ASSESSMENT OF NATURAL CLEANING AND BIOLOGICAL COLONIZATION ON OILED ROCKY SHORES: *IN SITU* EXPERIMENTS

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ABSTRACT: *When exposed rocky shores are affected by oil spills, the advised cleanup option, in most cases, is the "do nothing" This assumes that natural processes should rapidly clean up such shores and that remedial actions should have great detrimental effects in regard of ecological recovery. Few studies however deal with quantitative rates of natural cleanup on rocky shores. Therefore, CEDRE (Centre de Documentation de Recherche et d'Experimentations sur les Pollutions Accidentelles des Eaux) has conducted field experiments to determine the rate of such processes.*

Granite plates have been polluted with Arabian Light crude oil and Bunker C and set on exposed and sheltered sites. On an exposed site, the influence of tidal elevation has also been studied. The plates were situated in diverse biological communities; the recolonization of polluted and non polluted plates has been recorded during a 13-month survey.

The results show that the Arabian Light crude oil was rapidly washed away by the tide despite low wave energy even on the most exposed site. The persistence of Bunker C was much longer and seemed to be mainly a function of fauna and flora settlement.

At the beginning of the survey, all the plates at the exposed site were colonized by barnacles in equal densities whatever the nature of the oil. A second recruitment wave of barnacle colonized preferably the "crude oil plates" which in fact were clean at that time. Along the tidal gradient, non polluted lower plates were colonized by Porphyra *and* Fucus *while the polluted ones were essentially colonized by green algae.*

Introduction

The natural cleaning timescale is one of the basic data in the decision making process for cleanup response following an oil spill (API, 1997). On rocky shores however, the quantification of natural cleaning processes remains largely based on subjective data. As part of a study on "*How Clean is Clean,*" conducted on behalf of Elf and Total, CEDRE conducted an experiment in the aim of objectively quantifying the natural cleaning timescale on rocky shores.

As wave action is known to be the main process in natural cleaning, three physical factors were studied: the wave exposure, the slope (90°, 60, 30°) and the bathymetric gradient. The experiment was conducted on an islet inside the roadstead of Brest. Two types of oil, Arabian Light crude oil and Bunker C fuel oil, were used to determine the effects of oil properties. Removable artificial substrates, made of granite plates, were used to allow periodical *in situ* sampling and afterwards, oil extraction in laboratory.

As the colonization of the plates occurred early after the beginning of the experiment, the effects of the oil on settlement and the effects of settlement on natural cleaning were also monitored.

Material and methods

Experimental plots description. Experimental plots were defined by using elementary units consisting of a 1 sqm-wooden board with 36 (6 × 6) granite plates (15 × 15 × 2 cm) on it, fixed with stainless bolts placed in the middle of each of them.

Silicone was applied between plates to insure the oiltightness of the pavements during the oil spraying in order to apply a similar quantity on both the different plates and the different boards. The outer plates were defined as a buffer zone in order to avoid side effects. The 16 inner plates were designed for the monitoring of the natural cleaning and of the biological colonization (Figure 1).

Arabian Light Crude oil and Bunker C Fuel Oil were respectively applied on 6 and 12 boards. The Arabian Light was applied at a rate of 11g/m² which represent a thickness of approximately 10 µm, Bunker C oil was applied at a rate of 215 g/m² (215 µm). After oiling, boards were let for aging for 72 hours on the backshore before to be set on the intertidal zone.

Plots location. Five "Bunker C boards" were screwed on a moderately exposed slipway with a 30° slope within different biological communities gradually settled according to the

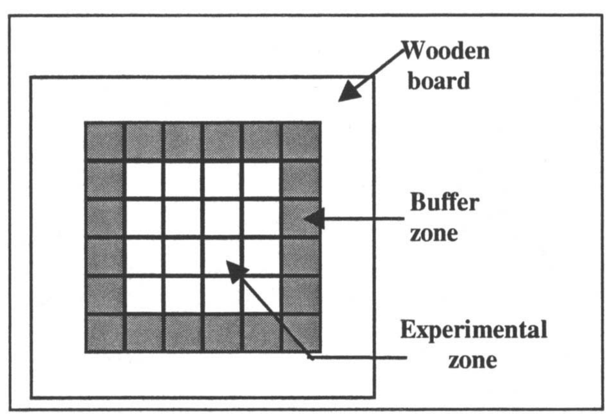

Figure 1. Diagram of a plot.

bathymetric gradient between mean high water mark and mean low water mark, and corresponding to, as follows from the top: the *Verrucaria maura*-dominated zone (level 1), the *Pelvetia canaliculata*-dominated zone (level 2), the *Fucus spiralis*-dominated zone (level 3), the *Fucus vesiculosus*-dominated zone (level 4), the *Fucus serratus*-dominated zone (level 5).

Three "Arabian Light boards" and 3 "Bunker C boards" were screwed in a vertical position on each side of a pier, one exposed, the other sheltered, in the level 3 zone. The sixth "Bunker C board" was screwed on a sloping (60°) rocky surface within the level 3 zone in a moderately exposed area near the slipway.

Oil extraction. At each sampling period, one plate was picked up from board and replaced by a clean one. Sampling periods were based on a base 2 logarithmic progression from T2 (2 days after beginning of experiment) to T256, between June 1997 and January 1998; a last sample was made at T384 (June 1998). Oil was extracted from theses plates with 300 ml of dichoromethane in a sonication bath. The quantity of oil remaining was then determined using gravimetric method.

Biological survey. Since the first recruitment of barnacles was observed, count of individuals was made on each sampled plate. Additionally, non polluted plates were taken in January, after the settlement period of Barnacles, to monitor the effects of oil. Algal cover on the plates was estimated each month.

Results

Natural cleaning. The results are expressed by the time needed to obtain a 50%-lost (Figure 2). These timescales have been deduced from curves shown on Figure 3. The timescales for a 50%-lost differed widely according to oil type, the 50%-lost occurred in 10 to 18 days for Arabian Light and in 70 to more than 380 days for Bunker C oil. Suprisingly, for both Arabian Light crude oil and Bunker C oil, the 50%-lost occurred later on exposed areas than on sheltered ones. Along the bathymetric gradient, natural cleaning seemed to be faster at level 3.

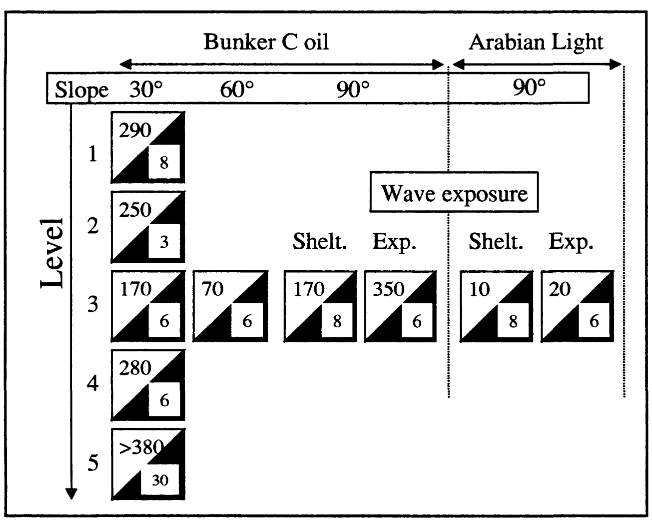

Figure 2. Timescales for 50%-lost in days (white triangles) and 100%-lost in years (black triangles) according to the level, slope, wave exposure (shelt. for sheltered, exp. for exposed) and type of oil. The 100%-lost has been obtained by extrapolation of the curves.

Biological colonization. Barnacles had only colonized the plates located on the exposed side of the pier. First, Cypris larvae were observed at T16 (June), their counting began at T32 (Figure 4). On Bunker C plates, densities remained stable along time whereas on Arabian Light plates, a peak was observed at T128 (September), which correspond to a second wave of recruitment, followed by a regular decrease explain by a natural mortality. Consequently, densities were significantly higher on Arabian light plates than on Bunker C plates at T128 and T256 (January). Densities on oiled plates, for both types of oil, were significantly lower than on unoiled plates sampled at T256. Colonization by macroalgae differed highly between the sites (Figure 5). The "Level 3/90°/sheltered" plots were only colonized by microalgae whereas green seaweed, belonging to the genus *Enteromorpha*, had been observed since August on the "Level 4" and "Level 5" plots and since November on both the "Level 3/30°" plot and the "Level 3/90°/exposed" plots.

On the "Level 5" plot, unoiled plates put down at T2 to T32 were colonized by *Fucus vesiculosus.* The species was firstly observed in September, its coverage regularly increased according to the growth of thallus. In March, the mean coverage was about 50% on the five colonized plates, the free space was occupied by *Enteromorpha sp.* In June, the coverage of *Fucus vesiculosus* reached 100%. The red algae *Porphyra umbilicalis* was observed from August to May on the unoiled plates at the "Level 4" plot, with a maximal coverage of 50% from January to March. Among unoiled plates, only these which were put down at T2 to T64 were colonized by *P. umbilicalis.* At this level, individuals of *F. vesiculosus* were also present on the unoiled plates put down at T2 to T16 but were smothered by *Enteromorpha sp.* On "Level 5" and "Level 4" plots, polluted plates were only colonized by *Enteromorpha sp.* At Level 3, the plates were also only colonized by *Enteromorpha sp.* On the slipway, the coverage reached its maximum of 40 to 60% in March on the unoiled plates and in May on the polluted ones. On the 60° inclined plan plot, just near the slipway, coverage was about 0 to 5%. On the exposed side of the pier, colonization was faster and coverage higher on unoiled plates and Arabian Light polluted plates than on Bunker C polluted plates.

Discussion-conclusion

The experiment showed some unexpected results, particularly, the natural cleaning rate of oil was faster on sheltered areas than on exposed ones. However, the comparison between timescales for 50%-lost and algal cover (Figure 2 and Figure 5) shows that the fastest natural cleaning coincides with the lowest algal cover. Moreover, the oil extraction, using sonication method, showed to be less effective when plates were colonized; consequently biologized plates were scrapped before extraction in laboratory. Therefore, it is expected that fauna and flora settled on polluted plates reduced the effects of wave action. The sheltered side of the pier was also oriented to the South whereas the exposed one was oriented to the north. During warm days, it was observed a "liquefaction" of the Bunker C oil on the sheltered plots which could also explain these unexpected results.

- Rate of natural cleaning was mainly a function of:
  - the oil viscosity, the 50% loss occurred in 2 weeks for Arabian Light crude oil and between 3 to more than 12 months for Bunker C Fuel Oil;
  - the coverage or density of fauna and flora settled after the pollution;
  - the bathymetric level, natural cleaning was faster in the high neap tide level.

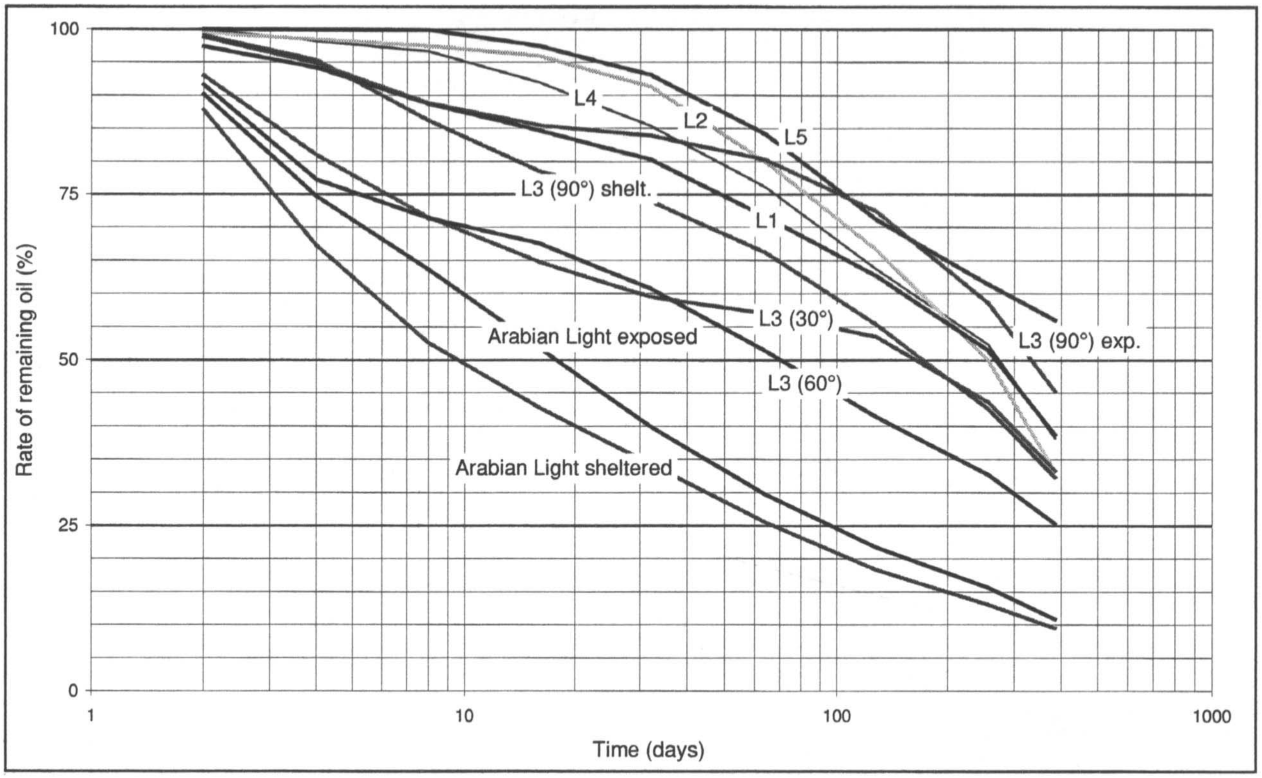

Figure 3. Rate of remaining oil. L1 to L5 mean Level 1 to Level 5, slope and wave exposure are given when needed.

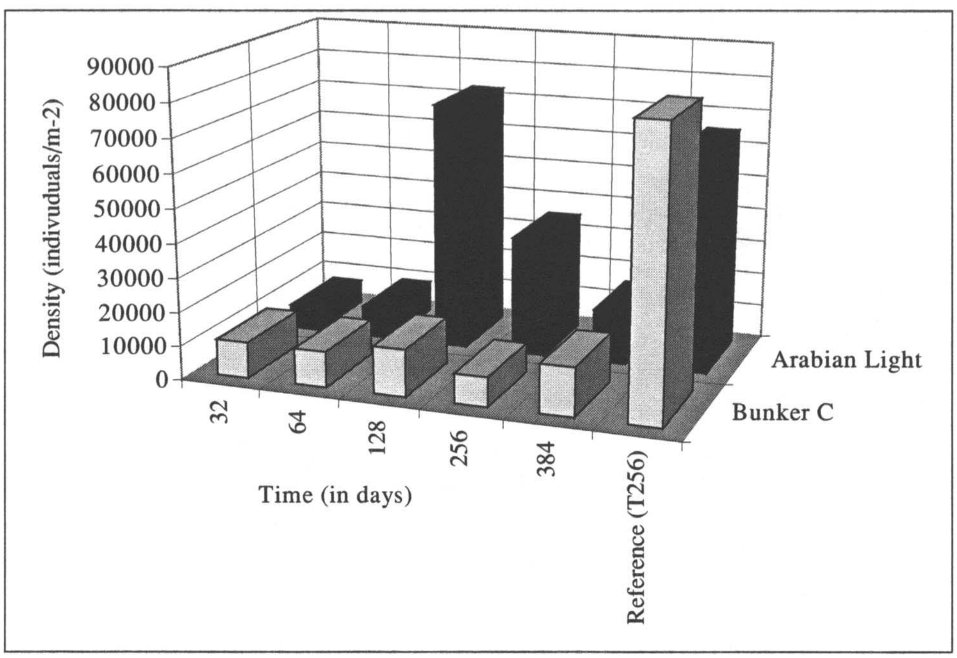

Figure 4. Density of Barnacles (number of individuals / m²).

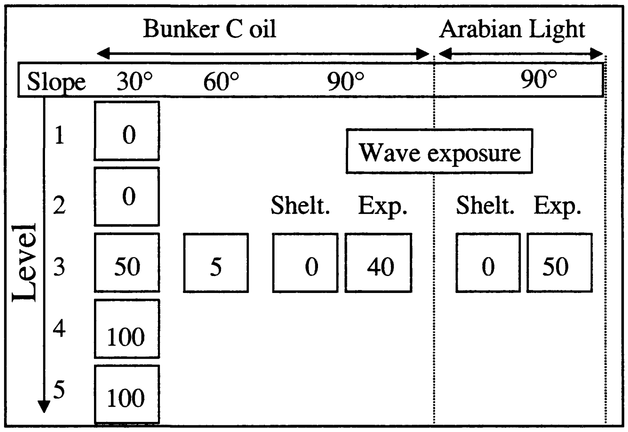

Figure 5. Percentage of algal cover by the opportunistic green algae *Enteromorpha* on oiled plates in May (T365) according to the level, slope, wave exposure (*shelt.* for sheltered, *exp.* for exposed) and type of oil.

- Wave exposure and inclination seems to have only minor effects when plates are colonized by macroalgae and/or Barnacles.
- Six months after the beginning of the experiment, only 20% of the initial quantity of Arabian Light crude oil remained; this correspond to a thickness of 1,5 µm which was not visually perceptible. One year after the beginning of the experiment, 25 to 55% of Bunker C oil remained corresponding to a visible thickness of 45 to 115 µm. The highest value corresponds to a colonized plot where the oil was masked by the algal cover, the lowest alue corresponds to a plot without any algal colonization and oil was still visible.
- Bunker C oil has significantly reduced the settlement of Barnacles and inhibited the settlement or growth of Fucoids.

It could be tempting to consider that as far as recolonisation processes take place, and they can occur as quickly as a few weeks, cleanup becomes unnecessary. This study shows however that (1) recolonisation can delay the natural cleaning of remaining oil, (2) the remaining oil can reduce the settlement of Barnacles, (3) in the *Fucus* belts, the remaining oil can delay the recovery of *Fucus* species and favor the colonization by opportunistic green algae. Therefore, for ecological and aesthetic points of view, it could be necessary to remove the stranded oil on rocky shores but, as cleanup is usually performed using hot water/high pressure washing, it can also worsen the short term impact of oil (Broman *et al.*, 1983; Houghton *et al.*, 1991; Lees *et al.*, 1993 ; Mauseth *et al.*, 1996 ; Mauseth *et al.*, 1997; Menot *et al.*, 1998) and delay the recovery (Houghton *et al.*, 1993; Houghton and Gilmour, 1995; Houghton *et al.*, 1997; Stekoll *et al.*, 1993). Therefore, the most suitable response should be to flush as soon as possible the oiled rocky shores by using low pressure/cold water jets in order to remove as much free oil as possible.

[1] Centre de Documentation de Recherche et d'Experimentations sur les Pollutions Accidentelles des Eaux

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