The *Erika* Oil Spill Impact on Terrestrial Vegetation: Main Results of a Five Year Monitoring Program

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Abstract

The grounding of the *Erika* off the south coast of Brittany (France) on December 12th, 1999 resulted in a large oil spill causing contamination scattered along 400 km of coastline. Due to very bad meteorological-oceanic conditions combined with spring tides, the oil reached lichen communities and coastal plants of the splash zone on rocky shores, dune vegetation and salt marshes.

A five year monitoring program was led on terrestrial communities with an ecological approach. 175 permanent quadrats were established on all types of affected vegetation communities and followed by a phyto-sociological method.

The results of this study tends to show: (i) minimized impact on heavily oiled vegetation (e.g. salt marshes) due to adequate removal of the bulk of oil (ii) light to moderate short (1 year) and medium term (2-3 years) damages due to oil or oil and clean-up, (iii) no significant evolution of vegetation composition and cover in most quadrats monitored, even when residual oil is still persistent, (iv) long term impact (>5 years) on slow growing communities like lichen, grey (fixed) dunes, (v) localised variable vegetation damages induced by cleanup operations depending on the level of oiling, conditions of clean-up operations and type of habitats. Technical and environmental experts involved in clean-up operations succeeded at minimizing this damage.

1 Introduction

On December 12th, 1999, the tanker *Erika* broke up and sank off the coast of Brittany (France), leading to the spill of 20 000 tonnes of heavy fuel oil. The first slicks had been drifting and weathering at sea for 12 days, in severe sea state conditions, leading to their fragmentation and scattering and to an extreme emulsification of the fuel before it reached the shore. At the beginning of the spill, due to a combination of exceptional gale-force winds and spring tides, the oil was projected on high levels along the coastline, upper than tidal zone, resulting in the significant oiling of the terrestrial rocky and dune vegetation. In seven days the bulk of oil deposits had occurred, scattered all along the south coast of Brittany to the Baie

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de Bourgneuf located south of mouth of the Loire, representing a stretch of around 400 km of coastline. A wide range of oiling was observed and all types of coastal habitats were contaminated: intertidal salt-marshes, lichen communities and phanerogams of aerohaline upper level on rocky and sandy shores.

Most of the oil deposits occurred in the upper part of the intertidal zone between mean high tide level and spring tide level, area with relatively low flora and fauna diversity. In vegetated areas, initial contamination by oil emulsion ranged from a few centimetres thick on sloping areas of rocky platforms and cliffs, to 15 to 20 cm on flat areas of intertidal marshes, boulders or sandy beaches.

There has been a considerable amount of information published for more than 25 years on oil impact on vegetation, optimisation of clean up and criteria to ascertain the appropriate end point for oil spill clean up operations (Sell et al., 1995). In most studies attention has been drawn mainly to salt-marshes, habitat the most often affected by oil spills because these plant communities are found colonising the mudflats from high water neap tide level. Evidence from case studies and experiments show that the damage resulting from oiling and the recovery times of oiled vegetation are extremely variable (IPIECA, 1994, Baker et al., 1993b). Oil pollution effects may vary according to the type and amount of oil involved, the degree of its weathering at sea, the time of year, and the species and age of the plants concerned (Baker, 1970). Recovery occurs within one year to five years. Prolonged recovery to 10 years or more can be explained by particular conditions like extensive deposits, intense treatment etc. (Sell et al., 1995) or for specific communities like lichens for which monitoring often stops before their slow growth rates have allowed recovery (Lallemant and Van Halluwyn, 1981).

The *Erika* fuel oil was composed of 90% of a heavy distillation residue and 10% of light fraction resulting from catalytic cracking used to lower the viscosity of fuel. *Erika* fuel is considered as a heavy fuel oil. Direct impacts of oil on plants result from both physical effects and chemical toxicity. The type of oil is the most important factor, "… weathered crude oils or heavy fuel oil are considered to be less toxic to marsh grass than lighter more penetrating oils more likely to cause acute toxic damage" (Baker, 1971). The short term, adverse effects of oil on plants range from reduction in transpiration and carbon fixation to plant mortality because oil physically prevents plant gas-exchanges (Baker, 1970, De Laune et al., 1979). After the *Erika* spill, plant leaves and soil were covered by fuel to different extents. Downward migration of petroleum through the soil, however, was limited due to the physical properties of the fuel. Yet, the contaminant may have been in contact with roots when clean silt covered the oil layer due to the sedimentation process, or when viscosity decreased, thus allowing oil to deep into rocks crevices due to temperature raise during summer or when hot water washing was implemented. As a consequence, in some conditions, roots system might have been in contact with petroleum compounds for several years.

A major scale clean-up operation was led under the POLMAR French national organization. The overall clean-up operation lasted till spring 2002, i.e. 2.5 years after the spill. *Cedre* and Environmental Evaluation groups, created under Prefect authority in each Department, rapidly set up specific recommendations for vegetation clean-up, consisting mainly of (i) cutting oiled part of the plants depending on species affected, (ii) manual removal of oil at the foot of the plant with small gardening tools avoiding removal of soil to protect roots and seeds, (iii) manual screening in sandy habitats,

(iv) fencing of light to medium oiled upper beach communities waiting for natural clean-up, (v) avoiding high pressure (HP) cleaning on vegetated rocky crevices. In addition, prior environmental recommendations were given to prevent clean-up operation impacts with careful management of sites during operations concerning access (direction and limitation of equipment or foot traffic), areas for equipment storage (location choice and protection) and protection of cliff plants during high pressure washing of oiled adjacent rocky areas.

Vegetation clean-up was not systematic; it was undertaken depending on the degree of oiling, sensitivity of plant species or natural habitats, socioeconomic or usage considerations. Removal of thick accumulations was a priority. In vegetated areas it mainly concerned intertidal marshes and the front part of dunes, while the removal of thinner layers on rocky shore vegetation was considered as fine clean-up with time to set-up a careful management of operations. For example, for the main intertidal marshland in the Baie de Bourgneuf, POLMAR clean-up operations were closely managed and supervised by botanists; moreover, private companies also contracted a botanist or specific teams for assistance in vegetation clean-up.

An extensive program of environmental impact assessment was initiated by the French Ministry of Environment. In this framework, two programs focused on impact on vegetation. A five year monitoring program was led on lichen and terrestrial communities with an ecological approach which results are presented in this paper, and a program addressed contamination of the plant tissues by aromatic hydrocarbons (Meudec and Poupart, 2003).

2 Method

Prior to the study, the authors were involved in surveys and clean-up operation follow-up. The monitoring program started when 175 permanent quadrats and transects, within half a square metre to a few square metres each, were established in July 2000 in 60 sites chosen among the 400 km of affected coast. It was not possible to sample at random, or to replicate adequately the quadrats, because of the extreme variation in the degree of oiling and ecological conditions on the Breton coast, where habitats are restricted in size and very varied, especially in rocky shore environments. As a consequence very few un-contaminated control sites (5) were analysed because of the lack of comparable situations. In order to mitigate these failings, the utmost was done to obtain an observation network that can be considered as representative of the variety of habitats and species, degree of oiling and clean-up conditions.

Among the surveyed sites, 31% of quadrats concerned oiled quadrats that were left uncleaned, 18% concerned quadrats with only incidental damage due to response activity and 50% concerned quadrats that were oiled and subsequently cleaned-up. Although there were data and knowledge of habitats and species distribution along the coastline, there were no pre-spill records which could be used for comparative estimates in the quadrats monitored.

These quadrats were accurately surveyed at least twice a year, in winter and spring or summer, from 2000 to 2004. In 2005, only 39 quadrats were monitored in 19 sites, as recovery of vegetation was considered to be completed in the rest of the quadrats. Careful visual observations were recorded, and temporal variations in communities were assessed using, counting of plants in narrow rocky crevices, phyto-sociological surveys based on method of Braun-Blanquet (de Foucault, 1986) check reference the years do not match up. In each quadrat, species composition, ground cover and spatial cover for each species (abundance/dominance coefficients), plant height (minimum, average and maximum) and phenology (state and characteristics of development) were checked. Photographs were made during each visit.

Figure 1 Location of Sites Monitored by Permanent Quadrats from 2000 to 2004 along the 400 km of Oiled Coast in Breton Departments: 29 = Finistère, 56 = Morbihan, 44 = Loire-Atlantique, 85 = Vendée

3 Results

3.1 Global Extent of Contamination and Representativeness of Quadrats Monitored

To evaluate the global extend of contaminated vegetation and to ensure all the types of habitats were surveyed by permanent quadrats, a global assessment of habitats initially affected by the spill has been carried out in July 2000 along 380 km of the coastline. The results of affected vegetation are presented in Table 1. Surfaces were not estimated, only linear information was collected and mapped on a scale of 1:25,000. In many places different habitats are superimposed along the beach profile.

The quadrats were representatives of the diversity of habitats impacted (Table 2). Note that the brackish marshes, developed on rocky platforms at the mouth of fresh water streams, are over represented because of the patrimonial species found in these habitats (e.g. *Rumex rupestris, Triglochin palustris*).

Table 1 Type and Extent (linear km) of the Habitats Affected by the *Erika* Oil Spill (July 2000)

Habitats affected by the spill	Extent (linear and % of the affected coast)
Rocky shores: chasmophytes and lichen communities of cliffs edges and crevices, aerohaline grass communities	109 km (48%)
Sandy habitats: upper beach, open dunes, grey dunes communities	88 km (39%)
Intertidal marshes communities	24 km (10%)
Brackish marshes and estuary habitats	7 km (3%)
TOTAL	228 km

Table 2 Habitats Diversity Representation in the Quadrats

Habitats	Number of quadrats by type			
	Oiled	**Oiled + cleaned-up**	**Incidental**	**Unoiled reference**
Upper sandy beaches and embryonic dune communities (16% of quadrats)	14	13	1	
White dunes (10% of quadrats)	3	2	6	
Grey dunes (10% of quadrats)		2	14	1
Upper pebble and shingle beaches (4%)	2	5		
Lichen communities of supra-littoral rocky shores (5% of quadrats)	2	6	1	
Rocky shores or cliffs ledges and crevices communities (26% of quadrats)	17	25		4
Aérohaline grass and moor (7%)	1	3	8	1
Intertidal saltmarshes (12%)	9	12		
Brackish marshes (14% of quadrats)	8	16		
TOTAL : 175	**54 (31%)**	**86 (49%)**	**30 (17%)**	**6 (3%)**

3.2 Oil Persistence

Heavy fuel oil persistence was noted in the supra-tidal zone (Table 3). The degree of persistence or disappearance depend on (i) thickness of oil layers, (ii) substratum mobility (e.g. residual tar balls in sandy beaches were rapidly dispersed by winter storm action on beach profile erosion), (iii) humidity degree of the habitat (in dripping vegetated cliffs or marshes the oil remained sticky until 2004 and 2005, (iv) exposition, specially to sun which enhance photo-oxidation (light spot or scattered projections on lichens communities showed from 2003 to 2005 good regression or disappearance on sun exposed rock faces) (v) sedimentation conditions (in marsh in which accretion was observed, buried oil layer remained until 2005).

Table 3 Oil Persistence According to Habitats and Substratum Characteristics

Habitats and substratum types	Summer 2000 maximum thickness and aspect of oil	2001	2002	2003	2004	2005
Sandy upper beach	10 -15 cm Sticky tar balls and pancakes; More or less buried	Sticky tar balls; ± buried	Very scarce dry tar balls	No trace	–	
White dunes	10-15 cm Sticky sandy tar balls and pancakes; More or less buried		Sticky and dry tar balls; ± buried	Very scarce dry tar balls	No trace but one quadrat	
Grey dunes	2-3 cm oil layer Dry skin on surface sticky under			almost dry crust; plants shoots through, slow erosion		
Upper pebbles and shingles beach	0.5 cm Sticky film	Dry film	No trace	–		
	10 cm oil layer Dry surface, sticky under		Dry pavement start to be eroded	Dry pavement erosion in progress		
Lichen supra littoral rocky shore	0.2 cm Sticky film	Dry film	Dry film start to reduce in sunny expositions	Dry film reduce faster in sunny expositions		Some oil spots disappe ared
	0.5 cm Sticky film	Dry film		Dry film start to reduce	Reduction in progress	
Rocky cliffs ledge and crevices	1 cm Sticky in Dry situations		Erosion of dry tar crust, start	Erosion in progress		traces
	1 cm Sticky in seepage zones			Start to dry, and erode	Erosion in progress	
	2 cm Sticky in dry situations		Tar crust have dried	Erosion in progress		
	2 cm Sticky in seepage zone				Erosion in progress	
Intertidal marshes	2 cm oil layer in erosive marshes	Sticky layer	Sticky layer, slow erosion		Start to dry Erosion progress	Scarce traces
	2 cm oil layer in marshes in accretion	Sticky layer	Sticky layer buried			
	7 cm oil layer in erosive marsh	Sticky layer	Sticky layer, erosion in progress		Sticky layer, erosion in progress	

3.3 Incidental Impacts of Clean-up Operations

Clean-up activities generated some vegetation damage on adjacent un-oiled areas. Extensive inventory and surface estimates of areas and communities affected by these impacts were carried out during all the follow-up of site clean-up. The main cause of damage consisted of (i) creation, enlargement and rutting of access in natural communities, (ii) temporary storage areas for clean-up material and oiled waste collected (iii) micro-cliff destruction due to access for mechanical equipment to beaches, (iv) rubbing up erosive action of ropes on cliff vegetation and soil due to clean-up at heights or in hard access places when the technique was not correctly managed. This inventory showed hat 2.5 km of track were widened, mainly on one island (Belle-île) where most sites are not accessible by roads, 45 locally damaged spots were identified corresponding to a total of nearly 30 000 square metres 1/3 of which were already floristically banalized coastal grass with presence of opportunistic species due to intense tourist usage. The rest of damages affected communities of floristic interest, (e.g. moor with *Erica vagans*, aerohaline grasses with *Armeria maritima, Frankenia laevis*, grey dunes with *Helichrysum stoechas, Ephedra distachya* and white dunes with *Ammophila arenaria*.

3.4 Impact on Coastal Communities

Upper Sandy Beaches and Embryonic Dune Communities (17 quadrats)

This level is characterized as an area of pollutant accumulation, important sedimentary changes, open vegetation cover with annual like *Atriplex laciniata*, *Cakile maritima* and a few perennial species like *Honkenya peploides* of which creeping stolons are not visible in winter. Clean-up techniques applied were (i) manual collect of major accumulations of oil , (ii) manual screening, (iii) fencing to avoid mechanical equipment traffic and disturbance of stolons and seeds, (iv) cutting of oiled perennial vegetation of embryonic dune (*Elymus farctus ssp boreal-atlanticus*).

In all the quadrats followed (oiled and cleaned or not), vegetation cover range from 30% to 90% in 2000 but one (15%) in which all Polygonum maritimum died due to oil. In some quadrats it was obvious that clean-up had emphasized the reduction of vegetation cover, but it was not possible to demonstrate it, because of the loss of the majority of the quadrats during a severe storm in winter 2001.The pursuit of the monitoring was qualitative and showed that none of these plant communities disappeared. A great variability was observed in vegetation cover from one year to another and could not be related to the spill but to natural or human action.
Apart from some necrosis noted on oiled *Honkenya peploides* plants in one quadrat in summer 2000, the plant development was normal in others.

White (Shifting) Dunes (11 quadrats)

When contaminated, these habitats dominated by *Ammophila arenaria subsp. arenaria,* where generally oiled on the edge, sometimes over a width of a few metres. Clean-up techniques consisted of (i) the cutting of oiled *Ammophila,* (ii) manual collection of main accumulations. The results of observations are exposed in Table 3 for oil contamination and persistence and in Table 4 for vegetation observations. Impact was limited and not noticeable within 2 to 3 years. Heavy vehicle tracks (7 quadrats) were rapidly overgrown, proof of the great dynamism of Marram grass.

Grey Dunes (17 quadrats)

White dunes give way inland to stabilized dunes colonized by a great variety of herbaceous grassland of xerotolerant species with abundant terricolous bryophytes and lichens cover. Due to their great floristic diversity, these habitats are protected at the European level. Few examples of grey dunes affected by oil projections when they developed in front of the shore on top of cliffs (climbing dune) or due to loss of oil during transportation of wastes (see Table 3). Dune grass died under tar layers (*Festuca rubra, Carex arenaria…*) and due to the stability of the substratum tar pancakes remained until the end of the project. From 2002, moss (*Tortula sp.*) and grass started to overgrow the tar pavement and new shoots of *Carex* grew through it contributing to break up the crust. In a few sites due to oil storage and vehicle access, the vegetation cover decreased severely and bare areas poorly recovered until 2005. Vegetation coverage was very low compared to control sites.

These habitats were quite not affected by direct oil contamination but some damages were linked to clean-up operations. Although degradations were localised, due to the low potential of recovery compare to shifting dunes habitats, degradations should have been avoid.

Upper Pebble and Shingle Beaches with Open Vegetation (5 quadrats, 2 transects)

Some of the oiled pebble and cobble beaches were heavily coated. When they were un-cleaned or partially cleaned by manual removal to preserve vegetation, residual oil formed a tar crust from 2 to 7 cm, progressively reduced but not totally disappeared in 2005. In these quadrats impact depend on species. *Crithmum maritimum* and *Elymus sp* grew among a 7 cm thick tar crust, but the creeping *Frankenia laevis* died when heavily coated. Some oiled cobbles and shingles were removed and replaced after cleaning in cement mixer. Natural re-colonisation started one year after, often with a great part of opportunistic species. Due to the lack of pre-spill data it is not possible to clearly relate this to the spill as it took place in very popular tourist areas where natural flora may already have been disturbed.

Table 4 Observations on White Dunes

Treatment	Number of quadrats	Phenology	Vegetation Cover	Comments
Oiled	3	Normal	Evolution of vegetation cover link to natural sand dynamic.	No impact noted on plants. Great quantity of sand blown in the three quadrats during 2001 storm.
Oiled and cleaned	2	Normal	Progression of vegetation cover between 2000 and 2001.	Re-growth observed the first year when *Ammophila* was cut.
Indirect impact	6	Normal	Reduction in vegetation cover. Veg. cover was from 60 up to 90% in 2000. Dissapearance of vehicle tracks observed from 2001 to 2003.	In one quadrat, the marks were lost, pursuit of qualitative observations.

Table 5 Observations on Grey Dunes

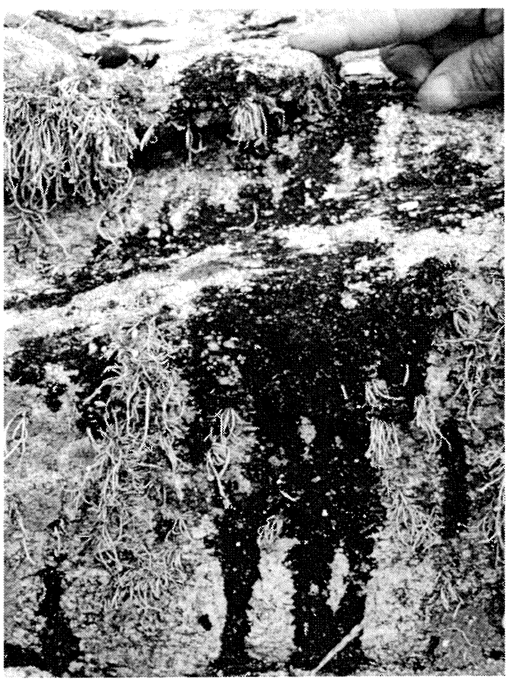
Treatment	Number of quadrats	Phenology	Vegetation Cover	Comments
Oiled and indirect	2	Normal	In 2000, coverage 55% and 65% due to tar deposits and trampling. No increase in 2004.	Dead plants under tar-crust.
Indirect impact	14	Normal	In severely damaged quadrats (5% vegetation coverage left in 4 quadrats) slow recovery, increase from 5 to 30% in 2004. In medium damaged (25 to 55% vegetation cover left in 2000). Increase of cover of an average of 20% in 2004.	In control sites, vegetation cover range from 90 to 100% 2 quadrats were abandoned because tourist trampling interference. One quadrat was lightly affected, the vegetation cover was 90% (same as in control site) but lichen *Cladonia sp.* disappeared and no re-growth was observed in 2004.

Table 6 Observations on Upper Pebble and Shingle Beaches

Treatment	Number of quadrats	Phenology	Vegetation Cover	Comments
Oiled	2	Normal	In 2000 vegetation cover only 50 and 80% due to tar-pavement. In 2004 cover increased in one quadrat from 50% to 75% the other remained stable (80%).	
Oiled and cleaned	5	Normal	In 3 quadrats, no vegetation cover after clean-up in 2000 and around 10% in 2004. In partially cleaned (to preserve vegetation), cover was maintained up to 50 and 90% in 2000. Regression observed (43 and 23% in 2004) due to marine erosion.	In 2 quadrats located in highly urbanized or tourist sites, re-growth of banal species was observed, but no pre-spill data to compare to link this to clean-up.

Lichen Communities of Supra-Littoral Rocky Shores (9 quadrats)

Splash zone lichen communities (*Caloplaca marina, Xanthoria parietina, Tephromela atra and Ramalina siliquosa*) were diversely affected by oil projections causing scattered spots or more or less continuous coating of a few millimetres. Response was variable. Scattered spots were left to natural evolution, clean-up by selective high pressure hot water washing was tried successfully in some places but extensive washing was done when rocks were heavily coated. In un-cleaned areas oil spots showed noticeable regression from 2003, especially on sunny exposed rock faces where part of them disappeared in 2005 (Figure 2). In terms of impact, coated lichens died except some fruticulose *Ramalina siliquosa* that seemed able to survive when only partially coated. In some quadrats, partially spotted, foliose lichen *Xanthoria parietina* started to decline only three years after the spill, but this could not be clearly attributed to oil as it maybe associated with a dry period of summer 2003, when the same phenomenon could be observed among lichen populations on un-oiled rocks. When high pressure hot water washing was rapid, example given by "drawing" made on rocks with *Caloplaca maritima*, all the lichen were not eliminated. After intense hot water high pressure washing, rocks were bare for years. No colonisation was observed even in 2005. To complete visual observations, scanning electron microscope ones were made in 2005 on some pieces of these bare rocks. For one of them, mycelium and micro-algae were observed in a micro-crevice. This was possibly the first stage of lichen colonisation. For the others, no micro-flora was noted and the rock surface appeared abraded.



Hoedic Island, Vas Plat, 07/2002: Un-cleaned oil projections on lichen *Ramalina* and *Xanthoria*.

Same place, 09/2005: Differential progress in natural degradation of oil, more efficient on well sunny exposed areas. Disappearance in 2005 of some *Ramalina* with oiled base still present in 2003.

Figure 2 Example of oil disappearence, quicker in well exposed rock faces (photo-oxidation).

Rocky Shores or Cliffs Ledges and Crevices Communities (45 quadrats)

Vegetated cliffs exhibit a complex pattern of variation reflecting the degree of maritime exposure, geology and geomorphology, biogeography and human management. On the most exposed cliffs there is a zonation from crevice and ledge communities of the steepest slopes beside the sea with *Crithmum maritimum*, *Spergularia rupicola*, *Inula crithmoides*, *Armeria maritima*, *Limonium sp.*, *Frankenia laevis.* In seeping areas *Glaux maritima, Juncus maritimus, Samolus valerandi, Apium graveolens* can be found and some protected species like *Rumex rupestris.* On cliff tops and cliff ledges where there is deeper accumulation of soils grasslands with *Festuca rubra, Armeria maritima*, *Cochlearia danica,*are found or heath with *Erica vagans*, *Erica cinerea, Calluna vulgaris*, *Ulex europaeus*. Rocky vegetated crevices on platform and cliffs were the habitat the most often oiled all along the coastline (Table 1). Level of oil contamination and persistence is described in Table 3. Oil deposits appeared as thin film of few millimetres to coating of 2 cm, at he foot of vegetation and/or coating on stem and leaves. Thicker layers could have been manually removed prior to the starting of the monitoring program. Clean-up consist of (i) manual removal of major part of oil with gardening tools, (ii) cutting only for oiled grass species (e.g. *Festuca rubra*). In addition high pressure washing was extensively used for adjacent areas and had some time damaged the margin of vegetated areas at least with oily projections. On top of cliff, damages consist more often in trampling and damage caused by material storages.

In un-cleaned quadrats, mortality of partially or totally coated plants was observed especially on low growing species like *Ameria maritima, Festuca rubra, Limonium cf dodartii, Spergularia rupicola, Frankaenia laevis.* No impact or light opening of vegetation cover was observed in the quadrats and but reinstatement was slow and not achieved. Plants development was normal from the first summer even if new shoots have to grow through tar layer. No noticeable change was observed in plant species composition.

In manually cleaned quadrats, even if applied carefully, removal of oil provoked partial destruction of the vegetation cover which appeared to be very slow to recover. Bare zones remained until 2005. High pressure washing done on the margin did not induce noticeable damages, often oiled projections and burnt that disappeared the next year, plants.

In heavily polluted rocks high pressure hot water washing induced damaged in the quadrats themselves, plants and soil disappeared (Figure 3). One species, *Crithmum maritimum* had shown a great resistance to high pressure washing due to its root system penetrating deeply in the crevices. During two years this species was visually predominant in treated areas. In these intensive, but localised, washed areas (11 quadrats) recovery process hardly started in 2005, plant diversity and cover were still very low.

Intertidal Saltmarshes (21 quadrats) or Brackish Marshes (24 quadrats)

Coastal salt muds are colonized by annual pioneer formations, glasswort swards mainly composed of annuals *Salicornia sp.* and *Suaeda maritima* and by perennial like *Athrocnemum perenne* or by perennial *Spartina sp.* grassland. Then, at upper level, appear salt meadows with *Halimione portulacoides*, *Puccinellia maritima* and at higher level *Suaeda vera* shrub.

One area of the coast was mainly affected, the Bourgneuf Bay where 5 of the 44 hectares of salt marshes were heavily oiled (Lacroix and Lauchaud, 2000). Oil-cakes but also slicks of hundreds to several thousands of square metres reached the intertidal marshes with a thickness of up to 20 cm before clean-up. Oil was also trapped in the channels. After the clean-up operation when the monitoring program started the major residual fuel deposits found were a few tar patches of around 1 to 2 square metres and up to 7 cm in thickness (Table 3). Others salt-marshes were only lightly affected.

Table 7 Observations on Rocky Habitats Type Upper Cliff Grassland

Treatment	number	Phenology	Vegetation Cover	Comments
Oiled	2	Normal	Veg. cover stable Species diversity stable	
Oiled and cleaned	3	Normal	Veg. cover 10 to 50 % after clean-up. Slow re-growth, veg. cover remained around 55% in 2004. Species diversity stable.	The clean-up was manual. Reference sites 80 to 90 % vegetation coverage
Indirect impact	3	Normal	Veg. cover 10 to 50% in 2000. Remained open around 55%. In one veg. cover was 75% but with enrichment in opportunistic species	

Table 8 Observations on Rocky Crevices Type

Treatment	number	Phenology	Vegetation Cover	Comments
Oiled	17	Normal	Veg. cover stable in 7 quadrats. In 7 other quadrats a few mortality induced light reduction of veg. cover not completely restored. Species diversity stable.	3 quadrats not considered Mortality concerned Armeria, Limonium.
Oiled and cleaned	14	Normal	**Manual clean-up**: Veg. cover reduction (<35% in 6 quadrats, <55% in 3 quadrats). Slow re-growth, in 2004, increase range from 5 to 35%.	Reference control site in same habitat, veg. cover = 80 to 90%
	11		**NHP clean-up**: Disappearing of plants in 11 quadrats, good re-growth for 3 (Crithmum), no re-growth in the crevices for 5 quadrats, poor re-growth in 3 quadrats: veg. cover = 6 to 10% and poor species diversity	

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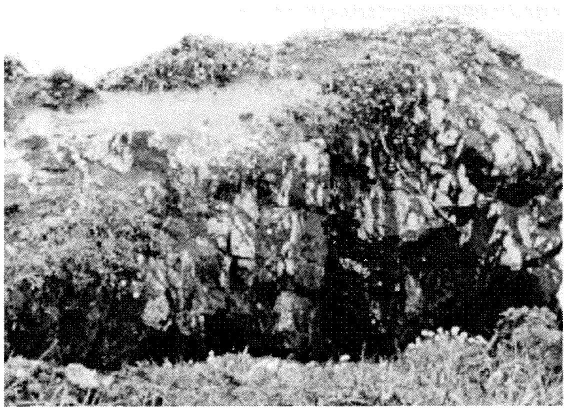


"La Grande Butte" Piriac/Mer (44) – Localised rocky ledge heavily polluted near tourist footpath In spring 2000. Green leaves may be seen on most oiled plants

Same place in summer 2004 – Intensive hot water high pressure washing was done during summer 2000. Until 2005 recovery is very poor

Figure 3 Intensively washed rocky platform, recovery process hardly started in 2005.

On mud deposits with seepage or small freshwater streams, many small brackish marshes of tens to hundreds of square metres wide, are developed and composed with a vegetation of reeds with *Phragmites australis*, *Scirpus maritimus*, *juncus Gerardii sp*. and rare patrimonial species like *Triglochin palustris*. Some were heavily polluted. Due to their ecological interest based on their species diversity, special attention was paid to them.

In all these marshes, clean-up was done manually and consisted of (i) manual removal of oil, (ii) cutting of oiled vegetation for *Spartina* and *Suaeda vera*. In addition, trampling was minimized by channelling and protecting foot accesses.

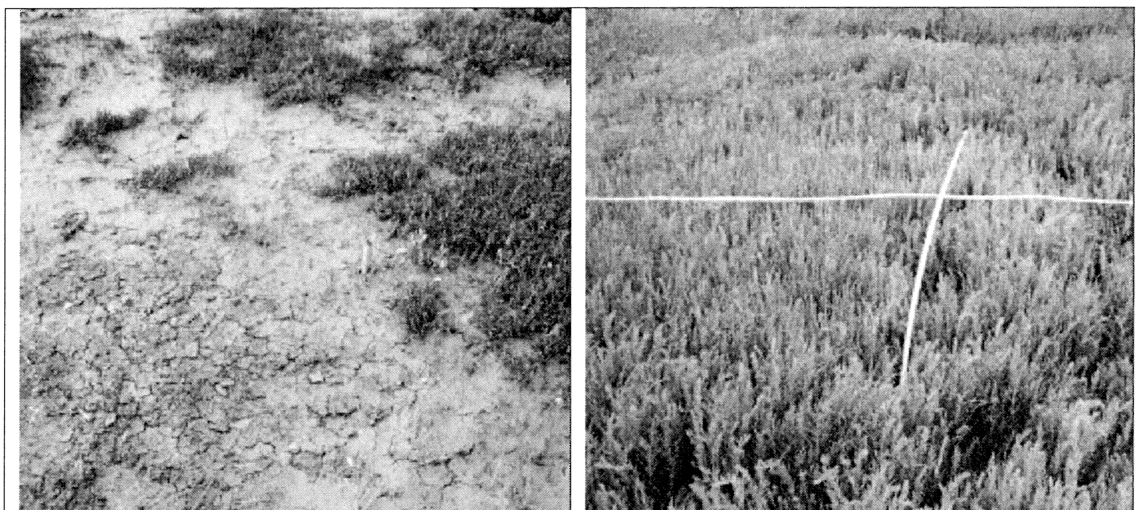
In the Bay de Bourgneuf, as annual plants were not already grown at the period of the spill, the main deposits concerned the high tide level around the edges of vegetation made up mainly of *Spartina maritima* sward and salt meadows, in of *Athrocnemum perenne* and *Halimione portulacoides*. The first summer following the spill the overall appearance of the marsh was globally in fair condition; therefore from place to place bare areas and residual oil were visible.

Compared to the degree of initial contamination, impact was limited, (i) necrosis was very scarcely observed the first year on oiled plants; (ii) on a tens square meters *Spartina maritima* died under tick tar pavement arrived after the clean-up, (iii) residual oil and manual clean-up generally did not affected re-growth of vegetation, (iv) therefore some species sensitive to trampling were lightly affected (annual *Salicornia* and *Suaeda*, *Halimione portulacoïdes*), (v) vegetation cover showed a decrease up to 75% in 2 quadrats due to removal of heavily contaminated algae by heavy machinery (Figure 4). These bare areas were progressively covered, from 2003, by annual species germinations, first stage of re-colonization process and followed by first perennial germination in 2004. In 2005 the marsh had a very good appearance even if in few places the perennial initial species were still partially replaced by annual species.

In the brackish marshes plants with important root systems were not damaged by oil and/or manual clean-up associated with minimal trampling. Only more sensitive species like *Eleocharis palustris* suffered temporary damages.

Table 9 Observations in Salt Marshes

Treatment	Number of quadrats	Phenology	Vegetation cover	comments
Oiled	9	Normal but 1 quadrat = limited growth	Stable no noticeable impact (6 quadrats). In 3 quadrats veg. cover = 70% to 90% due to tar pavement not completely disappeared in 2005.	2 quadrats marks lost in 2001 but no impact noticeable in summer 2000
Oiled and cleaned	12	Normal	In 6 quadrats, no impact noticeable, dense vegetation cover since summer 2000 (veg. cover = 94 to 98 %). In 4 quadrats, light opening of veg. cover. 2 quadrats, veg. cover in 2000 = 25% damage due to removal of contaminated algae by equipment. In 2005, veg. cover = 85% and 90% but mainly re-growth due to annuals.	In oiled and cleaned manually light opening of veg. cover occurred with annual species and *Halimione* more sensitive than *Spartina*



January 2002, still 75% perennial vegetation cover missing in one saltmarsh quadrat (*some Artrhrocemum perenne* remain, *Halimione portulacoides* is lacking).	In summer 2003 abundant annual cover, first sprouting of *Halimione portulacoides* appeared only in 2004.

Figure 4 Bare area due to oiled algae mechanical removal done in 2000 and first stage of colonization process due to annual species in 2003.

4 Conclusion and Discussion

Observations confirmed heavy fuel oil persistence, in fact, residual oil was observed up to 2005. The monitoring program also confirmed that adverse effects are more linked to coating than to toxic effects, as described in the literature from previous oil spill case studies (Stebbings, 1970; Baker, 1993; Bell, 1999).

Table 10 Observations in Brackish Marshes

Quadrat treatment	Number of quadrats	Phenology	Vegetation cover	comments
Oiled	8	Normal	No impact on veget cover = 95 to 100% in summer 2000 and the following years	
Oiled and cleaned	16	Normal	In 6 quadrats no noticeable impact neither of oil nor manual clean-up. In 2 quadrats veg.cover = 80% and 35% manual clean-up had an impact on the same species. In 3 quadrats drastic reduction of vegetation cover due to heavy machinery and a fire.	In one quadrat impact induced by un-appropriate fire of oiled debris, *Scirpus maritimus* was reduced in size and did not flourish.

Through the network of quadrats monitored and including un-cleaned quadrats, clear environmental benefit from the removal of bulk of oil is confirmed, rapid when heavy deposits, more organised and sized when contamination was of a lesser extent. It was more difficult to evaluate clean-up operations in the case of medium level pollution. In fact no impact was observed on vegetation in many medium to light oiled quadrats. In these cases, clean-up may induce more adverse effects and other criteria like usages or socioeconomics constraints were considered to decide opportunity and level of clean-up.

No disappearance of species or habitat or massive mortality were recorded. Necrosis or chlorotic phenomenons where only reported in few locations and only during summer 2000. Mortality due to oil cover was confirmed for 14 species and mainly concerned low growing plants with buds at the soil level (hemicryptophytes) like *Armeria maritima*, *Limonium sp.* or lichen communities. Plants with substantial underground root systems generally produced new shoots as soon as the first spring, often growing through oil layer, as described in previous studies on *Juncus maritimus* (Baker et al., 1993a).

In terms of incidental impacts of clean-up operations, the situation is more contrasted even if degradation of vegetal cover induced by operations (cleaning material deposits on site, widening of path to get access to the coast) remained localised compared to the extend of affected coast. Environmental advice and procedures implemented for this spill, in particular concerning vegetation, greatly limited the scale of clean-up damages.

As vegetation clean-up was done manually with specific teams, impact has been limited compared to the scale of the spill, but locally oil removal induced decrease in vegetation cover has not yet recovered in three types of habitats, (i) rocky exposed locations with difficult natural conditions, (ii) in grey dunes where the first re-colonization stages had hardly started in 2005, (iii) salt marshes where annual species are still more abundant, in some quadrats monitored, than initial perennials. Terrestrial habitats like aerohaline grasses were in some locations more or less banal before the spill, in term of species diversity and characteristics because of intense tourist frequentation and in these cases impact can be considered as minimal. In others like heath, affected species or habitats are of patrimonial interest and in those specific habitats; recovery is not yet achieved in terms of vegetation cover and characteristic species presence and diversity.

Among all affected habitats, fixed dunes, aerohaline grass and heath communities appear more vulnerable and had not yet recovered to a pre-spill state. Lichens communities destroyed by the pollution and washing had not started to settle on bare rocks at the end of the monitoring program.

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