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Epidermal diseases in bottlenose dolphins: impacts of natural and anthropogenic factors

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Experimental studies have highlighted the potential influence of contaminants on marine mammal immune function and anthropogenic contaminants are commonly believed to influence the development of diseases observed in the wild. However, estimates of the impact of contaminants on wild populations are constrained by uncertainty over natural variation in disease patterns under different environmental conditions. We used photographic techniques to compare levels of epidermal disease in ten coastal populations of bottlenose dolphins (*Tursiops truncatus*) exposed to a wide range of natural and anthropogenic conditions. Epidermal lesions were common in all populations (affecting >60% of individuals), but both the prevalence and severity of 15 lesion categories varied between populations. No relationships were found between epidermal disease and contaminant levels across the four populations for which toxicological data were available. In contrast, there were highly significant linear relationships with oceanographic variables. In particular, populations from areas of low water temperature and low salinity exhibited higher lesion prevalence and severity. Such conditions may impact on epidermal integrity or produce more general physiological stress, potentially making animals more vulnerable to natural infections or anthropogenic factors. These results show that variations in natural environmental factors must be accounted for when investigating the importance of anthropogenic impacts on disease in wild marine mammals.

Keywords: cetaceans; climate; contaminants; disease; pollution; skin

1. INTRODUCTION

In recent years, concern has been expressed over the possible effects of contaminants on the health of marine mammal populations (Addison 1989; Tanabe & Tatsukawa 1991). These long-lived top predators can accumulate high burdens of man-made chemicals in their tissues, particularly where they inhabit industrialized coastal environments (Holden 1978; Borrell 1993). Recent mass mortalities have highlighted the potential role of contaminants in disease susceptibility (Hall *et al*. 1992; Aguilar & Borrell 1994) and, in controlled experimental conditions, organochlorines and heavy metals have been demonstrated to adversely affect immune function (Swart *et al*. 1994). However, with few exceptions (Lahvis *et al*. 1995), most studies in the field have focused on recording tissue contaminant levels, but the actual consequences of these burdens on the health of their host populations remain unclear. Information from captive studies and other wild populations or species may be used to make inferences about the impacts of particular contaminant levels on a specific population. However, direct extrapolations are often invalidated by differences in other factors such as population density, diet and climate. As these factors may have profound effects on the health and dynamics of populations (Harwood & Rohani, 1996), their role needs to be investigated.

Assessing the health of free-ranging marine mammals is difficult and this is particularly so for cetaceans (whales, dolphins and porpoises). Studies of captive animals allow disease development to be monitored but cannot provide information on levels in the wild, while diseases in

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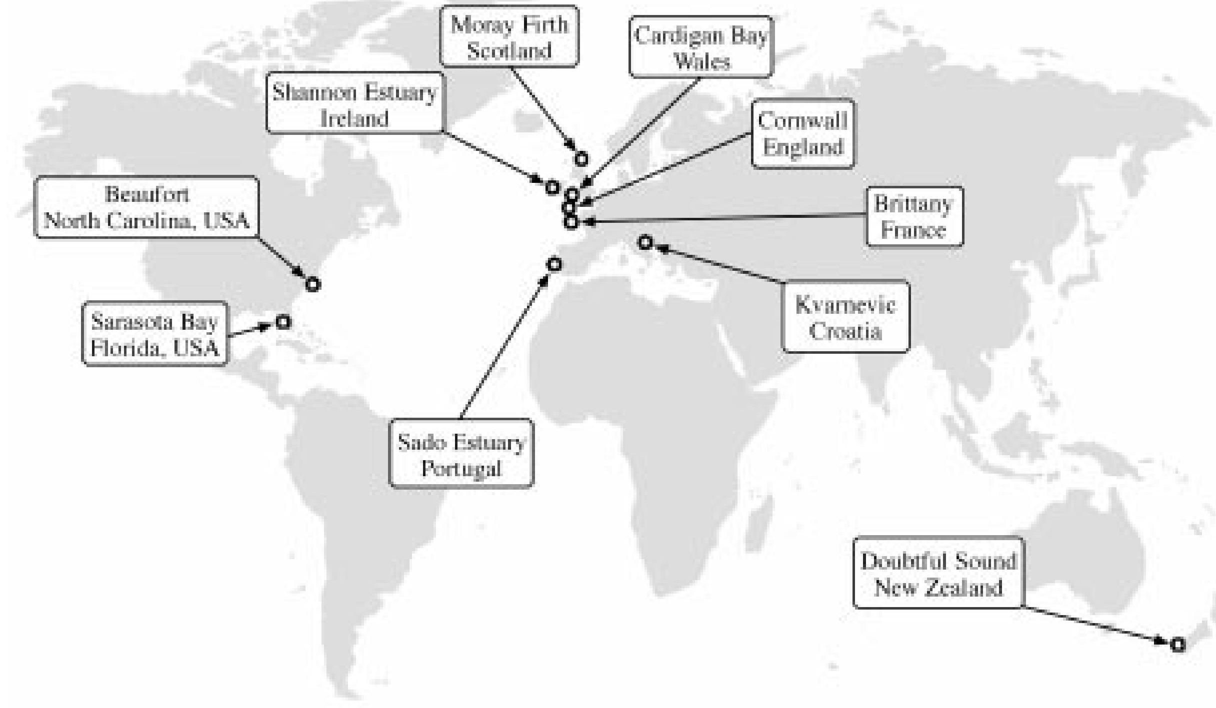

Figure 1. The geographical locations of the populations sampled.

stranded animals are, in most cases, unlikely to be fully representative of their populations of origin. Harvesting or lethal sampling provide greater opportunities for obtaining representative samples but are ethically inappropriate for small and already threatened populations. Temporary capture–release programmes permit sampling of known wild individuals, but these intensive studies have only been feasible in a few locations.

Cetaceans have no fur, so epidermal diseases are often highly visible and, consequently, are one of the most commonly reported categories of disease in these animals (Geraci *et al.* 1979; Geraci 1989; Baker 1992; Van Bressem *et al.* 1993, 1994; Bloom & Jager 1994). Furthermore, because of their visibility, their appearance, prevalence and severity can be remotely documented using photographs of the animals taken at sea (Thompson & Hammond 1992). Using this technique, levels of epidermal disease have been successfully documented in populations of wild bottlenose dolphins (*Tursiops truncatus*) off north-east Scotland and Portugal (Thompson & Hammond 1992; Harzen & Brunnick 1997; Wilson *et al.* 1997*a*). As bottlenose dolphins are distributed across a wide range of coastal habitats and are already studied using similar photographic techniques for other purposes (Wells 1991; Williams *et al.* 1993) they offer an ideal opportunity for studying the relationships between environmental and anthropogenic conditions and the development of natural epidermal diseases.

In this paper, we use existing data sources to compare the level of skin disease in ten populations of bottlenose dolphins inhabiting contrasting environments. In particular, we place the levels of skin disease previously reported in Scotland and Portugal into a broader context and assess whether the occurrence of these features is related to anthropogenic or natural environmental conditions.

2. MATERIAL AND METHODS

(a) *Study populations*

Ten photograph-identification studies (carried out off Croatia, England, Florida, France, Ireland, New Zealand, North Carolina, Portugal, Scotland and Wales) on coastal bottlenose dolphins were selected to represent populations experiencing a range of natural and anthropogenic conditions (figure 1). In nine populations, the dorsal fins and backs of free-ranging bottlenose dolphins were photographed during ongoing boat-based studies using standard methods (e.g. Wells 1991; Wilson *et al.* 1997*b*). In the tenth population (off North Carolina), individuals were photographed during brief captures (similar to those described by Scott *et al.* (1990)). Photographs were taken with manual or autofocus cameras and colour slide film. Individual dolphins were then identified and catalogued using natural marks and scars on their dorsal fins and backs.

(b) *Determining lesion prevalence and severity*

To determine the levels of epidermal disease, we chose a representative sample of individuals from each population. This sample comprised all animals photographed during the two-month period in which the greatest number of individuals in each study were identified. This limited time period was chosen to avoid problems arising from mark loss or change, thus excluding the potential for individuals to occur more than once in each sample (Wilson *et al.* 1999).

The photograph identification pictures in each sample were then examined. Categories of epidermal lesions, physical injuries and deformities were defined according to their visible characteristics (Wilson *et al.* 1997*a*). The best picture of each individual was then selected, ensuring that each was well lit, with the dorsal fin unobscured, parallel to and occupying a large proportion of the frame. These were then examined to determine the

Table 1. *Percentage prevalence and mean severity of epidermal lesions, deformities, injuries and parasites in each population*

(For prevalence, sample sizes are given in parentheses. Where photographs were of insufficient quality for a feature to be seen if present, then that picture was excluded from the estimate; this led to variation in sample sizes within each population. For severity, values in parentheses denote standard deviations and all values are expressed as percentages of the dorsal fin.)

	Scotland	Ireland	Wales	England	France	New Zealand	Croatia	Portugal	North Carolina	Florida
prevalence										
dark	78.5 (65)	48.1 (27)	57.1 (77)	75.0 (12)	64.3 (28)	71.4 (35)	44.0 (50)	75.0 (24)	75.0 (28)	44.9 (69)
pale	78.7 (75)	48.4 (31)	57.1 (77)	84.6 (14)	55.2 (29)	74.3 (35)	41.4 (58)	79.2 (24)	57.1 (28)	27.4 (73)
other	40.3 (67)	57.6 (33)	49.4 (81)	41.7 (12)	31.0 (29)	44.1 (34)	10.3 (58)	31.0 (29)	51.8 (28)	42.0 (69)
total lesions	98.5 (65)	85.2 (27)	89.6 (77)	100.0 (12)	78.6 (28)	94.1 (34)	74.0 (50)	91.6 (24)	85.7 (28)	62.7 (67)
deformities	4.9 (81)	— (35)	— (91)	— (14)	5.4 (37)	2.9 (35)	— (73)	2.6 (38)	— (28)	5.4 (93)
injuries	67.1 (79)	80.0 (35)	94.8 (96)	100.0 (13)	100.0 (36)	100.0 (33)	98.6 (73)	89.2 (37)	100.0 (28)	87.5 (88)
parasites	— (82)	— (35)	— (103)	— (13)	— (36)	— (33)	— (73)	— (37)	— (28)	28.8 (111)
severity	$n=45$	$n=9$	$n=72$	$n=10$	$n=26$	$n=21$	$n=48$	$n=24$	$n=28$	$n=56$
dark	2.6 (3.7)	0.2 (0.4)	0.4 (0.7)	0.9 (0.9)	0.4 (0.6)	1.2 (3.9)	0.3 (0.6)	0.3 (0.6)	1.0 (2.3)	0.2 (0.3)
pale	7.4 (10.0)	3.8 (7.8)	3.1 (5.3)	8.0 (13.4)	3.7 (6.9)	6.3 (10.3)	1.6 (6.0)	0.8 (1.2)	1.0 (4.7)	0.1 (0.4)
other	2.0 (3.4)	2.5 (3.6)	0.8 (2.5)	0.3 (0.7)	1.4 (2.3)	3.4 (6.5)	0.2 (0.8)	1.7 (4.0)	1.0 (3.3)	1.5 (5.9)
total lesions	12.1 (10.5)	6.5 (8.4)	4.3 (5.8)	9.2 (13.8)	5.4 (7.6)	11.0 (11.3)	2.1 (6.5)	2.8 (4.0)	3.0 (7.0)	1.8 (5.9)
injuries	2.2 (3.5)	5.9 (7.2)	5.1 (5.7)	5.9 (11.7)	2.0 (4.4)	2.2 (3.3)	8.9 (11.8)	4.9 (7.8)	0.3 (1.4)	0.1 (3.3)

prevalence of lesions, injuries or deformities and the severity of lesions. The prevalence of a particular feature was defined as the proportion of dolphins in a sample that had that feature and values were calculated by scoring each individual's best picture for the presence or absence of each type of mark. For lesions and injuries, only the dorsal fin was examined, but for deformities the back was also included. Because the lighting conditions varied between pictures, the presence or absence of a particular mark was recorded only if the picture was of sufficient quality to ensure that marks would be seen if present. This method led to variation in the number of animals within each sample, but avoided any bias resulting from variations in photograph quality.

To provide a measure of lesion severity, the proportion of an individual's dorsal fin covered by each type was estimated. Pictures were projected onto paper using a slide projector and outlines of the dorsal fin and any lesions traced. The lower margin of each dolphin's dorsal fin was defined as the horizontal line where the plane of the dorsal fin changed to that of the body. The area of the dorsal fin and marks were then measured from the drawing using a digitizing tablet and purpose-written software (Wilson *et al.* 1997*a*). To ensure consistency of lesion, injury and deformity recognition and picture quality thresholds between populations, all data selection, mark definitions, prevalence and severity estimates were carried out by the principal author.

(c) *Environmental and contaminant data*

Data on local environmental conditions for each population were obtained from published sources. For salinity, the means of data from surface and 30 m depths were used. Information on organochlorine and trace-metal contaminants was derived from studies of tissue samples from bottlenose dolphins which stranded at or near the range of each population under investigation. Where more than one study was conducted in the same area, we used an average of the published values. Relationships between lesion prevalence or severity and environmental factors were examined using ordinary least-squares regression. Because measures of prevalence and severity were both expressed as percentages, their values were arcsine transformed before analysis. Only factors for which data were available for four or more populations were considered.

3. RESULTS

Photograph-identification pictures of 583 individual dolphins were examined from the ten populations. All photographs were taken between 1992 and 1997. The number of individuals sampled in each population varied from 14 to 121 and, for those areas where abundance estimates exist, these samples represented between 56 and 100% of the total population size (Wells & Scott 1990; Williams *et al.* 1993; Wilson *et al.* 1999). A wide variety of lesions and other features were seen on the skins of these animals. These included 15 types of epidermal lesion, which were amalgamated into three groups. 'Dark lesions' were characterized by having areas of hyperpigmentation, 'pale lesions' by areas of hypopigmentation and 'other lesions' included orange patches, grey swellings and patches with a blue–grey sheen. Physical deformities included bent dorsal fins and spinal deformations. Five types of injury (nicks in the leading and trailing edges of the dorsal fin, parallel tooth scratches, irregular wounds and abraded fin tips) and an external parasite (*Xenobalanus sp.*) were also observed.

(a) *Prevalence and severity*

Epidermal lesions were common in all populations, with between 63 and 100% of the sampled animals being affected (table 1). Of the individual types of lesion, between six and ten types were seen in each population but the number of populations in which any particular lesion type was seen varied considerably. Five were almost universal (present in nine or ten populations), while six were restricted to just one or two populations. Two types were seen in only two areas (grey lumps and small white nodules) and both occurred in adjacent populations in this study (Florida and North Carolina).

Table 2. *Published values for environmental variables and contaminant burdens*

(Ranges in parentheses. nda denotes no data were available. Blubber samples used for organochlorines and liver for heavy metals. All contaminant values are given as wet weights unless asterisked. Sources: Peneda *et al.* (1980), Adams & Martin (1986), Geraci (1989), Kirby-Smith & Costlow (1989), Morris *et al.* (1989), Jones & Jeffs (1991), Law *et al.* (1991), Leonzio *et al.* (1992), Kuehl *et al.* (1994), Levitus *et al.* (1994), World Health Organization (1994), Corsolini *et al.* (1995), Kuehl & Haebler (1995), Salata *et al.* (1995), Wood & Van Vleet (1996), Kannan *et al.* (1997), McKenzie *et al.* (1997).)

variable	Scotland	Ireland	Wales	England	France	New Zealand	Croatia	Portugal	North Carolina	Florida
latitude (°)	57.8	53.6	52.2	50.1	48.5	45.3	44.6	38.5	35.7	27.5
temperature (°C)	9.2	12.5	11.4	11.6	13.5	12.0	17.5	17.0	19.0	24.5
salinity (psu)	34.270	35.250	35.185	35.185	35.185	34.685	35.750	35.810	35.750	35.875
UV-A (watts)	20.5	24.5	25.0	27.0	28.0	29.5	31.0	34.5	36.0	nda
UV-B (watts)	0.30	0.41	0.44	0.49	0.53	0.56	0.61	0.78	0.86	nda
ΣCB ($\mu g\,g^{-1}$)	5.0 (0.4–24.0)	nda	310.0	nda	nda	nda	584.0 (90–1000)	nda	nda	43.1* (1.5–187)
ΣDDT ($\mu g\,g^{-1}$)	4.72 (0.4–24.0)	nda	145.0	nda	nda	nda	170.0 (8–550)	nda	nda	15.3* (0.43–74.6)
Cd ($\mu g\,g^{-1}$)	0.02 (0.01–1.34)	nda	0.095 (0.07–0.12)	nda	nda	nda	0.75 (0.30–1.06)	nda	0.335* (nd–1.70)	nda
Hg ($\mu g\,g^{-1}$)	4.38 (0.80–300)	nda	20.5 (20–21)	nda	nda	nda	270.0 (12.2–13156)	nda	66.77* (nd–443)	nda
Pb ($\mu g\,g^{-1}$)	<0.16	nda	<0.65 (<0.6, <0.7)	nda	nda	nda	0.05 (0.05–0.05)	nda	1.38* (nd–5.0)	nda
Zn ($\mu g\,g^{-1}$)	65.3 (16.7–176)	nda	37.0 (32–42)	nda	nda	nda	162.0 (125–263)	nda	169.5* (16–722)	nda

[a] psu, practical salinity unit.

The prevalence of dark lesions was significantly correlated with the prevalence of pale lesions (Spearman's $\rho = 0.9$, d.f. $= 8$ and $p < 0.001$), but the prevalence of other lesions was unrelated to either dark or pale lesions (Spearman's $\rho = -0.01$, d.f. $= 8$ and $p = 0.48$ (dark) and $\rho = -0.09$, d.f. $= 8$ and $p = 0.40$ (pale)). The severity of lesions also varied considerably among populations (table 1). Pale lesions, for example, varied from 6% skin coverage in New Zealand to just 0.1% in Florida. Overall, lesion severity was correlated with prevalence (Spearman's $\rho = 0.74$, d.f. $= 8$ and $p < 0.01$).

The prevalence of injuries was also high, ranging from 67 to 100% (table 1). No relationships were found between the prevalence of injuries and lesions (Spearman's $\rho = 0.09$, d.f. $= 8$ and $p = 0.25$ (dark), $\rho = 0.19$, d.f. $= 8$ and $p = 0.30$ (pale), $\rho = -0.06$, d.f. $= 8$ and $p = 0.44$ (other) and $\rho = 0.11$, d.f. $= 8$ and $p = 0.38$ (total lesions)). Deformities were present in half of the populations but were always rare and never affected more than 6% of individuals. The severity of deformities could not be quantified using the photographic techniques used in this study.

External parasites were only observed in the Florida population, where they affected nearly 30% of individuals. These parasites may also have been present in the North Carolina population but would have been dislodged during the capture process.

(b) *Correlates of environmental and anthropogenic factors, with lesion prevalence and severity*

The latitude, water temperature, salinity and level of atmospheric UV radiation experienced by each population and available information on contaminant burdens in bottlenose dolphin tissues are presented in table 2. Only two variables, water temperature and salinity, showed significant relationships with the prevalence of epidermal lesions, while latitude, water temperature, salinity and UV radiation all showed significant relationships with severity (table 3). Comparisons of r^2 values suggest that water temperature and salinity had the strongest influence on both lesion prevalence and severity (figure 2). In contrast, there were no significant relationships between any of the contaminants studied and either the prevalence or severity of lesions. However, the sample sizes for these analyses were small and, therefore, had limited power. Nevertheless, when comparisons involving latitude, water temperature, salinity and UV were reanalysed for this smaller data set, relationships with salinity and water temperature remained significant (table 3).

4. DISCUSSION

Epidermal disease in cetaceans is well-documented but studies of those in wild animals have all been restricted to either dead individuals (Geraci 1989; Baker 1992) or to individuals from localized populations (Thompson & Hammond 1992; Van Bressem *et al.* 1993, 1994; Harzen & Brunnick 1997; Wilson *et al.* 1997*a*). In most of these studies, the authors have suggested that anthropogenic contaminants may play a contributory role in the formation of the epidermal lesions observed. However, there has been no context in which to place these findings and, hence, determine whether the diseases reported are simply novel rarities, specific to each particular geographical area or whether they are a more widespread feature of wild cetaceans. We infer from our results that epidermal disease is universal in coastal bottlenose dolphins and that a large proportion of the individuals in

Table 3. *Relationships between environmental variables and contaminant burdens, with lesion prevalence and severity*

(Ordinary least-squares regression analyses were used on arcsine-transformed lesion values. n = the number of populations for which data were available. The lower portion of the table represents tests on environmental variables where the sample size was matched with that for the contaminant tests.)

			prevalence			severity		
variable	descriptor	n	r^2	F	p	r^2	F	p
latitude	degrees	10	0.35	4.3	0.07	0.52	8.5	<0.05
water temperature	mean	10	0.56	10.0	<0.05	0.69	18.1	<0.005
salinity	mean	10	0.39	5.1	0.05	0.87	54.3	<0.0001
UV-A exposure	mean	9	0.14	1.1	0.33	0.46	5.9	<0.05
UV-B exposure	mean	9	0.12	0.9	0.37	0.46	5.9	<0.05
ΣCB	mean	4	0.09	0.2	0.7	0.26	0.7	0.49
ΣDDT	mean	4	0.04	0.1	0.81	0.21	0.5	0.54
cadmium	mean	4	0.82	9.1	0.09	0.59	2.9	0.23
mercury	mean	4	0.72	5.2	0.15	0.46	1.7	0.32
lead	mean	4	0.01	0.0	0.92	0.10	0.2	0.68
zinc	mean	4	0.47	1.8	0.32	0.40	1.3	0.37
latitude	degrees	4	0.86	12.3	0.07	0.63	3.4	0.21
water temperature	mean	4	0.91	19.7	<0.05	0.67	4.1	0.18
salinity	mean	4	0.95	41.38	<0.05	0.99	218.1	<0.005
UV-A exposure	mean	4	0.57	2.7	0.24	0.68	4.4	0.17
UV-B exposure	mean	4	0.44	1.6	0.34	0.58	2.7	0.23

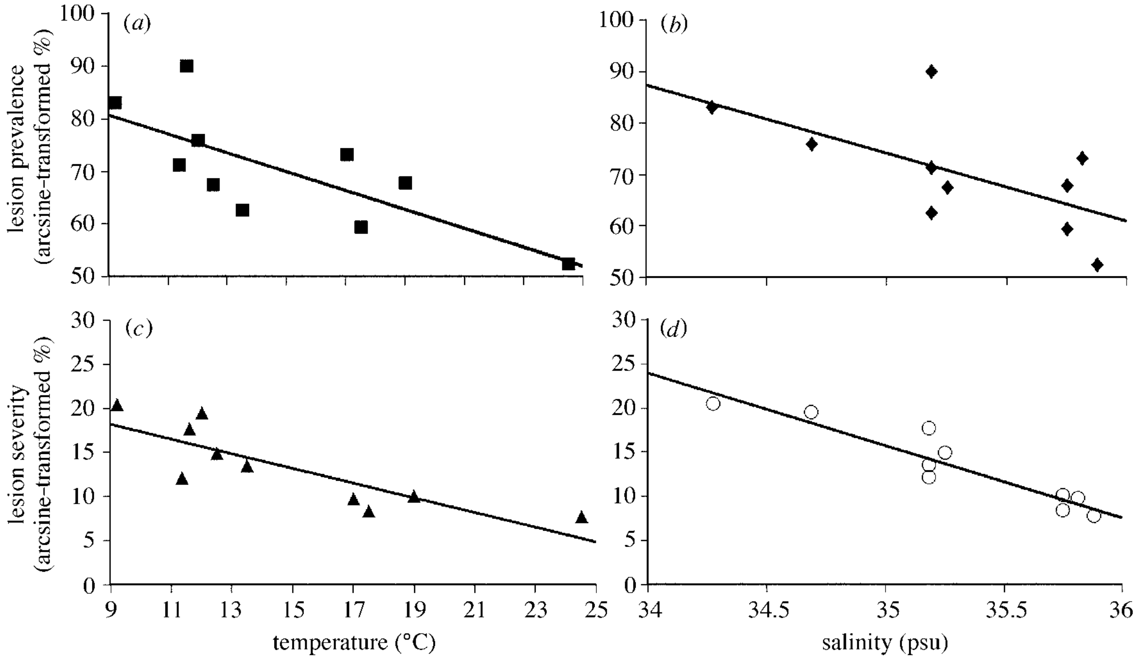

Figure 2. Prevalence and severity of all epidermal lesions plotted against mean annual water temperature and salinity. (*a*) Prevalence versus temperature, (*b*) prevalence versus salinity, (*c*) severity versus temperature, (*d*) severity versus salinity.

each population are affected. Furthermore, because only the dorsal fins of the dolphins were examined, and lesions were observed on other parts of the dolphins when they could be photographed, the total levels of prevalence are likely to be higher still.

Overall, 15 different types of lesion were observed but, because their cause was unknown, it is unclear whether they are stages of a single disease or are indicative of many different disorders. Only histological examinations using tissue samples from live or freshly stranded animals are likely to determine the immediate causative agents. However, the observation that, on average, only half of the different types of lesion were observed in any one population, would strongly suggest that more than one disease process is present. This is reinforced by the occurrence of two lesion types that were only seen twice and which occurred in adjacent populations where animals could be exposed to similar sources of infection.

Information was readily accessible for a range of natural factors, but few published data were available for contaminants in each population. Nevertheless, relationships between skin lesions and organochlorine compounds

(ΣCBs and ΣDDT) and trace metals (Cd, Hg, Pb and Zn) could be examined for four populations but no relationships were found.

However, significant relationships were detected between the levels of skin disease and natural environmental variables even when the sample sizes were reduced to match those used in the analyses for contaminants. High levels of epidermal disease were related to low water temperature and low salinity but, because both covary with latitude, the relationships could result from either factor alone or both in combination. Mechanisms by which these factors could damage cetacean skin are conceivable. Low salinity may cause cellular damage to the epidermis by disrupting its electrolyte balance (Fraser & Mays 1986) and so weaken its ability to shield the animal from infective agents in the surrounding water. However, as no relationships were found between physical injuries (which are another possible route of entry) and levels of disease, simple disruption of the epidermis' role as a physical barrier seems unlikely. Alternatively, thermal constraints imposed by low water temperatures may force animals to limit blood flow to the skin and so impede pathways for immune protection or limit the rate of epidermal cell regeneration (Feltz & Fay 1966). It is also possible that the lesions themselves may be an outward manifestation of more systemic physiological stress that is imposed by these environmental conditions.

One way to determine how environmental factors influence the formation of epidermal lesions would be to examine temporal changes in lesions for populations inhabiting areas with seasonally variable climatic conditions. Another would be to establish whether it is the rate of new infections or the rate of healing (longevity) that differs between populations. High infection rates or low healing rates could both result in high prevalence and severity measures. Whilst longevity could be calculated by examining serial photographs of individual dolphins, the rate of new infections could be derived by dividing the observed levels of disease (outlined in this study) by their calculated longevities.

Of all the populations examined in this study, the bottlenose dolphins in the Moray Firth experienced the lowest water temperature and salinity levels and the greatest severity of epidermal lesions (up to 66% skin coverage). This population is the highest-latitude, resident population of bottlenose dolphins known and the poor epidermal condition of these animals may be an indicator of the physiological stresses encountered by this frontier group. Indeed, it may itself be a factor limiting the distribution of this species further north and poses questions about the potential differences in epidermal composition between this and other dolphin species which live in polar and riverine habitats.

This study has shown that large amounts of variation in the levels of skin disease between bottlenose dolphin populations can be explained by natural variations in environmental conditions. Although no relationships were found with measured levels of contaminants in tissue samples, the low sample sizes available for this study, the variability in burdens between different age and sex strata (Wilson *et al.* 1997*a*) and the likely complexities of their impacts do not exclude the possibility that anthropogenic contaminants have subtle or synergistic effects on the development of epidermal disease in these animals. However, it is clear that, if the impacts of contaminants are to be compared between populations or if inferences from experimental studies are to be applied to wild populations, it is essential that the role of natural environmental factors is taken into account.

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As this paper exceeds the maximum length normally permitted, the authors have agreed to contribute to production costs.