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Abstract: Oil spills can have direct effects on organisms (mortality or morbidity), indirect effects (through alteration of lower trophic levels) or be associated to exposure to trace elements contained in oil (markers). An effect of the "*Erika*" oil spill was investigated by spatio-temporally comparing mortality, population structures, diets and concentrations of vanadium, nickel and porphyrins in small delphinids, seals and otters from the French Atlantic coasts. These species might differ in their vulnerability to oil. Changes in mortality and its demographic structures were within previously observed ranges. The diet of the common dolphin showed an extended period of high inter-individual variability in the year 2000. Vanadium concentrations in delphinids were chronically high, but did not increase significantly after the oil spill. Porphyrins concentrations in seals and otters were low suggesting a limited exposure to contaminants, but the ratio between proto- and copro-porphyrins in otter spraints from oiled vs. unoiled sites varied significantly. No measurable effect of the "*Erika*" oil spill was found in dolphins and seals.

Key words: Oil spill; *Delphinus delphis; Halichoerus grypus; Lutra lutra;* Mortality; Vanadium; Porphyrins; Bay of Biscay

Résumé : Impact de la marée noire de l'« *Erika* » sur les mammifères marins pélagiques et côtiers par la combinaison d'indices démographiques, écologiques, traceurs métalliques et bio-marqueurs. Les marées noires peuvent avoir un effet direct sur les organismes (mortalité ou morbidité), indirect (par l'altération des niveaux trophiques inférieurs) ou être à l'origine d'une exposition à certains éléments trace contenus dans le pétrole. Un effet possible de la marée noire de l'« *Erika* » sur les mammifères marins pélagiques et côtiers a été recherché en comparant spatio-temporellement la mortalité et sa structure démographique, les régimes alimentaires et les concentrations en vanadium, nickel et porphyrines chez les petits cétacés, les phoques et les loutres des côtes atlantiques françaises, espèces dont la vulnérabilité au pétrole est supposée différente. Les changements observés de mortalité et de sa structure démographique restent dans les limites des variations antérieures connues. Le régime alimentaire des dauphins communs n'a pas changé notablement à la suite de la marée noire. Les concentrations de vanadium chez les dauphins communs ont un niveau de base élevé, mais n'ont pas augmenté à la suite de la marée noire. Les concentrations de porphyrines chez les phoques et chez les loutres sont restées basses, suggérant ainsi une exposition limitée, mais le rapport entre proto et copro-porphyrines dans les épreintes de loutres originaires de sites exposés différait significativement de celui observé dans les sites indemnes. Aucun effet mesurable de la marée noire de l'« *Erika* » n'a été trouvé chez les dauphins communs et les phoques gris.

1 Introduction

Because the *Erika* sunk comparatively further offshore, oil slicks drifted at sea for a longer period before they reached the coastline than in most previous oil spills in European waters. Consequently, pelagic ecosystems were likely to be more exposed than in coastal oil spills. Indeed the ship sunk on December the 12th, 1999, but oil continued to drift and impact both pelagic and coastal ecosystems of the northern part of the Bay of Biscay until spring 2000. Another characteristic of this oil spill was its dramatic direct impact on wintering seabird populations, notably on the common guillemot, *Uria aalge*, with as many as 70 000 individuals being collected stranded and oiled, most of them dead, in the first few weeks after the spill. What was the impact of this disaster on marine mammals, the other warm-blooded top predators of the Bay of Biscay?

The dramatic effect of oil spills on auks is often generalised to all charismatic marine species, birds and mammals. There are indeed some intuitive reasons to compare these two groups. They are both marine top predators, sharing to some extent similar food resources and habitats. Doing this, they would be similarly exposed to man-induced disturbances. Additionally, they are air-breathing and warm-blooded animals and because of this they both have limited exchange with the water and have to maintain a good level of thermal insulation thanks to the structure and production of their tegument. However, important discrepancies between seabirds and marine mammals suggest that the latter might not be similarly vulnerable to oil than the former. Cetaceans and seals use the water column in much a different manner to seabirds; they spend a larger proportion of their time under the surface, notably they do not use the sea surface to rest or preen as seabirds do. Also, their tegument is either naked as in cetaceans or covered with a thin, albeit dense, layer of fur in seals and the insulation is solely or mostly ensured by the blubber layer of the inner tegument. Only otters differ in this respect and in some way are comparable to birds as they rely for their insulation on their thick fur and dense under-fur which entrap air as bird feathers do.

Oil can impact pelagic and coastal mammals in various ways. The first and most direct one is getting stuck in or stained with oil. This can occur by swimming at the sea-surface or by wandering across the upper tidal zone. Severe oiling can be directly lethal and partial oiling can be lethal by modifying insulation properties of the pelage, decreasing foraging performance or by ingestion of oil during grooming (otters only; Geraci and St Aubin 1990). As every particular cause of death, oiling is supposed to have a specific age structure signature, different from age structure of natural mortality (mostly unweaned and old individuals; Ralls et al. 1980) or of various sources of incidental mortality (unweaned dolphins and seals in gillnet by-catch – Da Silva 1996; Goujon 1996 – or adolescent and sub-adult dolphins in pelagic fishery by-catch – Van Canneyt et al. 1993). An indirect impact would be through a modification of prey availability as a consequence of the long exposure of pelagic habitats to drifting oil. The exact processes are unknown but experimental approaches carried out as part of the post-*Erika* monitoring programme, have shown that fish and invertebrates can absorb in their tissues hydrocarbons of the dissolved fraction of oil. These hydrocarbons can be lethal at high concentrations. Another indirect impact of oil on top predators is the bioaccumulation of oil specific trace elements. Poly-Aromatic Hydrocarbons (PAHs) are not bioaccumulated in living organisms as they are successfully metabolised at each trophic level; as a consequence they are unlikely to be found at higher concentrations in top predators when lower trophic level organisms are exposed (Geraci and Williams 1990; Frost et al. 1994). In contrast, some metallic trace elements, here vanadium and nickel, are abundant in the oil and can be transferred *via* food intake and bioaccumulate in top predators (Miramand and Fowler 1998). Vanadium is present in the environment from various natural and industrial sources; the *Erika* oil-spill introduced a massive amount of vanadium in the ecosystem that was detected in organisms of lower trophic level. Irrespective of their possible toxicity, higher concentrations of these elements can express the exposure of the entire food web. Finally, several biomarkers can express the toxicity of various contaminants (Reinjders et al. 1999). Porphyrins are tetrapyrrolic pigments that are intermediate metabolites and by-products of heme synthesis. Disruption of heme synthesis by a broad variety of contaminants, including among others PAHs and heavy metals, is known to be associated with increased porphyrin overall concentrations and modifications of their composition (Casini et al. 2003). After the *Exxon Valdez* oil spill, various research were designed to study the effect of oil exposure on the heme biosynthesis, in particular of the river otters, *Lutra canadensis* (Taylor et al. 2000) and Steller sea lions, *Eumetopias jubatus* (Beckmen et al. 2002) In such a situation, high levels of porphyrins were found in erythropoïetic tissues, kidney and liver as well as in faeces, secretions and excretion products (Casini et al. 2003).

In this study, we tried to find evidence of these four possible ways of impact on marine and coastal mammals by comparing spatially and temporally several types of indicators. Direct mortality indicators included numbers of animal stranded, apparent cause of death as well as age and reproductive status composition. Possible shift in food availability was examined from stomach content analysis in dolphins. Vanadium concentrations were measured in liver and kidney of dolphins, in seal blood and in otter spraints. Porphyrins were measured in seal blood and otter spraints. The specific hypotheses were as follow:

– if oil had induced direct mortality of marine mammals, stranding rates should be higher in the impacted zone and period, and a specific bio-demographic signature could be expected corresponding to a new cause of death;

– if oil had affected lower trophic levels, some shift in diet composition should be expected in the impacted zone and period;

– if a massive input of vanadium contained in oil occurred, these elements should have bioaccumulated in top predators in the impacted zone and period;

– if a toxic action of either oil or trace element should have occurred, porphyrin concentrations and compositions should have changed in impacted marine mammals.

This work is a synthesis of two distinct projects which aimed at estimating the impact of the *Erika* oil spill on grey seals, *Halichoerus grypus*, and Eurasian otters, *Lutra lutra* (Lafontaine and Hassani 2003) and on small cetaceans, notably the common dolphin, *Delphinus delphis* (Ridoux et al. 2003). These two projects are presented here as an integrated work – in which the outline of each original study cannot be readily identified – in order to give a synthesis of the impact of the oil spill as shown by using a multi-indicator monitoring approach. The reader will find detailed information and data in the two original reports.

2 Materials and methods

Target species

Three very different biological models were used: the common dolphin, *Delphinus delphis*, the grey seal, *Halichoerus grypus*, and the Eurasian otter, *Lutra lutra*. Because of their distinct morphological, ecological or behavioural characteristics, they were supposed to be differently exposed to oil spill hazards.

The small delphinids are pelagic top predators. Their naked skin is less prone to being stained with oil than the skin of haired mammals. Their sub-cutaneous blubber layer ensures insulation and is involved in streamlining the body outline and in the mechanical performance of swimming (synthesis in Berta and Sumich 1999; Reynold and Rommel 1999). In addition to sensory abilities shared by most mammals, they perceive their surroundings by echolocation, a specialisation of the auditory systems which makes them able to detect sharp changes in density among their aquatic environment. It is believed that this ability could help them detect oil slicks. Although their absolute abundance in the Bay of Biscay is not documented, their numbers are likely to be in the tens of thousands when one compares with neighbouring areas (Goujon et al. 1993; Hammond et al. 2002). They are highly mobile animals which live and forage socially in the Bay of Biscay at all seasons.

Seals are necto-benthic predators. Their tegument is covered with hair and is characterised by a thick blubber layer, which ensures insulation and has a key role as energy storage (synthesis in Reynolds and Rommel 1999). There is no permanent population of seals in the Bay of Biscay, but the area is regularly visited by vagrant individuals wandering from more northern colonies, located from west of Brittany to the British Isles. Most of these animals are yearlings and appear in the Bay of Biscay shortly after the peak pupping season in the southwest British Isles (Vincent et al. 2002). Furthermore, seals are amphibious animals, which use tidal or coastal reefs and sand banks to rest, breed and moult; doing this they are exposed to being oiled at their haul-out site and not only at sea.

Eurasian otters are mostly fresh water predators, but individuals whose home range includes some stretch of coastline can draw an extensive part of their food from the sea. Their fur and under-fur are abundant and play a key role in their insulation by entrapping a layer of air around their skin; grooming is an important component of their activity as it ensures the maintenance of their fur's properties. Otters are known to be resident in coastal wetlands, salt marshes, small estuaries and some islands of Brittany and the Bay of Biscay (Lafontaine 1986, 1991; Ridoux and Lafontaine 1995). Because of their riparian lifestyle they are exposed to oil both at sea and on the seashore (Conroy 2004).

All three species are protected by national regulations in most European countries. Additionally, they are all listed in either Appendices II or IV or both of the EU Habitat Directive and Eurasian otters are considered as vulnerable by the last IUCN quotation (IUCN; http://redlist.org).

Study areas, study periods and sources of materials and data

We defined impacted areas and not impacted ones from the extent of oil slicks along the coastline (Fig. 1) and we defined the *Erika* period as the year 2000. The biological material was made available by networks of field correspondents involved in the permanent monitoring of marine mammals stranded along the coasts of France. These pre-existing schemes allowed us to compare results obtained in 2000with reference situations represented by the range of variations documented from as much as 20 years of monitoring before and two years after the oil spill.

Mortality and demographic parameters

Every marine mammal reported to the stranding scheme was examined externally and necropsied by using standard protocols (Kuiken and Hartman 1992) when their decomposition condition allowed it. Age was determined by examining teeth slides after decalcification and staining (Perrin and Myrick 1980). Reproductive status was determined by examining gonads. Maturity in male was determined by testicular mass alone, whereas maturity of females was determined by the presence of ovarian scars (Perrin et al. 1984).

Dietary analyses

Analysis of the stomach samples was aimed at describing the diet in terms of prey occurrence, relative abundance, reconstituted mass and size distribution and followed a procedure which is now standard for marine top predators (Pierce and Boyle 1991; Croxall 1993; Ridoux 1994). The total number of food items was estimated from the number of diagnostic parts (mainly otoliths for fish, upper and lower beaks for cephalopods and eyes for crustaceans). Diagnostic hard parts were measured, which allowed original body length and mass to be back-calculated (Meynier 2004).

Trace element analyses

Analysis of trace element followed published protocols (e.g. Miramand and Fowler 1998). Liver and kidney samples of dolphins as well as seal blood and otter spraint were stored frozen. Before analysis, samples were mashed, lyophilized and reduced to a homogeneous powder. Sub-samples of *c*. 200 mg of these dry powders were digested in nitric acid in a microwave owen and analysed by using Induced Coupled Plasma Mass Spectrometry (ICP/MS, Ultra-mass 700, Varian). Detection limit was determined at 0.0025 $\mu g\ g^{-1}$ dry mass. Internal validations were carried out by analysing TORT-2 (NRCC) and showed that our results were within certified confidence interval for vanadium concentrations.

Porphyrin analyses

The spraint samples were firstly lyophilized (4 hours). The porphyrins were extracted from sub-samples of blood (50 μl) and spraint (50 mg) by acidification with chlorhydric acid and centrifugation during 5 min (2500 rpm). The levels were measured by using a spectrophotometer (SHIMADZU UV – 1605) for spraints with a detection limit of 30 nmol g^{-1} dry mass and by using a spectrofluorimeter (RF 540) for blood with a detection limit of 30 nmol g^{-1} (total blood).

3 Results

Mortality and demographic parameters

Stranding data of the year 2000 along the Atlantic coast were compared to a reference situation defined from data collected during the past 20 years. After the oil spill, stranding rates were at about 5−20 individuals per 10-day periods in December and January. Then a sharp peak at more than 300 individuals per 10-day period occurred in mid February and, finally, stranding rates remained low for the rest of the year (Fig. 2). The peak of February was composed of 91.5% common dolphins, of which none had any evidence of oiling either at external examination or necropsy; in contrast, 73% showed external marks of by-catch. In addition, a majority of the dolphins involved in this peak appeared in the south part of the Bay of Biscay: i.e. out of the impacted zone. Consequently, this peak was clearly another event of acute by-catch in pelagic fisheries and not a consequence of the oil spill. A possible effect of the oil spill must be looked for in the periods before and after this event. In order to filter out these discrete fishery-related events, we analysed the distributions of stranding numbers in the three zones of the study and determined a threshold above which we considered that an event of intense by-catch was going on and therefore data were filtered out. In a second step, we averaged the number of stranded dolphins for every 10-day period over the last 20 years in order to establish the background variations of this index. It then appeared that stranding rates for the year 2000 in the impacted zone, corrected for the by-catch event, did not depart from a range of one standard error around the average (Fig. 3), suggesting that figures observed after the oil spill were not different from background mortality. Comparisons of age and sex structures during the year 2000 in the impacted zone with a previous year (1997) or with the south zone did not show any significant difference (Chi Square tests, all comparisons not significantly different), further suggesting that no particular new cause of death affected the common dolphin population after the *Erika* oil spill.

For the grey seal and the Eurasian otter, the numbers of animals found stranded per year are usually far lower than of dolphins, thus preventing the type of analysis carried out above. However, we did not record any evidence of increased number of dead animals after the oil spill (no one otter found dead; number of seals not significantly different from background variations).

Food composition

This issue was tested on the common dolphin only as it was the only species for which samples were obtained in sufficient numbers, with 85 stomach samples collected from 1999-2002. The diet of the common dolphin was composed by 28 prey species of which pelagic fish accounted for as much as 79% by reconstituted mass (i.e. horse mackerel, *Trachurus trachurus*, 37%; sardine, *Sardina pilchardus*, 22%; sprat, *Sprattus sprattus*, 3%; anchovy, *Engraulis encrasicolus*, 11%; and mackerel, *Scomber scombrus*, 6%) whereas demersal fish represented only 13% (blue whiting, *Micromesistius poutassou*, 5%; hake, *Merluccius merluccius*, 3%; pout, *Trisopterus* spp., 3%; and whiting, *Merlangius merlangus*, 2%), the rest being mostly cephalopods. Modal sizes were from 10–20 cm. In the spatial and temporal comparisons, it appeared that the diet of the common dolphin during the year 2000 in the impacted area was characterised by quite a different composition than the one observed the same year in the south of the Bay of Biscay or in the same area the year before or the year after. However, almost all possible year-to-year or among-area comparisons showed drastic changes in dietary composition. Therefore, this cannot be considered as a consequence of the *Erika* oil spill.

Trace elements

In the common dolphin, we investigated bioaccumulation in target organs, kidneys and liver, whereas in the grey seal and the Eurasian otter, instantaneous exposure was looked at in seal blood and otter spraints. Samples from 132 common dolphins, 63 grey seals and 42 otters including pre-*Erika* and post-*Erika* periods and impacted vs. unimpacted areas were analysed.

In the case of the common dolphin, it appeared that vanadium bio-accumulated with age in the liver (ANOVA, $F = 31.46$, $p < 0.001$, Spearman correlation coefficient $R = 0.601$) but not in the kidney, where it was regulated instead (Fig. 6); additionally it was checked that there was no sex-related difference in the rate of bioaccumulation with age. From this basis, it was possible to compare vanadium concentrations in the liver of individuals of known age before and after the *Erika* oil spill. It appeared that no difference (Table 1; two way ANOVA, period alone: $F = 0.63$, $p = 0.43$, period and age: $F = 2.25$, $p = 0.11$) could be highlighted, the slight apparent decrease in vanadium concentrations being most probably a result of the slightly younger age of the sub-set of individuals examined after the spill. Similarly, when one compares vanadium concentrations in the liver amongst common dolphins of the same age classes and across geographic areas, animals from the impacted zone never show higher values than those from the north and south zones (Fig. 7; two way ANOVA: area alone $F = 1.34$, $p = 0.27$; age alone $F = 24.87$, $p < 0.001$; age and area $F = 3.85$, $p = 0.006$). Paradoxically enough, older individuals collected in the impacted zone had significantly lower vanadium concentrations than those collected in not-impacted zones (Kruskall-Wallis: $T = 1.09$; $p = 0.005$).

Vanadium in grey seal blood and otter spraints was compared between impacted and not impacted areas and periods in order to detect any possible effect of the spill. In either species, no significant *Erika* effect could be demonstrated (only 13 of 63 seal samples were above detection limit; ranges of values for every otter sites overlapped largely and showed no significant difference among sites (ANOVA: $F = 0.94$; $p = 0.4667$).

Porphyrins

We looked at porphyrin concentrations and composition in the blood of 63 grey seals and in the faeces of 42 otters. Spatio-temporal comparisons of the different sub-samples of grey seals showed that the individuals collected in the impacted area during the winter which followed the spill did not exhibit higher levels of porphyrins than those collected previously or in other areas. In contrast, in the more resident otters, it appeared that spraints from oiled sites (e.g. Mullembourg and Sebastopol in Noirmoutier Island, see location in Fig. 1) had significantly higher proportions (%) of coproporphyrins and lower proportions of protoporphyrins than spraints collected from estuarine habitats indirectly exposed to oil (Arbourg, Pompas and Pont d'Arm: coastal marshes of Mès, Loire-Atlantique, see location in Fig. 1) or from control sites located further up stream (Fig. 6; ANOVA for coproporphyrins: $F = 2.55$; $p = 0.0447$, ANOVA for protoporphyrins: $F = 3.55$; $p = 0.0104$). This would suggest that, unlike seals, otters living along the seashore and feeding at least partly on marine species showed an increased synthesis and excretion of coproporphyrins.

4 Discussion

No effect of the *Erika* oil spill could be detected on small cetaceans and seals irrespective of the type of indicators that were used. The extensive effort of seashore cleaning that took place after the disaster implied that numerous workers investigated the coastline at that time; it is therefore very significant that no increase in stranding statistics of pelagic and coastal mammals was recorded despite this increased observation and reporting effort. It is therefore very unlikely that an increase in direct mortality due to the oil spill would have remained unnoticed in these circumstances. The change in diet composition of the common dolphin is not particular to the year 2000 following the oil spill, in contrast medium scale changes, both temporal and spatial, appear to be an intrinsic characteristic of the common dolphin dietary ecology irrespective of years and areas and could the expression of the high mesoscale variability, both in time and space, of the availability of pelagic resources. As to vanadium concentration in common dolphin, it is clear that no acute change appeared as a result of the oil spill. However, when one compares these values with previous works (Table 2), it becomes clear that the background concentrations measured in the common dolphins of the Bay of Biscay are higher than in most areas and similar to regions affected by a chronic exposure to oil, such as in Alaska where high levels of vanadium are interpreted as an effect of the extraction industry (Franck et al. 1992; Mackey et al. 1995). This would suggest that dolphins of the Bay of Biscay would be either chronically exposed to hydrocarbons, possibly from maritime traffic, tanker cleaning out or continental exports, or would be directly exposed to vanadium of natural (river outputs) or industrial origin. Background information on vanadium in the environment is insufficient to assess these options.

In contrast, porphyrins considered as a biomarker of toxicity suggested a slight, yet significant, effect on coastal Eurasian otters. The fact that grey seals did not show any reaction in terms of porphyrin concentrations or composition, in spite of their dwelling at least partly in coastal habitats, is not really surprising when one compares them to otters. Probably the most striking difference between the two species is that grey seals are only erratic in the Bay of Biscay and, therefore, individuals found ashore probably spent only short amounts of time in the impacted zone. In contrast, most otters are truly resident in this area and therefore individuals whose home range includes coastal habitats are more likely to be affected. One possible interpretation of otter in Noirmoutier showing evidence of contamination would be that these animals had indeed been in contact with oil, either through food or incidental ingestion during grooming behaviour. A study of the feeding habits of otters living at Noirmoutier Island conducted at the same period (Mercier 2001) showed that otters feed mainly on eels, *Anguilla anguilla* (35% by number), sticklebacks, *Gasterosteus aculeatus* (25%), gobies (mainly, *Potamoschistus microps* and *P. minutus*, 25%), mullets (unidentified mugillids, 24%), sand smelt, *Atherina presbiter*, and plaice, *Pleuronectes platessa* (4% together). Otters thus appear to have a real value as indicators of local oil contamination; the full relevance and potential of this issue should therefore be explored further in future research.

This difference among the three biological models of this work is in agreement with the expected difference in each species' vulnerability to oil spill. This general result is in agreement with most previous assessment of major oil spill impact on marine mammals (Prieur and Hussenot 1978; Geraci and Williams 1990; Loughlin 1994; Conroy et al. 1997), showing that otters seem to be more vulnerable to oil spill than seals and, above all, than cetaceans. Restricted home range, which limits the ability to avoid the extended oil slicks, and semiopen habitats such as salt pans and marshes, can be seen as possible worsening factors for coastal otters.

More generally, this work illustrates the value of long time series and extended geographical coverage in marine mammal population monitoring scheme based on stranding networks. Indeed, reference situations can be adequately compared to post-disaster observations only when background variations and trends are understood, both spatially and temporally. Here, not all indicators had been equally documented in the past, therefore restricting their potential as monitoring indicators. This issue is closely related with the importance of tissue and organ banks. Indeed, one need not necessarily maintain a complete set of multiple, often expensive, analyses to be carried out routinely. Instead, an organ and tissue bank can preserve the potential to fully document pre-disaster spatio-temporal variations for a given indicator that is not routinely measured, and is therefore the indispensable complement of a marine mammal population monitoring scheme based on a permanent and geographically extended stranding network.

Finally, we consider that, if isolated ecological disasters (such as oil spills) have the potential to trigger extensive impact assessment programmes, chronic or recurrent threats to marine mammals and marine ecosystems (such as oil leakages, contaminant inputs, interaction with fisheries, climatic change or habitat anthropisation) are as pregnant issues to consider in long term monitoring as isolated ecological disasters.

Acknowledgements. We are grateful to ONCFS officers, E. Menard, L. Mercier and D. Montfort for their help to collect otter spraints on the field; the Breton Stranding Network Group, and the Oceanopolis Marine Mammals Team for their help to collect seal samples; Salima Taïbi (ESITPA/LAMSAT Rouen), who proceeded the statistical process. CRMM and ULR co-authors would like to warmly thank all the members of the National Stranding Scheme for their daily dedication during the last 30 years.

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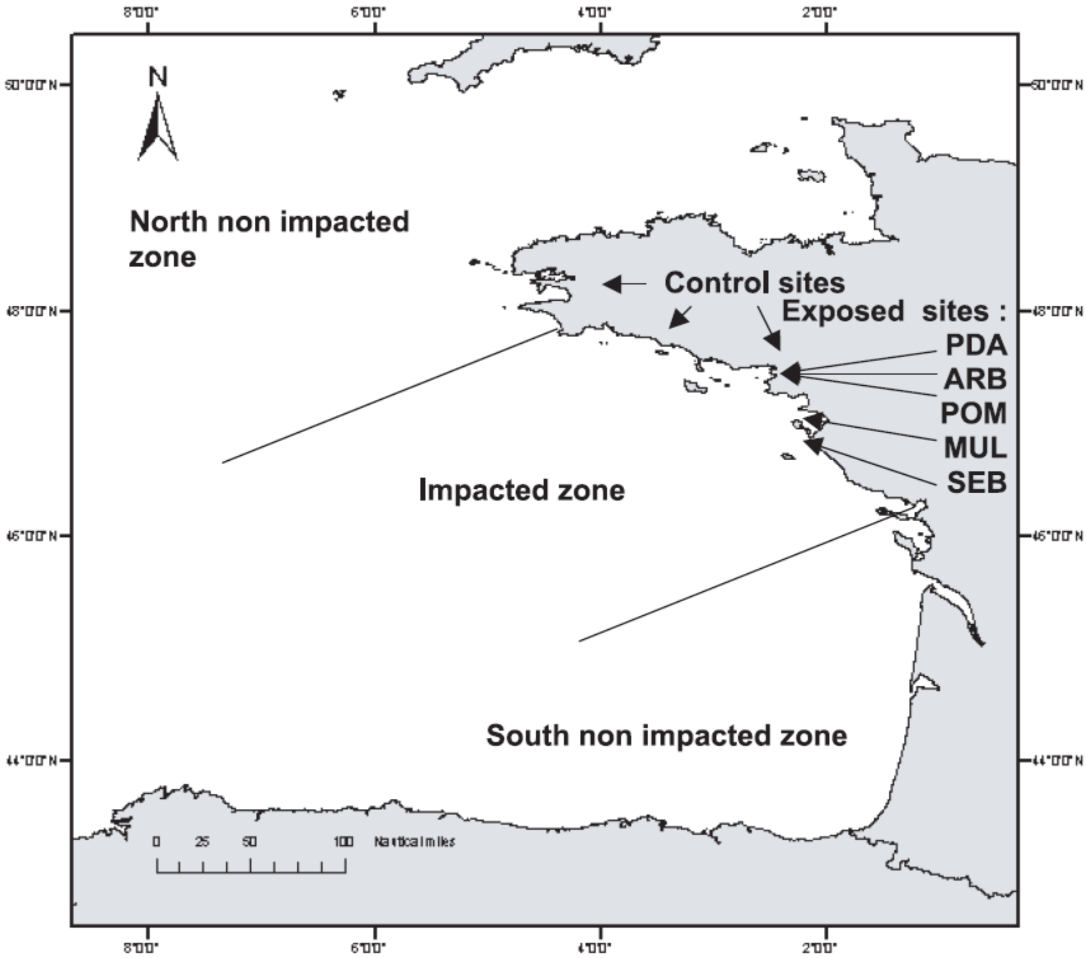

Fig. 1. The Bay of Biscay, the three zones defined from the extent of the oil spill along the coasts and the sampling sites for otters (inland control sites and coastal exposed sites: Pont d’Arm, Arbourg, Pompas, Mullembourg, Sebastopol).

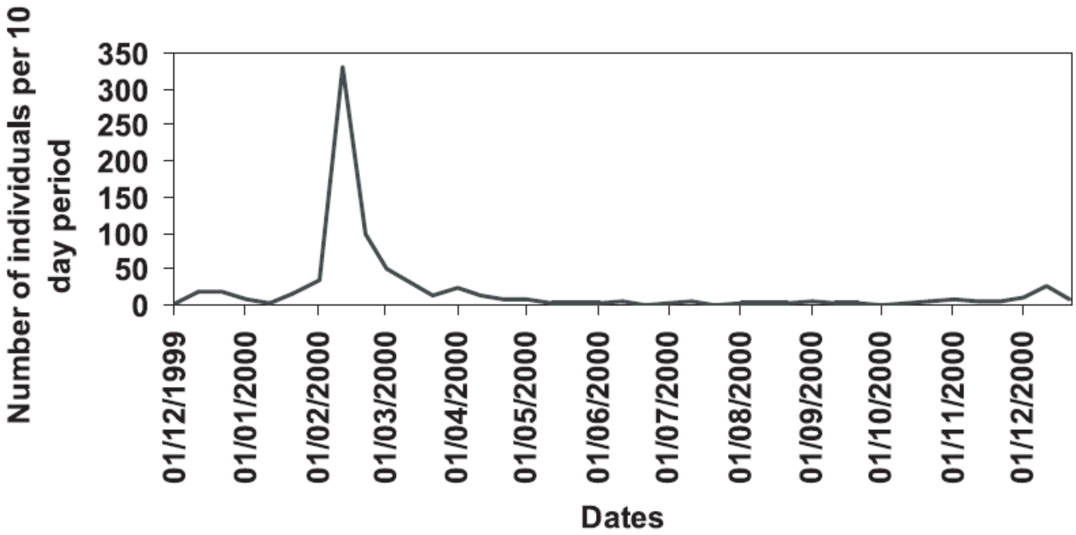

Fig. 2. Stranding records of common dolphin during the year following the oil spill, in numbers of individuals per 10-day period. During the peak of February, the geographical distribution of the stranded dolphins was as follows: 3% in the North, 28% in the impacted zone and 69% in the South.

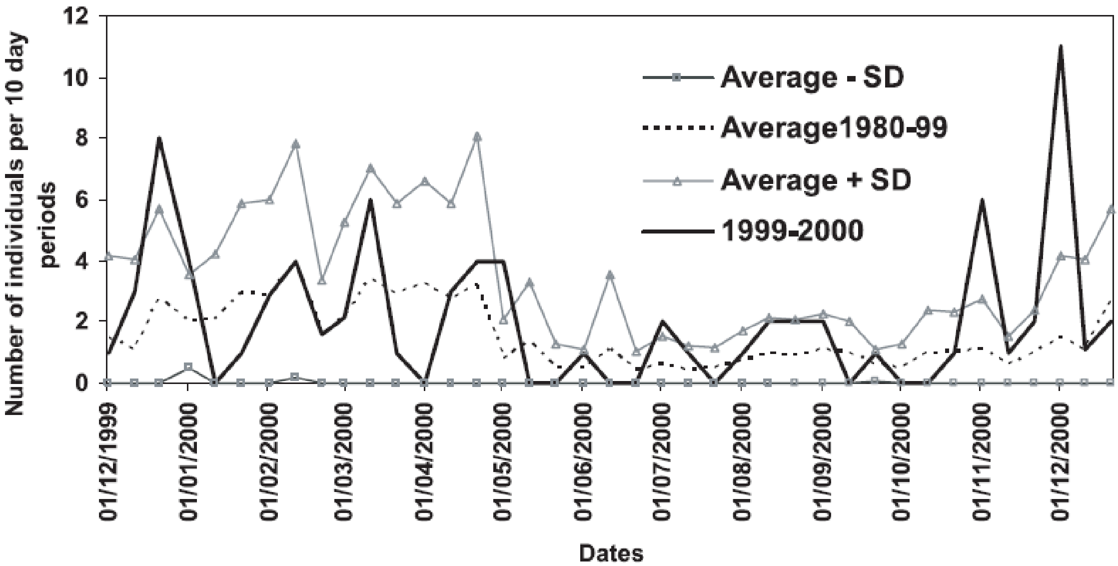

Fig. 3. Corrected stranding records of common dolphins during the year following the oil spill (thick black line), in numbers of individuals per 10-day period, as compared to average (thin black line with diamonds) ± standard errors (grey lines with open symbols) calculated over the past 20 years.

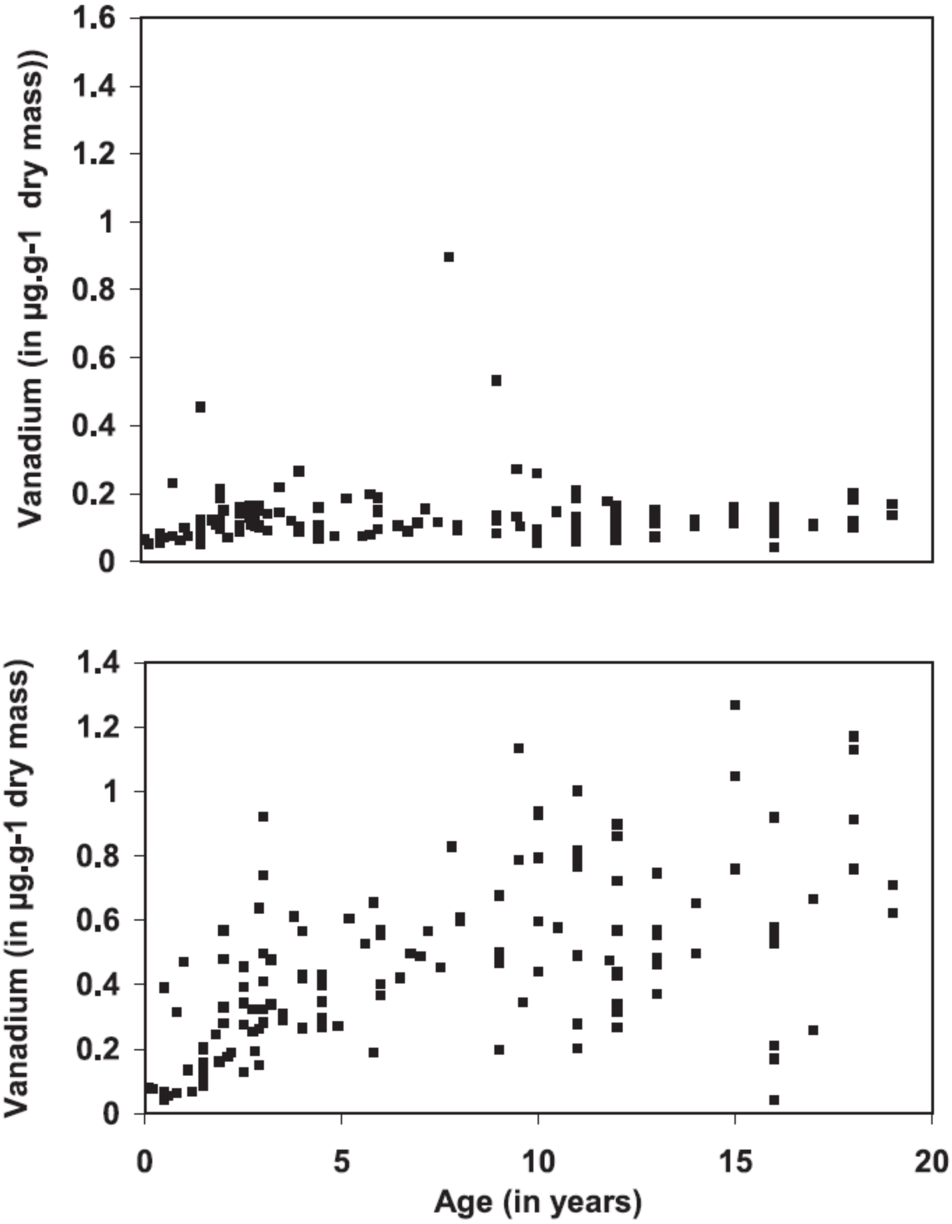

Fig. 4. Concentrations of vanadium (µg g^{-1} dry mass) in the kidney (upper frame) and the liver (lower frame) of the common dolphin, *Delphinus delphis*, of the Bay of Biscay as a function of the age.

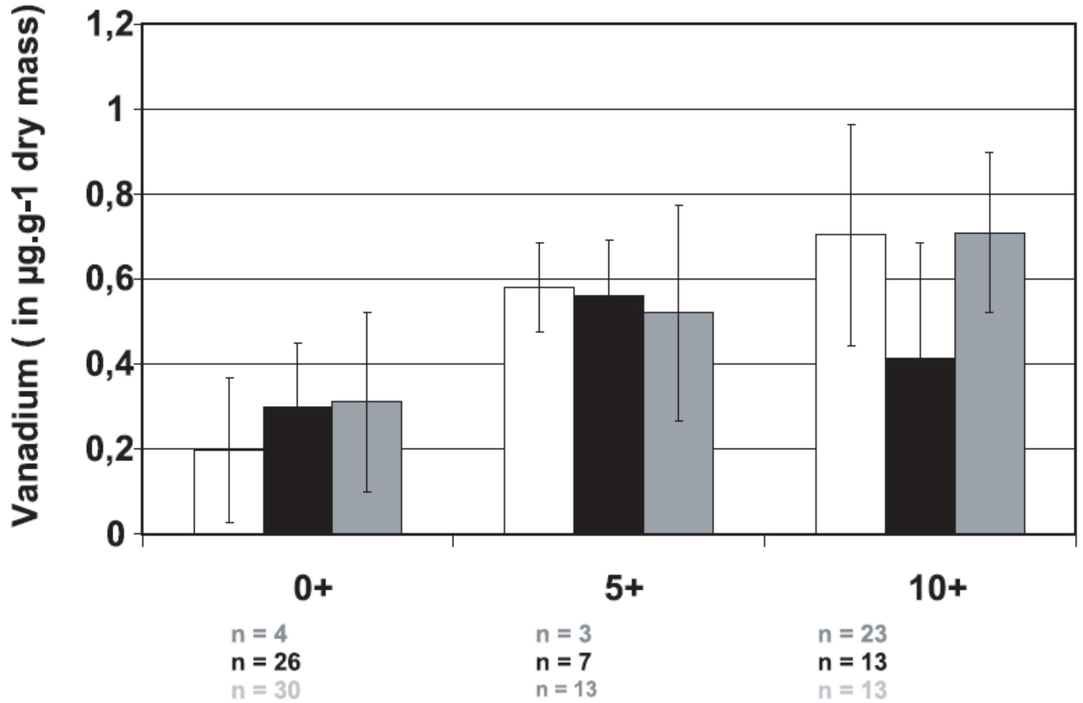

Fig. 5. Vanadium concentrations (µg g^{-1} dry mass) in the liver of common dolphins, *Delphinus delphis*, from the Bay of Biscay as a function of age categories and areas; 0+ stands for individuals of [0−5[years old, 5+ for individuals of [5−10[years old and 10+ for individuals older than 10 years old; *n* is sample size for each sub-set. The South Zone is shown in grey, the Impacted Zone in black and the North Zone in white.

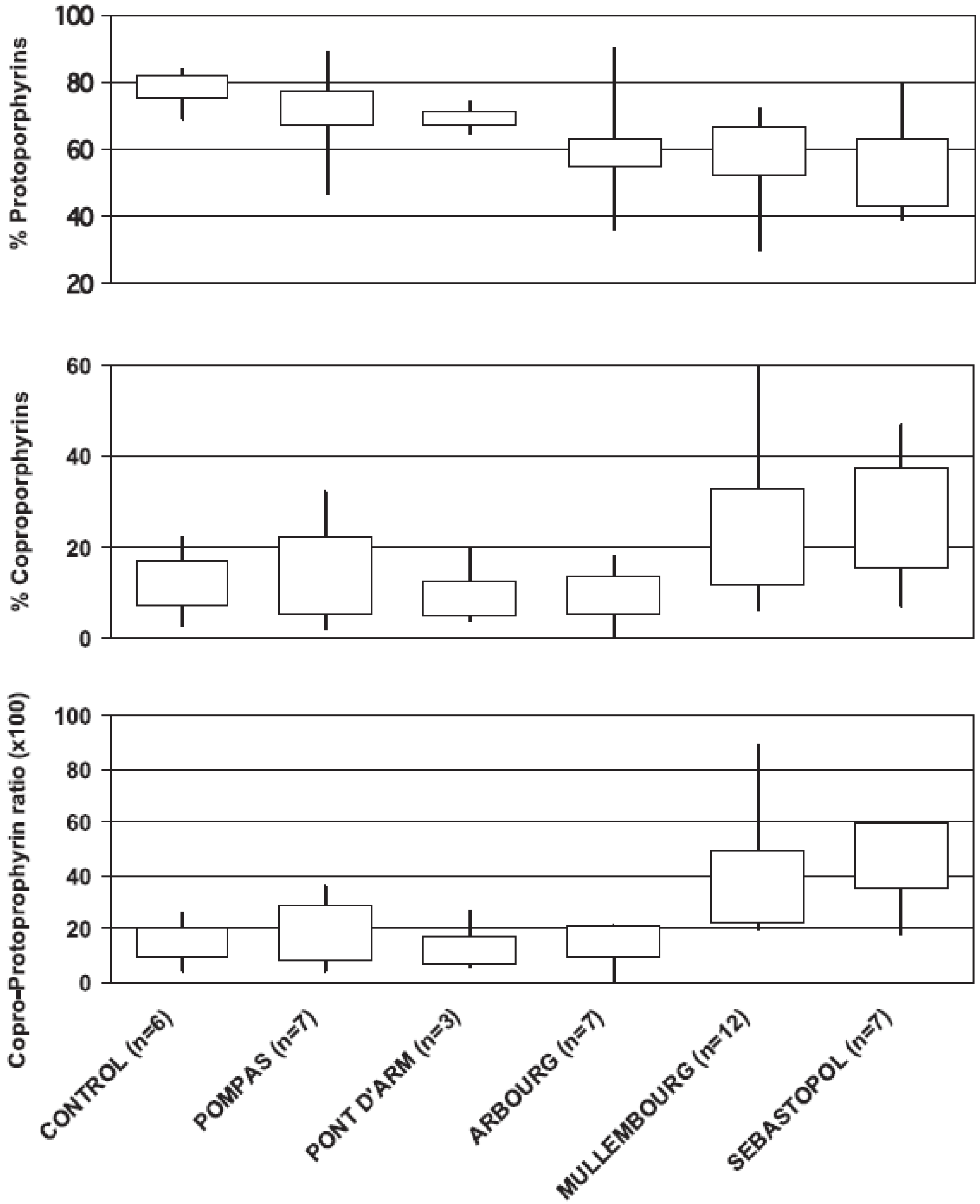

Fig. 6. Proportions of proto- (top) and coproporphyrins (intermediate) and the copro- /proto porphyrin ratio (bottom) in Eurasian otters, *Lutra lutra*, from the Bay of Biscay. Site locations are shown in Figure 1. Pompas, Pont d'Arm and Arbourg are three sites in which foraging home ranges include stretches of estuarine habitat; Mullembourg and Sebastopol are two sites in which foraging home ranges include coastline and salt marshes that were directly impacted with oil.

Table 1. Mean ± 1 SD and range of vanadium concentrations (µg g^{-1} dry mass) in the liver of common dolphins, *Delphinus delphis*, of known age before and after the *Erika* oil spill.

	N	Age (in years)		Vanadium	
		Mean ± SD	Range	Mean ± SD	Range
Before 2000	16	7.7 ± 5.6	0.2 – 19	0.53 ± 0.26	0.08 – 0.93
From 2000 onwards	116	6.4 ± 4.3	0.1 – 17	0.45 ± 0.27	0.04 – 1.27

Table 2. Reported vanadium concentrations (µg g^{-1} dry mass) in the liver of Cetaceans and Pinnipeds from various locations (*n* = sample size; * denotes that original concentrations per unit wet mass were converted into µgg^{-1} dry mass for the sake of comparability by using a dry mass/wet mass ratio of 0.25; values are given as means ± standard errors and ranges).

Species	Areas	*n*	Mean ± SD (range)	References
Common dolphin ***Delphinus delphis***	North East Atlantic	132	0.46 ± 0.27 (0.04 – 1.27)	our work
Harbour porpoise ***Phocoena phocoena***	North East Atlantic	14	0.22 ± 0.21 (0.05 – 0.66)	our work
Striped dolphin ***Stenella coeruleoalba***	North East Atlantic	26	0.32 ± 0.28 (0.03 – 0.28)	our work
Pilot whale ***Globicephala melas***	West Atlantic	9	- (<0.04 – 0.08) *	Mackey et al. (1995)
Harbour porpoise ***Phocoena phocoena***	West Atlantic	6	- (<0.04 – 0.09) *	Mackey et al. (1995)
White sided dolphin ***Lagenorhynchus acutus***	West Atlantic	4	- (<0.04 – 0.10) *	Mackey et al. (1995)
White whale ***Delphinapterus leucas***	Alaskan Arctic	15	0.49 ± 0.11 * (0.12 – 0.76) *	Mackey et al. (1996)
Greenland right whale ***Balaena mysticetus***	Alaskan Arctic	3	2.8 ± 2.3 * 0.34 – 4.8 *	Mackey et al. (1996)
Harbour seal ***Phoca vitulina***	West Sweden	10	- (0.07 – 0.69) *	Franck et al. (1992)
Harbour seal ***Phoca vitulina***	Baltic Sea	10	- (0.06 – 0.22) *	Franck et al. (1992)
Harbour seal ***Phoca vitulina***	North Pacific	58	- (0.06 – 6.4) *	Saeki et al. (1999)
Ribbon seal ***Phoca fasciata***	North Pacific	8	- (0.12 – 5.6) *	Saeki et al. (1999)
Grey seal ***Halichoerus grypus***	Baltic Sea	8	- (0.10 – 0.31) *	Franck et al. (1992)
		10	- (0.11 – 0.13) *	
		9	- (0.12 – 0.69) *	
Ringed seal ***Phoca hispida***	Baltic Sea	10	- (0.09 – 0.47) *	Franck et al. (1992)
		3	- (0.14 – 1.06) *	
	Alaska	13	1.91 ± 0.57 (0.08 – 1.89)	Mackey et al. (1996)
Bearded seal ***Erignathus barbatus***	Alaska	3	1.91 ± 1.95 (0.60 – 4.14)	Mackey et al. (1996)
Steller sea lion ***Eumetopias jubatus***	North Pacific	28	- (0.09 – 1.72) *	Saeki et al. (1999)
Northern fur seal ***Callorhinus ursinus***	North Pacific	50	2.26 (0.36 – 6.81)	Saeki et al. (1999)
	Alaska	53	1.19 (0.11 – 9.18)	