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PATTERNS OF MARINE TURTLE MORTALITY IN BRITISH WATERS (1992–1996) WITH REFERENCE TO TISSUE CONTAMINANT LEVELS

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Mortality patterns of marine turtles entangled in fishing gear, found dead at sea or stranded dead on and around the coast of Britain in the period 1992–1996 are described. Of a total of 38 dead turtles identified, 35 were leatherback turtles (*Dermochelys coriacea*) and three were loggerhead turtles (*Caretta caretta*). All *D. coriacea* were considered adults or subadults nearing sexual maturity. Six individuals were assessed as females, ten were classified as males and 19 were not sexed. *Dermochelys coriacea* (N=20 measured) ranged from 120 to 210 cm in curved carapace length (mean, 152 cm). The three *C. caretta* were juveniles, and ranged from 15 to 30 cm curved carapace length. Possible origins, causes of mortality and interactions with fisheries are discussed. In addition, contaminant levels were determined in the tissues of three *D. coriacea*. Concentrations of organic contaminants determined were found to be low.

INTRODUCTION

It has been well documented that marine turtles, especially the leatherback (*Dermochelys coriacea* (Vandelli)) and the loggerhead (*Caretta caretta* (L.)) range widely in European Atlantic waters (Brongersma, 1972; Gaywood, 1997; Penhallurick, 1990, 1991, 1993). Whereas the presence of *C. caretta* and any other cheloniid turtles in British waters is thought to be the result of animals being carried by currents from their normal habitat, it is widely accepted that *D. coriacea* should be considered a normal and regular member of the British marine fauna. Indeed, this species has been shown to possess numerous adaptations that allow it to function in temperate waters (see for example Frair et al., 1972; Davenport et al., 1990a).

In the Atlantic, *D. coriacea* nest on beaches of tropical regions which include sites in the Caribbean islands, Florida, Central and South America and the west coast of Africa (Boulon et al., 1996; Campbell et al., 1996; Fretey & Girardin, 1989; Girondot & Fretey, 1996; Spotila et al., 1996). It is thought that outside reproductive periods, this species ranges widely in search of its medusoid prey, which in British waters, mainly consist of Rhizostoma and Cyanea (Den Hartog & Van Neirop, 1984; Holland et al., 1990). Anecdotal accounts from around Britain and quantitative evidence from the Atlantic coast of North America suggest that abundance of both *D. coriacea* and their jellyfish prey may be correlated (Grant et al., 1996), however, there appear to be seasons where jellyfish are abundant and *D. coriacea* absent (S. Murphy, personal communication).

There is great concern over the future of the world leatherback population, which appears to be in decline. Some authors have suggested that, from current evidence, it is plausible that this species may be on the verge of extinction (Spotila et al., 1996). Although this view has been questioned (Pritchard, 1996), it is apparent that the status of, and threats to, this species in all parts of its range should be quantified and, where possible, addressed.

Data regarding recent patterns and causes of mortality and baseline tissue contaminant levels in other marine megafauna in British waters are quite well established (see for example Bucke, 1990; Law, 1994; North Sea Task Force, 1993). Information regarding similar parameters in marine turtles in British and other northern European waters is, at best, scant. Only levels of metals and organic pollutants in tissues of a single *D. coriacea*, stranded dead in Wales in 1988, have been described (Davenport & Wrench, 1990; Davenport et al., 1990b). This study attempts to qualify the levels of marine turtle mortality in British waters in recent years and investigates the species, sex, size-class composition of the individuals involved and possible reasons for mortality. In addition, baseline contaminant levels for *D. coriacea* are given as are recommendations as to priorities for further research.

MATERIALS AND METHODS

Marine turtle strandings

Data regarding marine turtle strandings from around Britain were tabulated for the period 1992–1996. These included cases of turtles stranded dead, turtles entangled in fishing gear which subsequently died, and turtles recovered dead at sea. Information consisted of data collected by both governmental and non-governmental organizations and compiled in numerous separate databases. Due to the retrospective nature of this study, not all data were collected in an identical way. However, similar data were collected in a sufficient portion of cases to allow comparisons to be made. These parameters included: date of discovery, species, size (medial curved carapace length or CCL), weight, and the presence of any lesions. In a limited number of cases, full necropsy was undertaken by veterinary pathologists.

Analysis of contaminant levels

Samples were taken for analysis of contaminant levels in three adult male *Dermochelys coriacea*, all of which drowned as the result of entanglement in fishing gear off the west coast of Britain. The locations, dates of these events and CCL for individuals 1–3 respectively, were: Tenby, Wales (12 September 1996, 170 cm); Drumbeg, Sutherland, Scotland (18 October 1993, 151 cm); Uig, Isle of Skye, Scotland (24 October 1995, 141 cm).

A range of trace metals plus arsenic and selenium were determined in liver and muscle tissue of individual 1, using acid digestion with microwave heating followed (except for mercury) by analysis using inductively coupled plasma/mass spectrometry. Total mercury was analysed using atomic fluorescence detection, following reduction with tin (II) chloride. All analyses were conducted under an analytical quality protocol requiring the analysis of blanks and reference materials alongside each batch of samples. Further details of method performance are given elsewhere (Law, 1994; Law et al., 1997). The liver sample from this individual was also analysed for organotin compounds (tributyl and dibutyltin) by gas chromatography with flame-photometric detection (Waldock et al., 1989), but these compounds were not found (limits of detection 0·006 and 0·008 mg kg^{-1} respectively). Total mercury, cadmium and lead concentrations were quantified in muscle and liver samples from individuals 2 and 3. Total mercury was analysed using a cold vapour absorption spectrophotometry technique according to an established methodology (Thompson & Furness, 1989). Cadmium and lead levels were ascertained by atomic absorption spectrophotometry according to the methodology of Stewart et al. (1994).

Adipose tissue samples from all three individuals were screened for organochlorine contaminants at two separate laboratories using comparable methodologies. Concentrations of organochlorine pesticides (including DDT and its metabolites) and a range of chlorobiphenyl (CB) congeners were determined by gas chromatography with electron capture detection (Allchin et al., 1989). The original methodologies have been modified in the light of recommendations from the intercomparison programme organized under the auspices of the International Council for the Exploration of the Sea (ICES) (de Boer et al., 1994). Data from both laboratories have been shown to yield comparable data in collaborative studies within ICES (Boon et al., 1997).

Adipose tissue and liver samples from individual 1 were analysed to determine levels of polycyclic aromatic hydrocarbons (PAH). Samples were analysed by coupled gas chromotography-mass spectrometry. Eighteen individual PAH compounds were determined.

RESULTS

Patterns of mortality

A total of 38 dead turtles was recorded during the period 1992–1996. Of these, three were *Caretta caretta* and 35 were *Dermochelys coriacea*. Table 1 lists the status of animals discovered (dead stranded, dead entangled, found dead at sea), by species, year and major geographic area. The strandings were quite widely distributed around north and western Britain as can be seen in Figure 1. However, there is a conspicuous clustering in Carmarthen Bay, Wales (N=13).

Table 1. *Discovery of marine turtles by year and major geographic region.*

		Year															
		1992			1993			1994			1995			1996			
		S	W	E	S	W	E	S	W	E	S	W	E	S	W		**Total**
Dermochelys coriacea	Dead stranding							2		5		5		6	7	1	28
	Dead entangled				1						1	2		1	1		6
	Dead at sea												1				1
	Total			2	1			2		5	1	7	1	7	8	1	35
Caretta caretta	Dead stranding	1		1							1						3
	All species	1	0	3	1	0	0	2	0	5	2	7	1	7	8	1	38
	Annual total		4			1			7			10			16		

S, Scotland; W, Wales; E, England.

The three *C. caretta* were found dead, stranded in the months of March, October and November and it is not possible to draw conclusions regarding temporal distribution, from such a small sample. In contrast, mortality events of *D. coriacea* (Figure 2) show a marked seasonality, with carcasses beginning to be discovered in July, rising to a pronounced peak in October (16/35=46%), with few carcasses being discovered in November, December and January. The majority of carcasses were discovered between August and October (28/35=80%).

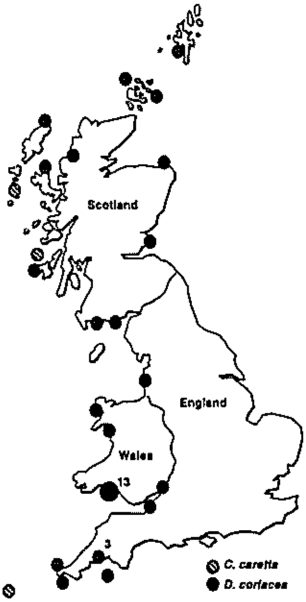

Figure 1. Schematic map of Britain to show locations where dead turtles were discovered (1992–1996).

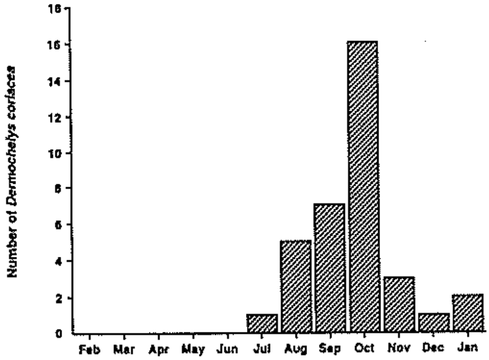

Figure 2. Temporal distribution of discovery of mortality events in *Dermochelys coriacea* (N=35) in British waters (1992–1996).

All *C. caretta* were small juveniles, of the size consistent with those expected to be found in the pelagic phase of marine turtle development (Musick & Limpus, 1997). Only one individual (19 cm CCL, weight 0·762 kg) was freshly dead when discovered on 7 November 1995, on Benbecula, Western Isles, Scotland and was subjected to full necropsy, showing it to have no detectable gross lesions. It was judged that this individual was likely to have died from starvation after it had strayed/been carried by currents from its normal developmental habitat.

Mean CCL of all *D. coriacea* in this study was 152 cm (N=20 animals measured, SD=25·0, range 120–210 cm). When compared with available literature values for sizes of nesting females at different Atlantic nesting colonies, all individuals of this species were thought to be adults or subadults approaching sexual maturity (except possibly the individual of 120 cm CCL) (Boulon et al., 1996; Campbell et al., 1996; Fretey & Girardin, 1989; Girondot & Fretey, 1996). Due to sexual dimorphism in tail length, the tail of adult females rarely extends more than a few centimetres beyond the caudal tip of the carapace (M. Girondot, personal communication), it was possible to sex 16 of the 35 individuals. Of these, six (37·5%) were sexed as females and ten (62·5%) as males. Although it is advisable to treat data based solely on sexing according to this criterion with caution since large immature males could feasibly be recorded as adult females, it is likely that individuals, mostly adults, of both sexes are found in British waters.

In at least six cases, the cause of mortality of *D. coriacea* is known to have been entanglement (Table 1). However, most of the turtles for which the cause of death was not known, were not subject to detailed necropsy by a veterinary pathologist. In several cases, evidence suggestive of previous entanglement was present, including lacerations and entangling ropes. In others (N=2), there were possibilities of earlier collision with marine vessels. It could not be established, however, whether these events were ante- or post-mortem.

One individual which appeared to have died as the result of causes other than entanglement was an adult female (167 cm CCL, weight 420 kg,) found dead on 26 December 1994, at Kircudbright, Scotland. This turtle was thought to have died as a result of starvation, caused by a primary obstruction of the digestive tract by ingested plastic and metal litter. In addition, the animal was likely to have been further compromised by a chronic necrotic lesion in the shoulder, caused by a large fish hook embedded deep within the pectoral muscle.

Contaminant levels

The results of metal contaminant analyses are given in Tables 2 & 3. There was considerable interindividual variance in the levels of metals investigated. However the general patterns were similar, with liver levels generally exceeding those of muscle. Cadmium concentrations in the three individuals in this study ranged from 5 to 88 mg kg^{-1} dry weight in livers and from 1·4 to 7·5 mg kg^{-1} dry weight in muscle. This range is almost tenfold greater than that found in the individual from Porthmadog, Wales (Davenport & Wrench, 1990). Lead levels ranged from 0·02 to 14·0 mg kg^{-1} in liver and were $<$0·09 mg kg^{-1} in muscle from all individuals.

Table 2. *Concentrations of trace metals, arsenic and selenium in liver and muscle tissue of individual 1 (mg kg^{-1} wet weight).*

Tissue	TS%	Cr	Fe	Ni	Cu	Zn	As	Se	Ag	Cd	Hg	Pb	Hg:Se
Liver	31·8	<0·018	5770	<0·062	9·7	42	2·6	6·5	0·17	28	0·37	4·3	0·022
Muscle	33·3	0·97	38	0·53	0·76	51	4·7	4·3	<0·003	2·5	0·013	<0·031	0·0012

Hg:Se, molar ratio of the concentrations of mercury and selenium; TS%, dry tissue percentage and is presented so data can be expressed on a dry weight basis for comparative purposes.

Table 3. *Concentrations of trace metals, arsenic and selenium in livers of leatherback turtles from individual 1 (this study) and selected metals in individuals 2 and 3 compared with another individual stranded at Porthmadog, Wales in 1988 (mg kg^{-1} dry weight). The values for the latter are mean values derived from four replicate analyses (Davenport & Wrench, 1990).*

Tissue	Individual	Ni	Cu	Zn	As	Se	Cd	Hg	Pb	Hg:Se
Liver	1	<0·19	31	132	8·2	20	88	1·2	14	0·02
	2	n.d.	n.d.	n.d.	n.d.	n.d.	12	0·82	0·02	n.d.
	3	n.d.	n.d.	n.d.	n.d.	n.d.	5	0·29	0·04	n.d.
	Porthmadog	2·1	0·15	2·6	0·58	1·4	0·22	0·39	0·12	0·11
Muscle	1	1·6	2·3	153	14	13	7·5	0·04	<0·09	0·001
	2	n.d.	n.d.	n.d.	n.d.	n.d.	1·4	0·29	<0·01	n.d.
	3	n.d.	n.d.	n.d.	n.d.	n.d.	2·8	0·12	<0·01	n.d.
	Porthmadog	1·6	0·26	1·9	0·21	3·6	0·06	0·12	0·31	0·013

n.d., not determined.

Mercury levels in the present study varied between 0·29 and 1·2 mg kg^{-1} in liver and 0·04 and 0·12 mg kg^{-1} in muscle. These levels were similar to the Porthmadog individual. It is not known whether turtles are able to detoxify methylmercury ingested from their diet, immobilizing mercury as the selenide as in marine mammals. The concentrations of mercury, are however very low, as are mercury/selenium ratios observed (Hg:Se <1), suggesting that mercury is unlikely to have adversely affected the health of these animals.

Concentrations of all organochlorine compounds were low (Table 4). This was especially true of pesticide residues. Only *p*, *p*,'-DDE could be detected consistently in all three individuals with a range of 0·010–0·068 mg kg^{-1} wet weight. The fact that *p*, *p*'-DDT is essentially present only as *p*, *p*'-DDE indicates uptake remote from the source of the DDT. In all three cases, the major CB compounds present were, in decreasing levels, CB153, CB138 and CB180. Sum of levels of the ICES7 congeners gave a range of 0·035–0·16 mg kg^{-1} wet weight. Although not all congeners were measured in all individuals, it is thought that the sum of all congeners is representative with a range of 0·047–0·23 mg kg^{-1} wet weight. This range is considerably lower than the level of 1·2 μg g lipid^{-1} described by Davenport et al. (1990b).

Table 4. *Concentrations of organochlorine contaminants in adipose tissue of three leatherback turtles from British waters (mg kg^{-1} wet weight).*

Individual	Lipid%	α-HCH	β-HCH	γ-HCH	HCB	Dieldrin	p, p'-DDD	p, p'-DDE	p, p'-DDT
1	41	<0·001	<0·001	<0·001	0·003	0·033	<0·001	0·068	<0·001
2	74	<0·001	n.d.	<0·001	<0·001	<0·001	<0·001	0·010	<0·001
3	50	<0·001	n.d.	<0·001	0·002	0·013	<0·001	0·057	<0.001

CB18	CB31	CB28	CB52	CB49	CB47	CB44	CB66	CB70	CB74	CB101
<0·001	<0·001	<0·001	<0·001	<0·001	<0·001	<0·001	0·006	n.d.	n.d.	<0·001
n.d.	<0·001	<0·001	0·012	0·002	n.d.	<0·001	n.d.	0·002	<0·001	0·004
n.d.	<0·001	0·001	0·012	0·002	n.d.	0·003	n.d.	0·002	0·001	0·006

CB110	CB151	CB149	CB118	CB153	CB105	CB141	CB138	CB158	CB187	CB183
<0·001	<0·001	<0·001	0·012	0·073	0·005	<0·001	0·047	0·001	0·033	0·006
0·0002	n.d.	0·001	0·001	0·008	<0·001	n.d.	0·005	<0·001	0·005	n.d.
0·0008	n.d.	0·004	0·008	0·046	0·003	n.d.	0·025	0·001	0·019	n.d.

CB128	CB156	CB157	CB180	CB170	CB194	ΣICES7	ΣCBs
0·007	<0·001	n.d.	0·032	0·013	0·003	0·160	0·230
<0·001	<0·001	<0·001	0·005	0·001	<0·001	0·035	0·047
0·004	0·001	0·001	0·024	0·011	0·004	0·123	0·178

n.d., not determined as part of specific analysis.

Results of PAH analyses are given in Table 5. Polycyclic aromatic hydrocarbon (PAH) concentrations are very low or undetectable with $\sum$PAH concentrations of 12 and 5·5 μg kg^{-1} wet weight in adipose tissue and liver respectively. The higher molecular weight (MW) PAH of primarily combustion origin (MW 228, 252, and 276 Da; benz[*a*]anthracene to benzo[*ghi*]perylene) were not detected in either tissue.

1996 are unprecedented. Since 1994, an expanding pot-based whelk (*Buccinum undatum*) fishery has been in operation. This has grown annually since 1994 and was projected to have increased to a value of £1·5 million or more in 1996, but the fishery was interrupted by the 'Sea Empress' oil spill off Milford Haven. Along with other activities, the whelk fishery was closed under the Food and Environment Protection Act (FEPA), 1985, from 28 February to 29 August 1996, and a voluntary ban was operated by fishermen in the area from the time of the grounding on 15 February until the FEPA order was in place. However, fishing was underway by the time peak numbers of *D. coriacea* might have been expected in the region. Circumstantial evidence would suggest that this fishery may be of concern with regard to its interaction with an endangered species.

It is not known how individuals become entangled. It may be that the turtles collide with buoy ropes by chance. Alternatively, turtles may actively attack rope/buoy systems as potential prey items such as jellyfish, or they may be attracted by the scent of bait/captured target species and subsequently become entangled. It is possible that some combination of these factors act together. Amelioration of the problem would appear difficult. In an area consistently shown to yield an unacceptable level of turtle/fishery interactions, consideration should be given to a closed season, coincidental with the peak in turtle abundance. Peak abundance would need to be ascertained, by an aerial surveying regime.

It is worthy of note that, although the absolute number of turtles discovered dead in British waters may be low, it is likely that those discovered are only a portion of those killed or dying. In addition, a modelling study regarding *C. caretta* (Crouse et al., 1987) has suggested that population levels may be strongly influenced by the levels of subadult and adult mortality. Therefore, the impact of fisheries and any other causes of mortality in British and European waters may be significant or important, especially given the suspected global decline of *D. coriacea* (Spotila et al., 1996). A further impact of northern European fisheries on *D. coriacea* stocks has recently been highlighted. A study of incidental catch by the British tuna fishing fleet demonstrated a catch rate of eight *D. coriacea* per 10,000 tuna, with a 100% mortality rate of turtles caught (N. Tregenza, personal communication).

This study has highlighted the need for further detailed investigations of the biology of these endangered (*D. coriacea*) and threatened (*C. caretta*) species to be undertaken. It is recommended that more information be gathered concerning the dispersion of these species in British and other northern European waters through aerial or sea based surveys. Given the lack of detailed empirical knowledge regarding demographic parameters in these species and given their endangered/threatened status, it would appear that strandings in Europe may offer opportunities to bridge some of the gaps in the knowledge base. For example studies of bones might elucidate age of individuals (Zug et al., 1986; Zug & Parham, 1996). An increase in the proportion of animals subject to full necropsy would further elucidate mortality factors acting upon these populations. Since *D. coriacea* is the top predator of a very poorly studied food-chain (Holland et al., 1990), secondary analyses such as the determination of contaminant levels would not only enable monitoring the health of populations, but in conjunction with identification of dietary items, could augment the scant information of the synecology of this enigmatic species.

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