin in which the samples were preserved. The low values for these samples therefore indicates significant leaching of contaminants into the preserving medium. It is interesting that

the leaching of PCBs is apparently considerably higher than the other contaminants. Due to the unknown extent and apparent chemical specificity of this leaching from the samples the results of these analyses will not be discussed further.

Contaminant concentrations remained almost constant between the two subsequent years (1996/97 and 1997/98 collections), although different species were collected (Table 2).

3.2 CONTAMINANT PROFILES

Concentrations of PCBs, PCDD/F HCB and heptachlor-epoxide were strikingly similar for the 1996/97 and 1997/98 collections (Table 2). In contrast, there were statistically significant differences in p,p'-DDE and p,p'-DDT between years (Mann-Whitney U test, p=0.026 and 0.065 respectively).

It must also be remembered that different species were collected in the two field seasons (i.e. Northern Royal albatross 1996/97 and Chatham Island mollymawk in 1997/1998). It therefore seems more probable the differences in the DDT group compounds result from the different feeding habits and ranges of the two species.

The abundance of p,p'-DDT compared to p,p'-DDE in the Chatham Islands is considerably higher than that detected for North Pacific albatross (Auman *et al.* 1997). DDT/DDE ratios for black-foot and Laysan albatross from Midway atoll were 0.023 and 0.095, respectively, while ratios in the current study for Northern Royal albatross, Northern Buller's mollymawk, and Chatham Island mollymawk were 0.19, 0.12 and 0.20, respectively. It would therefore seem that the southern birds are exposed to higher levels of relatively 'fresh' DDT. However, it should be remembered that the p,p'-DDT levels in the southern birds are lower than in the northern species. Therefore if the p,p'-DDT is a general atmospheric source, the southern birds are apparently exposed to lower levels of p,p'-DDT. The increased ratio of DDT/DDE in these birds is therefore caused by relatively lower levels of DDE generated as a metabolic product of accumulated DDT. The lower levels of DDE could be explained by the lower historic levels of contamination in the southern oceans and/or by limited metabolism of DDT to DDE in these birds.

Profiles of PCB, PCDD and PCDF congeners detected in the Chatham's albatrosses were compared to profiles detected in North Pacific albatrosses and New Zealand marine mammals (Figures 2 - 4). The profile of PCB congeners detected in albatrosses from the two locations were similar (Figure 1). However, the Midway albatrosses showed a greater abundance of the lower chlorinated congeners while the Chatham's albatrosses had a higher proportion of the more highly chlorinated congeners. The profile in the Midway albatrosses is therefore more similar to that detected in open ocean marine mammals from the southern hemisphere than to the Chatham's albatrosses (Figure 2). It is believed that the abundance of lower chlorinated PCB congeners in open ocean species is indicative of atmospheric deposition being the major source of contaminants to these remote areas (Jones *et al.* 1998). The fact

that the Chatham's albatrosses profile resembles the Hector's dolphin profile would indicate that, as in the case of the dolphins, local or inshore sources of PCBs represent a significant source of contaminants to these birds. The actual source of these contaminants (i.e., South America or New Zealand) is not indicated.

A common characteristic of the two albatross profiles is the low proportion of PCB #101 compared to PCB #99. In marine mammals these congeners are usually present at similar concentrations, while albatross appear to have an ability to metabolise or selectively eliminate PCB #101.

While the PCDD and PCDF congener profile is also similar for the two albatross groups, again the Chathams profile is more similar to the Hector's dolphin profile than to the Midway albatross profile (Figure 3). In particular the low levels of 1,2,3,7,8-PeCDF distinguish the southern ocean samples. The Chatham's albatrosses are distinguished from both the Midway albatross and Hector's dolphin by a high abundance of the octachlorinated congeners, particularly octachloro-dibenzofuran.

3.3 EGG SHELL THINNING

In 1996/97, samples were collected from eggs which were observed to have thinner shells than normal. Tissues from these eggs were analysed for PCDD/F, PCBs and organochlorine pesticides to assess a possible cause-effect linkage between the observed thinning and contaminant burdens. A shell thickness frequency histogram was plotted to assist in sample selection (Figure 4). The "thin-shelled" eggs were the four eggs with the thinnest shells ($\leq$ 0.25 mm). Six of the eggs with the thickest shells ($\geq$ 0.35 mm) were chosen as the comparison "thick-shelled" group. Samples were analysed as individuals and tested for statistical differences in contaminant concentrations using the non-parametric Mann Whitney U test (Table 3). The samples were assigned to two groups for statistical analysis.

Statistical analysis of contaminant data for "thin" and "thick" shelled eggs revealed no significant differences ($p < 0.05$) in contaminant concentration means (Table 3). In fact several of the contaminants, notably PCDD/F, PCBs and some pesticides were lower in the thin-shelled eggs compared to the thick-shelled eggs. This observation is probably due to the lower, but not statistically significant, lipid contents of the thin-shelled eggs.

Comparison of DDT group compounds to shell thickness showed no apparent relationship (Figure 5), while heptochlor-epoxide and HCB (Figure 6) were present in greater concentrations in thick-shelled eggs compared to thin-shelled eggs.

3.4 HAZARD INDEX

To further assess the possible adverse effects of contaminants on the reproduction of these albatrosses, hazard indices (HIs) were calculated for each

species (Table 5). The HI is calculated as the concentration of the contaminant divided by a "reference dose", usually a no-observable-adverse-effect-concentration (NOAEC) based on the species, contaminant, and end point of interest (Giesy *et al.* 1994). The HI therefore reflects the likelihood of the occurrence of adverse effects.As lowest-observable-adverse-effect-concentrations (LOAECs) are generally 5-10 fold higher than NOAECs, it is unlikely that adverse effects will be seen until HIs exceed 10. In general, when HIs exceed 20, adverse effects are likely to be detectable at the population level. In practice, species-specific data are not available for the species studied, so for this study NOAECs were assumed to be similar to other fish-eating birds (Giesy *et al.* 1994). For PCBs, the NOAEC chosen was the average of those for other birds. A NOAEC of 7 pg/g was chosen for TEQ based on extensive work on fish-eating in the North American Great Lakes. This value has also been shown to accurately predict adverse reproductive effects in albatrosses from the North Pacific (Auman *et al.* 1997).

The calculated HI values for the Chatham's albatrosses are low (<0.1) for DDT group compounds and total PCB concentrations. We can therefore conclude that it is unlikely that these contaminants pose any immediate threat to albatross reproduction.

HI values for TEQ were close to the NOAEC of 7 pg/g. Given that LOAEC are generally 5 to 10 times higher than NOAEC values, we can conclude that TEQ concentrations in the Chatham's albatrosses are probably within the same order of magnitude as the LOAEC for adverse reproductive effects. While this margin of safety for adverse effects may be comforting, it is clearly not as large as would be desired. We would therefore concur with Jones *et al.* (1996) that there remains little global assimilative capacity for TEQ.

4. Conclusions

Albatrosses on New Zealand's offshore islands accumulate a range of persistent organic pollutants. Significant among these contaminants are the now globally ubiquitous DDT group compounds. Also present are PCB, PCDD and PCDF congeners and a range of chlorinated pesticides. The range of contaminants accumulated is similar to that accumulated by marine mammals living in the same areas and similar to that accumulated by albatrosses in the North Pacific Ocean. These similarities suggest that global atmospheric transport and deposition represent a major source of contamination to the Southern Ocean. However, the accumulation of a relatively greater proportion of higher chlorinated PCBs in the Southern Ocean albatrosses may indicate some the accumulation of some PCBs from non-atmospheric sources. A similar increase in higher chlorinated PCBs is also observed in Hector's dolphin, an inshore feeding species, compared to open ocean marine mammals.

From the comparison of thick- and thin-shelled eggs it seems unlikely that the presence of POPS in these species is contributing to the observed adverse effects. The concentrations of the POPS detected, particularly the DDT

group compounds, are well below those known to cause egg shell thinning in other species. In addition, while TEQ seem to pose the greatest risk to these species, they are not known to cause egg shell thinning. Low-resolution mass spectrometry screening of the samples for high levels of other organic contaminants did not indicate the presence of other major non-polar organic contaminants. Scheduled high-resolution mass spectrometry may indicate the presence of additional contaminants, but concentrations can be expected to be relatively low.

It therefore seems more likely that a causative agent for the egg shell thinning may be an environmental factor. A possible cause could be colony density (Chris Robertson, Department of Conservation, personal communication) but additional field work will be required to address this issue.

The relatively high concentrations of chlorinated contaminants contributing to I-TEQ in North Pacific albatross is of considerable concern. The concentrations detected in some of these species have been demonstrated to be causing adverse reproductive effects. While concentrations detected in the Southern Ocean albatrosses are considerably lower, the `margin of safety' for these contaminants appears to be between a factor of 5 and 10. Together these observations suggest that there remains little global assimilative capacity for TEQ. In addition, as global trends in TEQ are not yet well understood, the significance of this contamination may change with time. It would therefore seem prudent to design some mechanism for future monitoring of contaminants in Southern Ocean albatross.

5. References

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Table 1. Sample collection data.

ESR Sample	Species	Location	Date
960147/1	Northern Royal albatross	Little Sister Is.	20/1/96
960147/2	Northern Royal albatross	Little Sister Is.	20/1/96
960147/3	Northern Royal albatross	Little Sister Is.	21/1/96
960147/4	Northern Royal albatross	Little Sister Is.	22/1/96
960147/5	Northern Royal albatross	Little Sister Is.	22/1/96
960147/6	Northern Royal albatross	Little Sister Is.	22/1/96
970067/3	Northern Royal albatross	Little Sister Is.	3/11/96
970067/4	Northern Royal albatross	Little Sister Is.	6/11/96
970067/5	Northern Royal albatross	Little Sister Is.	6/11/96
970067/6	Northern Royal albatross	Little Sister Is.	7/11/96
970067/7	Northern Royal albatross	Little Sister Is.	7/11/96
970067/11	Northern Royal albatross	Little Sister Is.	9/11/96
970067/12	Northern Royal albatross	Little Sister Is.	9/11/96
970067/20	Northern Royal albatross	Little Sister Is.	13/11/96
970067/21	Northern Royal albatross	Little Sister Is.	13/11/96
970067/23	Northern Royal albatross	Little Sister Is.	13/11/96
970067/comp'	Nothern Buller's mollymawk	Little Sister Is.	13/11/96
970692/1	Chatham Is. mollymawk	The Pyramid	Oct-97
970692/2	Chatham Is. mollymawk	The Pyramid	Oct-97
970692/3	Chatham Is. mollymawk	The Pyramid	Oct-97
970692/4	Chatham Is. mollymawk	The Pyramid	Oct-97
970692/5	Chatham Is. mollymawk	The Pyramid	Oct-97
970692/6	Chatham Is. mollymawk	The Pyramid	Oct-97

' Composite of five individual samples.

Table 2. Persistent organic contaminants in Southern Ocean seabirds.

Sample	Species	PCB	PCB-TEQ	PCDD/F	PCDD/F TEQ	Sum TEQ	% TEQ PCB	pp-DDE	pp-DDT	HCB	Heptachlor-epoxide	DDT/DDE (%)
960147/1	NRA	2.52	0.49	n.a.	n.a.			6.32	0.56	< 0.8	0.21	8.9
960147/2	NRA	9.40	1.68	n.a.	n.a.			21.8	2.07	< 0.7	0.94	9.5
960147/3	NRA	7.09	1.55	n.a.	n.a.			14.0	0.16	< 0.9	0.71	1.1
960147/4	NRA	14.5	2.35	2.97	0.360	2.97	86.7	38.8	1.09	2.72	1.27	2.8
960147/5	NRA	11.7	1.89	n.a.	n.a.			38.5	3.86	2.22	0.70	10.0
960147/6	NRA	5.67	1.28	n.a.	n.a.			12.2	1.64	< 0.8	0.73	13.4
Mean		**8.48**	**1.54**	**2.97**			**86.7**	**21.9**	**1.56**	**1.09**	**0.76**	**7.6**
970067/3	NRA	28.9	4.14	4.88	1.11	4.88	78.9	40.3	4.57	3.69	0.88	11.3
970067/4	NRA	21.6	4.33	4.46	0.977	4.46	81.6	32.4	5.16	5.27	1.43	15.9
970067/5	NRA	50.3	5.66	5.08	1.26	5.08	81.8	69.4	4.42	3.94	1.84	6.4
970067/6	NRA	18.0	3.24	3.22	0.817	3.22	79.9	15.8	4.49	3.85	0.98	28.4
970067/7	NRA	66.7	9.55	6.30	1.60	6.30	85.7	23.9	1.35	5.28	1.78	5.6
970067/11	NRA	33.0	6.57	5.79	1.26	5.79	83.9	44.3	11.9	4.17	0.78	26.9
970067/12	NRA	31.4	5.57	3.86	0.948	3.86	85.5	37.9	6.30	7.35	0.36	16.6
970067/20	NRA	19.8	2.76	6.32	0.740	6.32	78.9	30.3	7.72	3.17	0.20	25.5
970067/21	NRA	39.6	4.26	3.66	0.712	3.66	85.7	56.5	19.0	1.38	0.31	33.6
970067/23	NRA	28.0	4.20	3.03	0.780	3.03	84.3	34.6	8.51	4.53	0.66	24.6
Mean		**33.73**	**5.03**	**4.66**	**1.02**	**6.05**	**82.6**	**38.54**	**7.34**	**4.26**	**0.92**	**19.5**
970067/comp	NBM	19.4	3.28	4.62	0.740	4.62	81.6	34.6	3.99	2.63	0.87	11.5
970689/1	CIM	22.3	2.68	4.28	0.974	4.28	73.3	41.4	6.99	3.77	0.53	16.9
970689/2	CIM	40.1	6.12	5.55	1.33	5.55	82.1	79.8	9.60	4.73	0.75	12.0
970689/3	CIM	22.1	4.29	3.32	0.668	3.32	86.5	44.3	7.20	3.93	0.56	16.3
970689/4	CIM	30.8	4.82	3.47	0.802	3.47	85.7	45.7	15.1	3.66	0.86	33.0
970689/5	CIM	26.3	4.78	4.57	0.975	4.57	83.1	58.6	12.2	4.31	1.00	20.8
970689/6	CIM	39.8	7.16	5.50	1.27	5.50	84.9	66.4	15.2	7.12	1.15	22.9
Mean		**30.23**	**4.98**	**4.45**	**1.00**	**5.98**	**82.6**	**56.0**	**11.05**	**4.59**	**0.81**	**20.3**

Species: NRA = Northern Royal albatross; NBM = Northern Buller's mollymawk; CIM = Chatham Island mollymawk.
n.a. not analysed
DDT/DDE (%) calculated as ([DDT]/[DDE])*100

Table 3. Contaminant concentrations in thick- and thin-shelled Northern Royal albatross eggs collected from the Chatham Islands, November 1996.

	Thick Shell (n=6)	Thin Shell (n=4)	p='
Shell Thickness (mm)	0.43	0.16	0.001
Lipid (%)	4.33	3.28	0.134
DDE (ng/g)	37.3	40.4	0.670
DDT (ng/g)	5.60	9.95	0.136
DDT/DDE ratio	0.17	0.24	0.394
Heptachlor epoxide (ng/g)	1.20	0.51	0.055
HCB (ng/g)	4.98	3.19	0.055
Sum PCB (ng/g)	36.8	29.1	0.522
PCB TEQ (pg/g)	5.82	3.84	0.055
PCDD/F TEQ (pg/g)	1.14	0.84	0.054
Total TEQ (pg/g)	6.96	4.68	0.055

' p values for Mann Whitney U test of difference between groups.

Table 4. Comparison of contaminant concentrations between Chatham's albatrosses and North Pacific albatrosses. For Midway Island albatrosses: PCB and TEQ data from (Jones et al. 1996); DDT group data from (Auman et al. 1997).

Location	PCBs (ng/g)	E-TEQ (pg/g)	p,p'-DDT (ng/g)	p,p'-DDE (ng/g)	DDT/DDE
Midway Atoll	Black-footed albatross				
	688	124	35.5	1550	0.023
Midway Atoll	Laysan albatross				
	220	48.4	11.5	121	0.095
mean	444	86.2	23.5	836	
Chatham Islands	Northern Royal albatross				
	33.73	6.05	7.34	38.54	0.19
Chatham Islands	Northern Bullers mollymawk				
	19.4	4.62	3.99	34.6	0.12
Chatham Islands	Chatham Island mollymawk				
	30.2	5.98	11.01	56.03	0.20
mean	27.8	5.55	7.45	31.39	
Ratio of means	0.06	0.06	0.42	0.04	

Table 5. Hazard indices for Southern Ocean seabirds.

	Contaminant	Concen-tration [a]	Reference Dose [b]	HI
Northern Royal albatross				
	TEQ (pg/g)	6.05	7 pg/g	0.86
	PCB (ng/g)	33.7	400 ng/g	0.08
	DDE (ng/g)	38.5	3 500	0.01
Northern Buller's mollymawk				
	TEQ (pg/g)	4.62	7 pg/g	0.66
	PCB (ng/g)	19.4	400 ng/g	0.05
	DDE (ng/g)	34.6	3 500	0.01
Chatham Island mollymawk				
	TEQ (pg/g)	5.98	7 pg/g	0.85
	PCB (ng/g)	30.2	400 ng/g	0.08
	DDE(ng/g)	56.0	3 500	0.02

[a] from Table 2

[b] Reference dose forTEQ from (Auman et al. 1997) and for PCBs and DDE (Giesy el al. 1994).

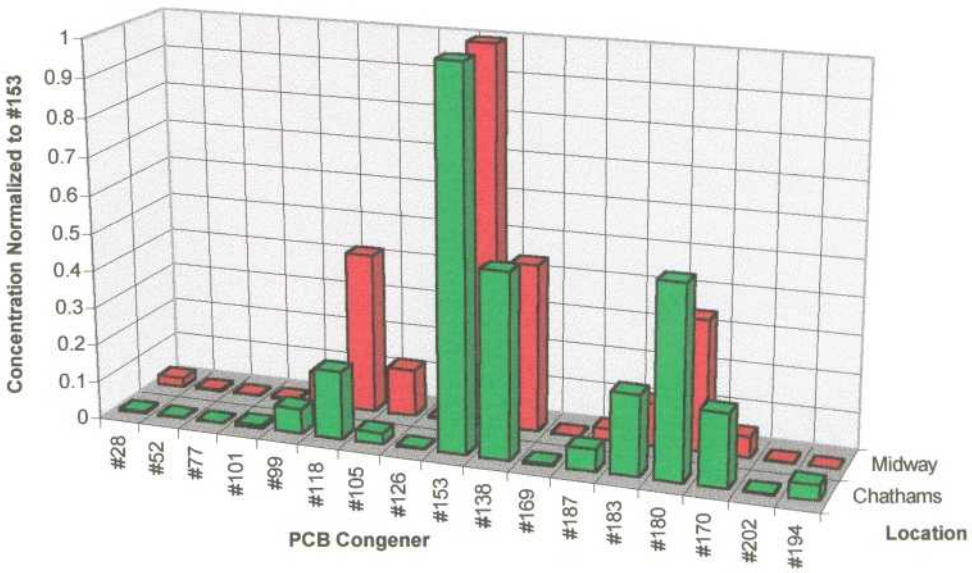

Figure 1. PCB congener profile for albatross egg tissues from Midway Atoll (1993/94) and the Chatham Islands (1996). PCB congener concentrations are normalised to the concentration of congener #153.

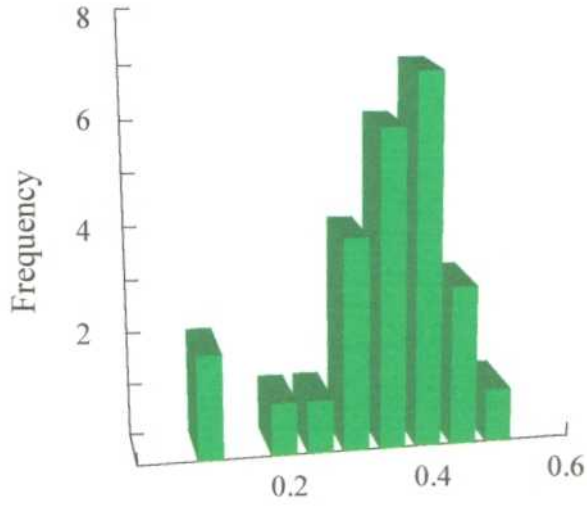

Figure 4. Egg shell thickness frequency distribution for the submitted samples of Northern Royal albatross from the Chatham Islands, November 1996.

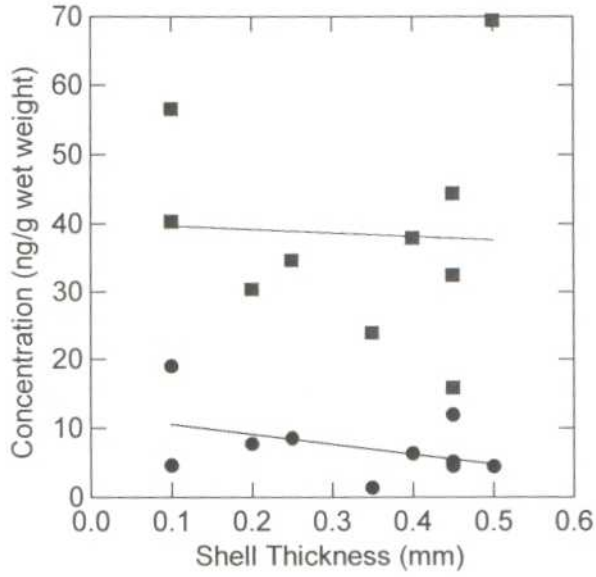

Figure 5. Relationship between DDT group compounds and egg shell thickness in Northern Royal albatross samples from the Chatham Islands, November 1996. p,p'-DDE =squares; p,p'-DDT = circles.

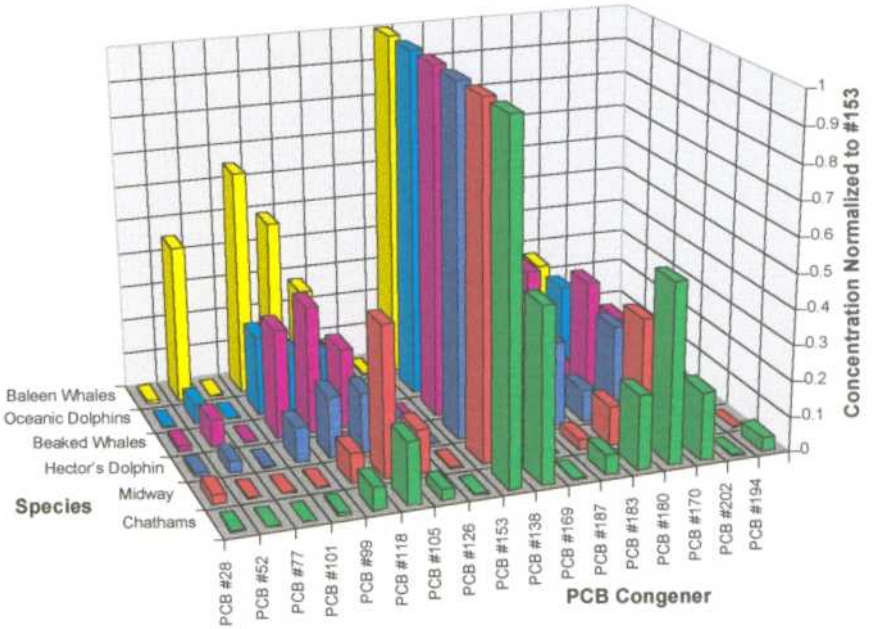

Figure 2. PCB congener profile for albatross egg tissues from Midway Atoll (1993/94) and the Chatham Islands (1996) compared with that for Southern Ocean marine mammals (Jones *et al.* 1998). PCB congener concentrations are normalised to the concentration of congener #153.

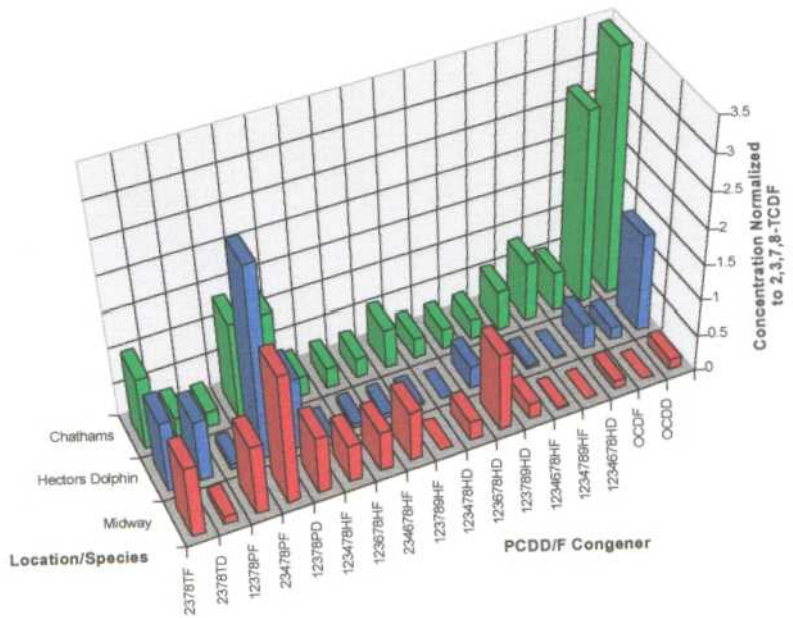

Figure 3. PCDD and PCDF congener profile for albatross egg tissues from Midway Atoll (1993/94) and the Chatham Islands (1996) compared to that for Hector's dolphin PCB (Jones *et al.* 1998). Congener concentrations are normalised to the concentration of 2,3,7,8-TeCDF.

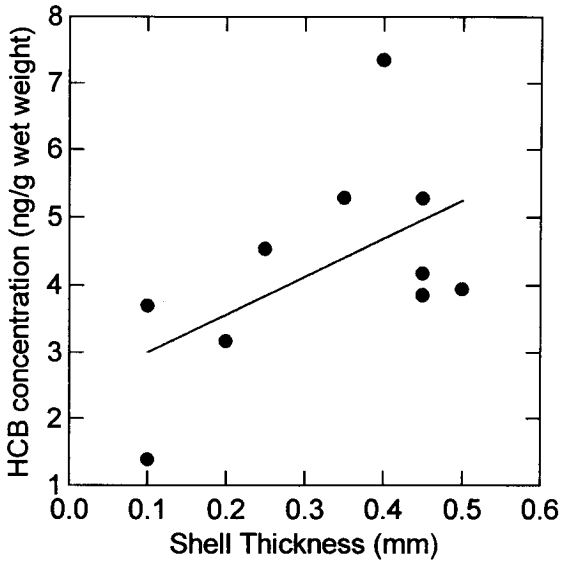

Figure 6. Relationship between concentration of HCB and egg shell thickness in samples of Northern Royal albatross from the Chatham Islands, November 1996.