Oil contamination of gannets and their nests on Grassholm subsequent to the Sea Empress oil spill

[Oil contamination of gannet nesting material from Grassholm and St Kilda colonies, November 1996: Interim Report.]

David Santillo[1], Steve Colombé[2], Paul Johnston[1] and Ian Bullock[3]

[1]Greenpeace Research Laboratories, Department of Biology, University of Exeter, Prince of Wales Road, Exeter EX4 4PS. [2]Channel Seabirds Research Group, Station Halt, Brampford Speke, Devon EX5 5HF. [3] Royal Society for the Protection of Birds, Tegfan, Caerdwdi, St Davids, Pembrokeshire SA 62 6QP.

Contents

1. Introduction

On 15 /2/96 the *Sea Empress*, with a cargo of 130,000 tonnes of Forties light crude oil, ran aground whilst navigating the entrance to Milford Haven, this resulted in the loss of 71,945 tonnes of crude oil and 364 tonnes of bunker fuel.

By the end of February approximately 200 km of coastline had been either moderately or severely contaminated. Offshore, oil was reported from Lundy Island, 18 km from the North Devon coast and on 14 March substantial quantities of oil and oiled birds were reported from the south-east coast of Ireland. Whilst accurate information on the extent of the shoreline impacted is available (MPCU, 1996), the extent and residence time of contamination offshore is far less clear.

Grassholm, situated 23 km WNW of the entrance to Milford Haven, supports the worlds second largest gannetry with an estimated population of 30,000 pairs. Gannet nests are perennial constructions 30-60 cm high, built out of seaweed, grass and items of floating debris collected from the sea. Almost all gannet nests, therefore, contain man-made materials, often in substantial quantities (Montevecchi, 1990; Norman *et.al.*, 1995).

At the time of the *Sea Empress* incident it is estimated that 80% of the adult breeding population of gannets on Grassholm had returned to the colony. On a ship based survey between the 25-29/2/96, immediately after the spill, only 0.39% of 1,279 gannets recorded showed some degree of oiling, and a similar percentage were observed carrying nest material (Colombé *et.al.*, 1996). The small proportion carrying nest material suggests that at that time they had not started nest building.

During the aftermath of the *Sea Empress* incident it is suggested that very little if any oil directly impacted Grassholm (MPCU, 1996). Oil spill modeling indicates that substantial quantities of oil were swept south and west towards Ireland, through sea areas where gannets may have been present (Colombé *et. al*, 1996). The main movement of gannets recorded during the incident was along a south-west - north-east axis from Grassholm (Ibid.). By 6/3/96, a boat survey carried out near Grassholm recorded that 49% of all birds and 86% of those flying towards the island were carrying nest material (Colombé, 1996). On the 7/4/96 an estimated 4.4% of gannets on Grassholm showed some degree of oil contamination. It was apparent that they were becoming oiled a long time after most of the oil from the *Sea Empress* was assumed to have dispersed. Based on these data the following hypothesis was suggested:

That gannets on Grassholm were becoming contaminated by collecting oil contaminated nest material. This oil contaminated material when incorporated in the nest heaps might, in turn, result in a decrease in fertility or hatching success in contaminated nests.

Reduction in fertility from exposure to oil can occur via direct physiological effects on the adult or via the embryo by absorption through the eggshell. Contaminated adult birds ingest oil when preening. Ingested oil has been shown to reduce reproductive success in a number of seabird species (Hartung, 1965; Fry *et. al.*, 1986; Butler *et. al.*, 1988; Ainley *et. al*, 1981; Fowler *et. al.*, 1995). Reductions in egg production, fertilisation rate and eggshell thickness following ingestion of oil by breeding adults have been reported for a number of water and seabirds, most notably mallards and auklets (Coon and Dieter 1981, Ainley *et al.* 1981). In addition, adults exposed externally to oil in water can transfer sufficient oil to the embryo to reduce hatching significantly (Albers 1980).

Eggs may become contaminated either from contact with oiled plumage or as might be the case with gannets through contaminated nest material. Coverage of the egg surface with oil-derived hydrocarbons can also reduce hatching success through interference with gas exchange (Albers 1977). Absorption of crude and fuel oil through the shell has been shown to reduce hatching success and in some cases post hatching survival (Hartung, 1965; Patten & Patten, 1979; Parnell *et. al.*, 1984, Wanjala & Leighton, 1996)

This report presents the results of investigations to assess whether nest material contaminated with oil from the *Sea Empress* was incorporated into gannet nests on Grassholm and, if so, whether there was any effect on fertility or productivity in contaminated nests. The results are based on comparative analysis of material from both successful and failed nests on Grassholm for oil-derived hydrocarbons, specifically PAHs (polycyclic aromatic hydrocarbons) and long-chain paraffins. PAHs are among the more toxic components of oil and are also generated as products of incomplete combustion of fossil and renewable fuels. Four samples from St Kilda, Scotland, was used as a background control from a remote location.

2. Materials and methods

The oiling rate of adult gannets within the colony was determined by scoring approximately 1000 birds in a subsection of the colony. Oil contamination was taken as any visible oil spot. Counts were made using binoculars on the 7/4/96, 12/5/95 & 9/4/97.

A simple measure of productivity was obtained by scoring approximately 1000 nests on 20/7/96. For the purposes of this study, success was defined as the production of a live offspring i.e. that an egg hatched. Nests where one or both adults were standing or loafing with no apparent offspring, and nests where a bird was obviously brooding an egg were scored as unsuccessful. This method has been employed at the colony in previous years.

Unsuccessful nests (‘test’ nests), were identified by comparing enlarged photographs taken on the 12/5/96 (when all birds were incubating) and again on the 2/7/96, by which time any birds incubating in May would be expected to have young. Nests where birds were apparently incubating on the on both dates were deemed to be unsuccessful. ‘Control’ nests were taken as those where a young gannet was present. For the purposes of a 'site' control, ten samples were obtained in May 1996 from nests on St Kilda, the worlds largest gannetry, situated approximately 60 km west of the Outer Hebrides and 700 km NNW of Grassholm. Samples from Grassholm were collected on the 8/11/96. Nest piles were cut in half vertically and approximately 30-50 cm^3 of material removed from the upper 5cm. Following collection, samples were stored frozen in sealed aluminium containers prior to analysis.

A subset of 14 samples of nest material were selected for this preliminary study, focusing on failed nests on Grassholm (7 samples) in order to determine in the first instance whether PAHs and paraffins would be detectable in the nest material. Three samples from successful nests on Grassholm were included for comparison, in addition to four samples of nest material from the remote location of St Kilda.

Two further samples of debris from the periphery of the colony on Grassholm, which were clearly oil contaminated, were included in an attempt to fingerprint the weathered oil present.

The limitations to the sample set were determined by availability of funds.

All samples were forwarded to The Institute of Terrestrial Ecology for analysis. 6-7g sub-samples were dried with anhydrous sodium sulphate, extracted in hexane and extracts evaporated down to 5 ml. Extracts were cleaned on alumina, eluting with hexane. 2,6-dichlorobenzonitrile was added as an internal standard to the cleaned extract.

Extracts were analysed by GC/MS, using standards to quantify range of PAHs and long-chain hydrocarbons. Extraction efficiency for each of the analytes was determined by extraction of spiked samples. Limits of detection and extraction efficiencies are given in Appendix 3.

3. Results

3.1 Contamination of birds

On the 7/4/96 in a sample of 1,000 there were 44 contaminated birds, representing 4.4% of the sample observed. Five weeks later on the 12/5/96 no oil contaminated birds were visible in the colony. A year later on the 9/4/97 in two independent observers scored 1,000 and 800 birds for oiling, this resulted in estimates of 5 (0.5%) and 6 (0.75%) respectively of birds showing some sign of oil contamination. None of the birds exhibited greater than 25% of their body oiled and in most cases it was restricted to a few small spots.

3.2 Productivity

Rough estimates of productivity have been made at the colony since 1993 (Table 1)

Table 1: Percentage of gannet nests on Grassholm with young in July 1996

Year	%
1993	60
1994	57
1995	67
1996	68/72 (two counts)
1997	84

3.3 Contamination of nesting material

All data, reported as ug/kg (PAH) or mg/kg (paraffin) wet weight of nesting material (ppb), are included in Appendices 1 and 2. Values are corrected for percent recovery. Limits of detection are included in Appendix 3 (as ug in whole sample).

PAHs were present at detectable levels in all samples of nesting material, including those from St Kilda. Total PAH concentrations for the ten nests sampled on Grassholm (combining failed and successful nests) ranged from 189-2059 ug/kg wet weight. The data distribution was skewed towards a smaller number of more contaminated nests and a larger number showing lower levels. No difference was detectable between concentrations in the three successful nests and the spread of concentrations recorded in the failed nests (unpaired t-test, p=0.63).

Mean total PAH concentration for Grassholm (successful and failed nests together) was 643 ug/kg (n=10). Given the skewed nature of the data (standard deviation 606 ug/kg), the median, 370 ug/kg, may be a better indicator of the centrality of the data. In comparison, the four samples analysed from St Kilda yielded a mean total PAH concentration of 504 ug/kg (standard deviation 211 ug/kg) and a median of 587 ug/kg.

Whereas the mean concentration on Grassholm was higher, the small number of highly contaminated nests had a significant skewing effect on the mean. Nest sites on St Kilda showed less variation in contaminant levels, with substantial concentrations in all four nests analysed but without individual heavily contaminated nests. The differences in sample size between islands make further analysis of these differences inadvisable; it may simply be that heavily contaminated nests were not included within the smaller set of samples analysed from St Kilda.

It is interesting to note, however, that total PAH concentrations in nesting material from St Kilda did not appear to be significantly lower than on Grassholm (unpaired t-test, p=0.27), contrary to what was expected given St Kilda's relatively remote location.

Concentrations of individual PAHs (other than naphthalene) varied widely from sample to sample, showing similar skewed distributions. Of the PAHs present, phenanthrene, pyrene and chrysene were among the most abundant in nesting material from Grassholm (mean values 201, 88 and 148 ug/kg respectively). Median values were 96.0 (phenanthrene), 38.5 (pyrene) and 75.4 ug/kg (chrysene). Corresponding means for the samples from St Kilda were 219.7, 44.0 and n/d (not-detected, below limits of detection) ug/kg respectively, and medians, 227.7, 50.4 and n/d ug/kg respectively.

Mean and median values for each of the PAHs identified at the two sites are presented in Figure 1. The relative abundances of different PAHs were similar at both sites, the principle differences being the prominence of chrysene in nests on Grassholm, a compound absent from all four nests from St Kilda, and the consistently and significantly higher levels of naphthalene on St Kilda (unpaired t-test, $p=0.048$).

Paraffin residues were detected in only 5 of the 10 samples from Grassholm, and in 3 of the 4 samples from St Kilda. This is due partly to the much higher limits of detection for these residues than for the PAHs (Appendix 2). The levels recorded in nesting material from St Kilda appeared to be of a similar order, with n-undecane and n-octacosane particularly abundant. Given the paucity of data, further statistical analysis is not feasible.

Of the samples from Grassholm, the two showing the highest overall levels of paraffins were samples GN6006 and GN6012, which were also among the most contaminated with PAHs. Nevertheless, this pattern was not consistent throughout the data set. Sample GN6005, which contained the lowest total PAH concentration (189 ug/kg), was found to contain 3210 ug n-undecane per kg wet weight (ppb).

It would appear, therefore, that levels of paraffins did not correlate well with PAH contamination of the nest material, although with levels below limits of detection for most of the paraffins in the majority of the samples, it is not possible to consider this further at this stage.

Samples of oiled plastic debris and feathers collected from the edge of the colony on Grassholm showed, as expected, much higher PAH and paraffin concentrations

than those in the nests themselves. The relative abundances of PAHs differed between plastic and feathers, the profile for the plastic being more similar to that of the nesting material than that on the feathers. For the plastic, phenanthrene and pyrene were particularly predominant. These differences may reflect variations either in the origin or degradation of the oils on the debris. We are currently awaiting fingerprints for both weathered and unweathered *Sea Empress* crude for comparison.

4. Discussion

4.1 Contamination of birds

There is a clear difference between the oiling rates of adult birds between 1996 and 1997. It is likely that in April 1996 the higher rate in oiling was due to birds coming into contact with oil from the *Sea Empress*, either via collecting contaminated nest material or by direct contact with oil on the surface of the sea. The first assessment of oiling rates of birds on Grassholm was made approximately six weeks after the spill. It is entirely possible that a higher proportion of birds were oiled in the intervening period. It is clear from the count on the 12/5/96 (when no oiled birds were visible) that gannets are quite capable of cleaning all traces of oil from their plumage. This has also been reported from other colonies where quite heavily contaminated birds have been seen without any traces of oil after a period of a few weeks (S.Wanless pers. comm.)

4.2 Productivity

Whilst the estimates of productivity on Grassholm since 1993 have been based on a rather unsophisticated count method, the method has been consistent year to year and conducted by the same observer. It is therefore reasonable to conclude that there was no apparent impact on productivity in 1996 following the *Sea Empress* spill. However, if only 5% of birds were contaminated, any impact on fertility or embryo viability resulting from oil would be masked by the confidence limits of the productivity assessment. The proportion of birds oiled, would have had to have been very large to be noticed using this method. These results highlight the need for systematic, accurate monitoring at a wide range of seabird colonies around the UK coast, in particular those that are situated in ‘high risk’ areas

4.3 Contamination of nesting material

The results available to date indicate that PAHs were detectable in samples from both successful and failed nests on Grassholm and in all samples of nest material collected from St Kilda. Paraffins were detectable in some samples, but the picture is much less clear for these compounds.

The lack of published data on levels of PAHs and other contaminants in nesting material makes comparisons with previous studies difficult. Perhaps the most useful data set for comparative purposes is that published by Jones *et al.* (1989) reporting levels of a range of PAHs in soils from various (49) locations in Wales, including some taken on or close to the St David's peninsula. These authors report typical mean and median values for PAHs in Welsh soils, based on a subset of their full data set, excluding the most contaminated sites. These are presented in Table 2 below. As for the current study, levels in soils were highly variable and the data showed a high degree of skewing.

Mean and median total PAH concentrations in nesting material from Grassholm are of the same order as, if slightly higher than, those for a typical range of surface soils from mainland Wales (Jones *et al.* 1989). With respect to individual PAHs, the Grassholm samples showed relative enrichment with phenanthrene in particular, but also with pyrene, chrysene, naphthalene and acenaphthylene, when compared to the typical soil values. Benzo[a]anthracene was also present at significant concentrations in the nesting material; this PAH was not included in the analyses of Welsh soils. Note that the soil data were reported as ug/kg dry weight. The conversion of the nest material data from a wet weight to a dry weight basis would magnify this enrichment.

The differences are yet more marked if levels in nesting material are compared with concentrations for those soil samples taken by Jones *et al.* (1989) from rural locations around St David's Head, immediately onshore from Grassholm. Again, phenanthrene and pyrene are particularly elevated in comparison in nesting material from Grassholm. Most of the nests sampled from Grassholm yielded total PAH concentrations higher than those reported for surface soils from the St David's peninsula. Although PAH levels in a soil sample taken 0.5 km from an oil terminal at Milford Haven showed significant elevation above background (Jones *et al.* 1989), several of the nest samples still showed greater contamination.

On the basis of their extensive data set, Jones *et al.* (1989) made a generalised distinction between "remote/rural" and "urban" soil samples as < and >600 ug/kg total PAH respectively. PAH levels in three of the nest sites sampled from Grassholm exceed this boundary value, despite the fact that it represents a relatively remote island site.

Perhaps more significantly, levels in two of the nests sampled from St Kilda also slightly exceeded the boundary value. This is surprising, given the remote location of the island. When comparing levels on St Kilda with those on Grassholm it should be noted that the samples were collected at different times of year; the significance of this is not known. Nevertheless, the limited data so far available from the St Kilda nests indicate that PAH accumulation may be a common characteristic of gannetries, particularly in older nests, reflecting widespread, if patchy, oil contamination of debris collected from the sea surface. These results

Table 2.
Means, medians and ranges for PAH concentrations in gannet nesting material from Grassholm and St Kilda, compared to similar statistics for surface soils from rural areas of Wales (from Jones *et al.* 1989).

PAH	Grassholm			St Kilda			Wales		
	mean	median	range	mean	median	range	mean	median	range
naphthalene	25.4	25.3	20.9-30.6	131.1	123.0	32.8-245.6	8.7	2.4	<1-131
acenaphthylene	33.3	12.2	10.2-159.5	n/d	n/d	n/d	3.0	<1.0	<1-23
fluorene [1]	28.4	8.0	n/d-137.5	16.0	12.1	n/d-31.9	61	37	12.4-453
phenanthrene	202.9	62.7	n/d-785.4	219.7	227.7	88.2-335.1	72	22	7.7-772
fluoranthene	61.1	42.9	22.2-177.1	32.8	35.3	12.4-48.2	156	42	17-1550
pyrene	95.8	38.8	16.2-282.5	44.0	50.4	13.3-61.8	63	29	11-456
benzo[a]anthracene	40.2	42.7	n/d-82.5	43.3	50.1	n/d-66.1	-	-	-
chrysene [2]	164.2	80.9	32.8-590.2	n/d	n/d	n/d	123	36	13.4-1120

n/d indicates concentrations below limits of detection (see Appendix 2); - indicates PAH was not included in analyses. For acenaphthylene, phenanthrene and benzo[a]anthracene in Grassholm samples, values below limits of detection were assumed to be half the limit of detection for the purpose of calculating means. [1] value for Welsh soil is for fluorene and acenaphthalene combined. [2] value for Welsh soil is for chrysene and 1,2-dibenzanthracene combined.

would seem to suggest exposure of adults, egg and young to elevated PAH concentrations from nesting material even within colonies remote from anthropogenic activity. A more extensive survey of PAH concentrations in nesting material from other colonies, and perhaps from other species, would be very useful in order to put these data into context.

The reasons for the differences in relative abundance of different PAHs between the nesting material and soils are also unclear. Jones *et al.* (1989) reported that, in soil at more contaminated sites, phenanthrene increased markedly in dominance compared to other PAHs. The predominance of phenanthrene in the nest samples from both sites was highlighted above.

As noted by Laflamme and Hites (1978), combustion and oil contamination are the probably the most important sources of global PAH contamination. PAHs in soils from remote locations may arise from local sources or through deposition of airborne contaminants, primarily particulates. There are some biogenic sources, including the degradation of pinene and other complex plant-derived compounds, but these are generally only locally significant in forest soils. Although deposition may have contributed in part to the levels recorded on Grassholm, the inclusion of contaminated debris during nest construction is a more likely source. It may helpful to compare PAH levels in undisturbed soils from Grassholm and St Kilda with levels in nesting material. This might allow differentiation between PAHs from deposition sources and those accumulated through the collection of floating debris for nest building.

The relative abundance of some PAHs compared to others in the nest samples may be explained in part by relative volatilities and degradation rates. Naphthalene, for example, is highly volatile and would be expected to be lost relatively rapidly from contaminated material. In addition, whereas degradation half lives for naphthalene, acenaphthylene and fluorene range between 16 and 60 days, those for phenanthrene, pyrene and chrysene range from hundreds of days to several years (Howard *et al.* 1991).

With the available data it has not been possible to detect the impact of the Sea Empress spill on PAH contamination of nesting material on Grassholm. Mean total PAH levels were of a similar order at both sites studied, although significant differences in relative abundance of PAHs (higher naphthalene on St Kilda, higher chrysene on Grassholm) were noted. These may reflect differences in the sources of sea surface and debris oil contamination in the vicinity of the two colonies. A biogenic origin for the PAHs detected seems unlikely given the concentrations present. Some PAHs may be extractable from plastic debris, although again it seems unlikely that this could account for the levels observed. The consistently higher concentrations of naphthalene on St Kilda warrant further investigation.

Law et al. (1997) present an extensive survey of PAH contamination of surface waters around the UK. These authors note that PAH concentrations at offshore sites were generally low or undetectable, with more significant levels measurable only in coastal and estuarine waters. Nevertheless it is unlikely that the presence of oil-contaminated debris would correlate well with dissolved PAH concentrations, other than in exceptional circumstances (e.g. in the vicinity of a spill). Through selection of isolated patches of floating debris during nesting, gannets may effectively concentrate small pieces of contaminated material, collected over a wide area, into the nest structure.

As noted above, data for Grassholm were skewed by a small number of more heavily contaminated nests, a phenomenon not seen on St Kilda, although such nests may simply not have been detected with the smaller sample size used. Clearly levels of contamination are likely to reflect the types of material used in the construction of the nests; substantial variation in PAH concentrations from nest to nest may, therefore, be expected. Analysis of a larger number of the nest samples taken from St Kilda would allow a better understanding of the distribution of contaminants between nests.

Matrix heterogeneity was a significant problem. Four samples (three from Grassholm and one from St Kilda) were subsampled and run in duplicate. Differences were observed between levels of individual PAHs from the two runs, particularly those present at concentrations close to the limits of detection, as may be expected. Nevertheless, for three of the four samples, differences between duplicate total PAH determinations were less than 30%. For the fourth sample, poorer agreement resulted in large part from the detection of anthracene at substantial concentrations in one subsample which was below LOD in the second subsample. We are currently in the process of obtaining chromatograms for the two subsamples in order to resolve this difference.

Problems of sample heterogeneity could be minimised by collection and analysis of larger samples. This may also help to improve the detection of paraffins, which were close to or below limits of detection for many of the current samples. The possibility of increased sample size in terms of sample preparation will be explored in case further funds become available for a more extensive sampling programme in future.

5. Conclusions

- The rapid increase in the percentage of Grassholm gannets which showed clear signs of oil contamination in early 1996 suggests that the *Sea Empress* spill may have been responsible. Although the slick itself was unlikely to have reached Grassholm, it is possible that oil residues were carried to the colony either on the feathers of birds or on marine debris collected during the subsequent nest building period (see below).

- Estimates of gannet productivity did not reveal a significant fall in reproductive success following the *Sea Empress* spill in 1996. However, the data available are fairly crude and may only have been expected to have revealed a relatively large fall in productivity.

- Levels of PAHs were significant at both sites when compared to levels measured in soils from rural sites on shore, suggesting the accumulation of oil-contaminated debris in the nest structures. Nevertheless, the available data do not indicate a significant difference in total PAH concentrations between nesting material collected from Grassholm and St Kilda. The levels on St Kilda suggest that such accumulation may be a common characteristic of gannet nests. Further samples of nesting material from both Grassholm and St Kilda are available. Should funds become available in the future, analysis of these samples could provide a clearer overview of relative contaminant levels at the two sites and between nests at each site. However, given the absence of historical data sets for PAH levels in nests at either site, it is unlikely that we will be able to link directly the presence of PAHs to the collection of contaminated material from any one particular incident.

- The limited data available to date do not suggest significant differences in PAH and paraffin contamination between successful and failed nests on Grassholm. This may simply be due to the relatively crude method by which nest failure was assessed and to the fact that nest samples could not be collected until after the nests had been vacated. The analysis of the complete sample set available may provide further information. At this stage, such further analyses are limited by availability of funding.

- The toxicological significance of the levels of hydrocarbons determined in the nesting material is not known. Certainly, many of the PAHs found are known to be toxic, following both acute and chronic exposure. The current investigation does suggest that PAH exposure is characteristic even of relatively remote colonies. However, the extent to which contamination of nest material would lead to contamination of the egg, embryo or developing young cannot be determined from these data.

6. Acknowledgements

This project was partially funded by the Countryside Council for Wales, and a grant from the Seabird Group. The hydrocarbon analysis was funded by Greenpeace UK.

Stuart Murray the warden of St Kilda, for collecting nest samples from the island.

7. References

Ainley, D.G., C.R. Grau, T.E. Roudybush, S.H. Morrel and J.M. Utts (1981). Petroleum ingestion reduces reproduction in Cassin’s auklets. Mar. Poll. Bull. 12: 314-317.

Albers, P.H., (1977). Effects of external applications of fuel oil on hatchability of mallard eggs. In Fate and Effects of Petroleum Hydrocarbons in Marine ecosystems and Organisms, Wolfe, D.A., [Ed.]. Pergamon, New York: 158-163.

Albers, P.H., (1980). Transfer of crude oil from contaminated water to bird eggs. Environ. Res. 22: 307-314.

Butler, R. G., A. Harfenist, F. A. Leighton, and D. B. Peakall. 1988. Impact of sublethal oil and emulsion exposure on the reproductive success of Leach's storm petrels:short and long-term effects. Journal of Applied Ecology **25**:125-143.

Colombé, S.V. 1996. Irish Ferry Crossings Survey Report, March 1996. Unpublished report to Seabirds at Sea Team, JNCC, Aberdeen.

Colombé, S.V., Reid, J.B., & Webb, A. 1996. Seabird studies off south-west Wales and south-east Ireland following the *Sea Empress* incident at Milford Haven, February 1996. *JNCC Report*, No. 225

Coon, N.C., and M.P. Dieter (1981). Responses of adult mallard ducks to ingested South Louisiana crude oil. Environ. Res. 24; 309-314.

ESAS

Fowler, GS, Wingfield, JC, Boersma, PD. 1995 Hormonal and reproductive effects of low-levels of petroleum fouling in Magellanic penguins *Speniscus magellanicus*. Auk 112: 382-389.

Fry, D. M., J. Swenson, L. A. Addiego, C. R. Grau, and A. Kang. 1986. Reduced reproduction of wedge-tailed shearwaters exposed to weathered Santa Barbara crude oil. Archives of Environmental Contamination and Toxicology **15**:453-463.

Hartung, R. 1965 Some effects of oiling on reproduction of ducks. Journal of Wildlife Management, 29: 872-874.

Howard, P.H., R.S. Boethling, W.F. Jarvis, W.M. Meylan and E.M. Michalenko (1991). Handbook of Environmental Degradation Rates. Lewis Publishers, Michigan, USA: 725 pp.

Jones, K.C., J.A. Stratford, K.S. Waterhouse and N.B. Vogt (1989). Organic contaminants in Welsh soils: polynuclear aromatic hydrocarbons. Environmental Science and Technology 23(5): 540-550.

Laflamme, R.E., and R.A. Hites (1978). The global distribution of polycyclic aromatic hydrocarbons in recent sediments. Geochim. Cosmochim. Acta 42: 289-303.

Law, R.J., V.J. Dawes, R.J. Woodhead and P. Matthiessen (1997). Polycyclic aromatic hydrocarbons (PAH) in seawater around England and Wales. Mar. Poll. Bull. 34(5): 306-322.

Montevecchi, W.A. 1990 Incidence and types of plastic in gannets' nests in the northwest Atlantic. Canadian Journal of Zoology 69:295-297.

MPCU 1996 The Sea Empress Incident. A report by the Marine Pollution Control Unit. Coastguard Agency 1996.

Norman, F.I., Menkhorst, P.W., Hurley, V.G. 1995 Plastics in nests of Australian Gannets *Morus serrator* in Victoria, Australia. Emu 95:129-133.

Parnell, J.F., Shields, M.A., Frierson, D. 1984. Hatching success of brown pelican eggs after contamination with oil. Colonial Waterbirds **7**:22-24.

Patten, S. M., and L. R. Patten. 1979. Evolution, pathobiology, and breeding ecology of large gulls (Larus) in the northeast Gulf of Alaska and effects of petroleum exposure on the breeding ecology of gulls and kittiwakes. Environmental assessment of the Alaskan Continental shelf Final reports of the principal investigators Volume 18. Biological Studies. US Department of Commerce, US Department of Interior.

Wanjala, SL & Leighton, FA. 1996. Effects of Prudhoe Bay crude oil on hatching success and associated changes in pipping muscles in embryos of domestic chickens (*Gallus gallus*). Journal of Wildlife Diseases 32: 209-215.

Lab. code	Location	Nest	PAH concentration (ug/kg wet weight)															
			nap	acenap	acenapy	fluor	phen	anth	fluoran	pyr	B[a]A	chry	B[b]F	B[k]F	B[a]P	diB[a,h]A	B[g,h]P	I[1,2,3-cd]P
gn6005	Grassholm	failed x1	23.46	n/d	n/d	n/d	41.87	n/d	22.16	24.63	n/d	53.78	n/d	n/d	n/d	n/d	n/d	n/d
gn6006	Grassholm	failed d2	20.89	n/d	n/d	34.06	397.91	n/d	51.32	202.06	67.17	174.39	n/d	n/d	n/d	n/d	n/d	n/d
gn6007	Grassholm	failed b3	24.87	n/d	n/d	n/d	62.7	n/d	37.59	38.24	n/d	80.85	n/d	n/d	n/d	n/d	n/d	n/d
gn6008	Grassholm	failed b6	25.25	n/d	n/d	n/d	n/d	n/d	42.89	38.76	57.6	70	n/d	n/d	n/d	n/d	n/d	n/d
gn6009	Grassholm	failed c1	23.71	n/d	n/d	n/d	26.97	n/d	26.86	28.76	54.02	63.41	n/d	n/d	n/d	n/d	n/d	n/d
gn6010	Grassholm	failed c6	25.64	n/d	54.05	137.5	785.41	n/d	101.92	282.47	82.5	590.24	n/d	n/d	n/d	n/d	n/d	n/d
gn6014	Grassholm	failed d1	28.58	n/d	n/d	n/d	46.45	n/d	37.71	16.18	26.52	32.8	n/d	n/d	n/d	n/d	n/d	n/d
gn6011	Grassholm	control	30.64	n/d	n/d	19.89	129.16	n/d	52.04	69.38	20.65	134.14	n/d	n/d	n/d	n/d	n/d	n/d
gn6012	Grassholm	control	25.25	n/d	159.45	28.85	331.25	n/d	177.1	161.85	42.71	278.04	n/d	n/d	n/d	n/d	n/d	n/d
gn6015	Grassholm	control	36.08	n/d	n/d	n/d	182.98	n/d	54.24	20.93	250.54	n/d	n/d	n/d	n/d	n/d	n/d	n/d
gn6013	St Kilda	control	32.82	n/d	n/d	16.04	88.22	n/d	12.4	13.29	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d
gn6016	St Kilda	control	135.44	n/d	n/d	n/d	335.11	n/d	32	44.54	51.61	n/d	n/d	n/d	n/d	n/d	n/d	n/d
gn6017	St Kilda	control	245.56	n/d	n/d	31.91	179.79	n/d	48.24	61.75	66.13	n/d	n/d	n/d	n/d	n/d	n/d	n/d
gn6018	St Kilda	control	110.51	n/d	n/d	n/d	275.53	n/d	38.59	56.29	48.60	n/d	n/d	n/d	n/d	n/d	n/d	n/d
gn6003	Grassholm	feathers	288	n/d	n/d	n/d	1240	n/d	2012	9433	16739	20488	n/d	15382	n/d	1393	n/d	1523
gn6004	Grassholm	plastic	103.07	330.61	5216	27396	157297	n/d	42530	98557	4107	38293	n/d	49273	n/d	9329	n/d	10203

Appendix 1: PAH concentrations (as ug/kg wet weight of nest material or debris). Abbreviations are as follows: nap - naphthalene, acenap - acenaphthalene, acenapy - acenaphthylene, fluor - fluorene, phen - phenanthrene, anth - anthracene, fluoran - fluoranthene, pyr - pyrene, B[a]A - benzo[a]anthracene, chry - chrysene, B[b]F - benzo[b]fluoranthene, B[k]F - benzo[k]fluoranthene, B[a]P - benzo[a]pyrene, diB[g,h]A - dibenzo[g,h]anthracene, B[g,h}P - benzo[g,h]perylene, I[1,2,3-cd]P - Ideno[1,2,3-cd]pyrene. All data are corrected for extraction efficiency.

Lab. code	Location	Nest	Paraffin concentration (mg/kg wet weight)														
			oct	non	dec	undec	dodec	tetradec	hexadec	octadec	eicos	Tetracos	Octacos	dotria	hexatria	tetracon	tetratetra
gn6005	Grassholm	failed x1	n/d	n/d	n/d	3.91	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d
gn6006	Grassholm	failed d2	n/d	n/d	n/d	n/d	n/d	0.64	1.13	1.8	1.72	0.51	1.33	0.54	0.84	n/d	n/d
gn6007	Grassholm	failed b3	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d
gn6008	Grassholm	failed b6	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d
gn6009	Grassholm	failed c1	n/d	n/d	n/d	1.1	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d
gn6010	Grassholm	failed c6	n/d	n/d	n/d	n/d	n/d	n/d	n/d	1.66	n/d	n/d	n/d	n/d	n/d	n/d	n/d
gn6014	Grassholm	failed d1	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d
gn6011	Grassholm	control	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d
gn6012	Grassholm	control	n/d	n/d	n/d	3.52	n/d	n/d	n/d	n/d	n/d	3.06	n/d	0.33	n/d	n/d	n/d
gn6015	Grassholm	control	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d
gn6013	St Kilda	control	n/d	n/d	n/d	1.22	n/d	n/d	n/d	n/d	n/d	0.4	1.25	0.43	n/d	n/d	n/d
gn6016	St Kilda	control	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	0.31	n/d	n/d	n/d	n/d
gn6017	St Kilda	control	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	0.69	0.79	n/d	n/d	n/d
gn6018	St Kilda	control	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d	n/d
gn6003	Grassholm	feathers	n/d	n/d	n/d	n/d	n/d	n/d	n/d	12.39	44	94.6	143	3.73	n/d	n/d	n/d
gn6004	Grassholm	plastic	n/d	n/d	n/d	n/d	13.09	939	7114	11408	6692	8714	5950	3475	1096	333	56.8

Appendix 2: Paraffin concentrations (as **mg/kg** wet weight of nest material or debris). Abbreviations are as follows: oct - octane, non - nonane, dec - decane, undec - undecane, dodec - dodecane, tetradec - tetradecane, hexadec - hexadecane, octadec - octadecane, eicos - eicosane, tetracos - tetracosane, octacos - octacosane, dotria - dotriacontane, hexatria - hexatriacontane, tetracon - tetracontane, tetratetra – tetratetracontane. All data are corrected for extraction efficiency.

Compound	Limit of detection (ug)	Percentage recovery (%)
Naphthalene	0.0362	79
Acenaphthalene	0.0351	94
Acenaphthylene	0.143	78
Fluorene	0.102	94
Phenanthrene	0.0632	94
Anthracene	0.173	95
Fluoranthene	0.048	85
Pyrene	0.0597	97
Benzo[a]anthracene	0.0854	93
Chrysene	0.0861	85
Benzo[b]fluoranthene	0.652	56
Benzo[k]fluoranthene	0.331	58
Benzo[a]pyrene	0.341	78
Dibenz[a,h]anthracene	1.68	72
Benzo[g,h,i]perylene	0.22	54
Ideno[1,2,3-*cd*]pyrene	0.0357	65
n-octane	2.65	72
n-nonane	1.89	80
n-decane	2.25	79
n-undecane	1.92	80
n-dodecane	1.75	79
n-tetradecane	1.74	75
n-hexadecane	1.61	69
n-octadecane	1.46	68
n-eicosane	1.057	64
n-tetracosane	1.24	60
n-octacosane	0.793	60
n-dotriacontane	0.641	58
n-hexatriacontane	0.754	56
n-tetracontane	0.583	57
n-tetratetracontane	0.629	56

Appendix 3: limits of detection and spiked recoveries for PAHs and n-alkanes