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IMAROS 2

Deliverable D5.1
Summary report of WP5
Shoreline Response

KYSTVERKET

Cedre

DELIVERABLE D5.1

SUMMARY REPORT OF WP5
SHORELINE RESPONSE

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FINAL REPORT

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EXECUTIVE SUMMARY

Under the IMAROS 2 project (2024–2025), Work Package 5 (WP5) focused on examining the behavior of Low Sulphur Fuel Oils (LSFOs) on shorelines and identifying appropriate response strategies. Six specific tasks, led by three project partners (Cedre, NCA, and Transport Malta), were developed to deepen the understanding of how these oils interact with various substrates and to establish practical guidelines for effective cleanup operations.

The three large LSFOs' samples tested within Work Package 3 (Tasks 3.2 and 3.3, focused on weathering) and Work Package 4 (mechanical recovery), along with a comparative heavy fuel oil, were studied both at the pilot scale and in natural environments. Rock tiles coated with a layer of oil were used to simulate contaminated bedrock. At the pilot scale, high-pressure washing procedures were tested under various pressure and temperature conditions. The effectiveness of different cleaning agents was also evaluated.

Similarly, contaminated tiles were deployed in natural environments in France and Norway. They remained in place for several months to assess, at different intervals, the natural degradation of the oils under varying hydrodynamic and climatic conditions, as well as the natural recolonisation of the rock surfaces by biota. Simplified comparative trials were also conducted in Malta.

Building on findings from the previous IMAROS project, which highlighted the potential for oil penetration into certain types of rock, polluted granite tiles were used to investigate the potential release of toxic compounds into the water. The collected water was then used as a culture medium for algae and copepods, with tests conducted to measure algal growth inhibition and copepod mortality.

Finally, the behavior of the oils in interaction with different sediment types (sand, gravel, and pebbles) was studied using a device developed at Cedre—the shoreline test bench. Concurrently, cleaning techniques were tested at NCA using a new device specifically designed for this project.

The main observations and findings from the tests conducted on rocky substrates are as follows:

- Oil penetration was observed in all rock types tested, though the extent varied depending on both the nature of the LSFO and the rock type.
- The efficiency of high-pressure washing is dependent on the type of oil and substrate.
- For thick layers of fluid oils, washing efficiency is high, even without the use of shoreline cleaning agents.
- For oils with high pour points or those that are viscous/semi-solid, washing efficiency is significantly reduced (<10%). While shoreline cleaning agents can improve efficiency, results remain unsatisfactory (<20%).
- Increasing the water temperature enhances washing efficiency (30–60%).
- Washing operations effectively remove thick oil layers, but rocks often remain stained. No significant difference in efficiency was observed between the tested LSFOs and the comparative heavy fuel oil.
- Natural cleaning processes—such as wave energy and solar radiation—contribute to completing the cleaning process, particularly in temperate and warm climates. In cold climates, although some oil removal is visible, tiles remain heavily stained even after eight months of

exposure to natural conditions. The comparative heavy fuel oil demonstrated intermediate behavior in terms of natural recovery and recolonization.

- Toxicity tests on algae and copepods did not indicate higher toxicity for the tested LSFOs compared to traditional heavy fuel oil.

The tests conducted on sand, gravel, and pebbles yielded the following key findings:

The behaviour of LSFO is highly temperature dependent, and few degrees difference may be important. To increase beach cleaning efficiency, the following techniques can be listed:

- Flushing (with increased water temperature);
- Shoreline cleaning agents;
- Tumbling (concrete mixer or excavator based screening machine, with water and/or shoreline cleaning agents and/or sorbents as bark or peat, with increased water temperature);
- Manual use of sorbents for polishing;
- “Tactical” use of surf washing (Moving oiled pebbles to the surf zone) can also be efficient, alone or together with other cleaning techniques and recovery methods.

The use of those techniques can be challenged by stickiness of the LSFOs, leading to re-contamination of pebbles due to re-attachment of LSFOs. This challenge could be mitigated with a closed cleaning station equipped with a receiving pool of high water volume.

If oily effluents are released in the sea, attention must be drawn to the skimmers efficiency (see operational guidelines for sea operations) Responders must also be prepared to potentially implement manual recovery methods (e.g. with hooves).

Main findings from this WP are summarized in the Operational Guidelines dedicated to the shoreline response (Deliverable D1.6).

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IMAROS 2: Deliverable D5.1

1 CONTEXT AND OBJECTIVES

The objectives of the Work Package 5 (WP5) of the IMAROS 2 project were to:

- identify possible gaps and solutions within shoreline clean-up methods and/or equipment;
- give operational recommendation by categorizing the different types of LSFO and associated response options;
- study the potential toxicity of LSFO absorbed in rocks on marine organisms.

In order to achieve those objectives, the WP was divided into six tasks which are described in the Table 1.

Table 1 Detail of the six tasks part of the WP5

Tasks	Partner involved / Conditions	Objectives
5.1 – Rock cleaning	Cedre / washing robot	Assess cleaning efficiency on rock tiles polluted with different LSFOs
5.2 – Efficiency of cleaning agents	NCA / washing robot	Evaluate the efficiency of cleaning agents on the rock tiles cleaning operations
5.3 – Release and toxicity of oil absorbed in rocks	Cedre / polluted tiles	Assess the potential impact of soluble compounds released by polluted tiles on the algal growth and copepods mortality
5.4 – Rock colonization by biota / Natural recovery	Cedre, NCA, TM / polluted tiles in natural environment	Evaluate the natural degradation of polluted tiles exposed to natural conditions for one year and assess the biota recolonisation
5.5 -Interaction with sediments	Cedre / shoreline test bench	Assess the behaviour of LSFOs when in contact with sediments of different granulometry and exposed to tidal cycles
5.6 – observations on practical cleaning techniques	NCA / Shoreline clean-up simulation container and other laboratory scale cleaning tests	Compare different practical cleaning techniques and observe oil behaviour

2 MATERIALS AND METHODS

The four same samples were tested in the six tasks: the three large samples IM-27, IM-28 and IM-29 detailed in the deliverable D3.1, and a heavy fuel oil for comparison.

2.1 Rock cleaning (Task 5.1)

The potential efficiency of high-pressure washers for cleaning the oil on the shoreline was assessed at the pilot scale using a device developed at Cedre, the washing robot.

2.1.1 The washing robot

The equipment (Figure 1) is composed of the following main parts:

- a stainless steel frame with an internal volume of about 300 litres;
- a trolley with the washing nozzle;
- a support frame for the polluted hard surfaces;
- two electric screw jacks allowing horizontal and vertical movements of the trolley;
- a high pressure water washer (as can be found in most of oil spill response stockpiles);
- a programmable control driving the two electric screw jacks;
- a water supply with temperature regulation.

The equipment ensures consistent washing conditions for all the successive tests (spraying width, speed and distance). The hard surfaces (granite tiles) are thus washed exactly in the same way, allowing comparative tests.

Figure 1 The washing robot

2.1.2 Hard Substrates and oil addition

The rocky shoreline was simulated by using granite tiles, dimensions 15 x 15 x 2 cm. Tiles were purchased from a local landscaper store (the granite coming from a quarry in Spain). The surface of the tiles was not smoothed down in order to recreate a substrate as natural as possible (Figure 2).

Figure 2 Granite tiles used in this experiment

It was decided to work on fresh oils and not on the weathered (emulsified) ones, because, even if the oil which reaches the coastline is emulsified, when deposited, the emulsion will break and only a layer of oil will remain on the shore.

Prior to the beginning of the experiment, the four oils tested (IM-27, IM-28, IM-29 and HFO) were placed in the oven overnight at 50°C.

Around 3 grams of each LSFO, and of the comparative heavy fuel oil, were added, thanks to a syringe, on the tiles and spread with the finger in order to cover the totality of the surface (Figure 3 and Figure 4). After oiling, all the tiles were supposed to dry in a horizontal position for 6 days before washing. Due to a mechanical failure of the washing robot in the middle of the experiment, the washing of half of the tiles was postponed and were consequently let for drying for five months.

Figure 3 Example of tile after oil addition and after spreading with the finger

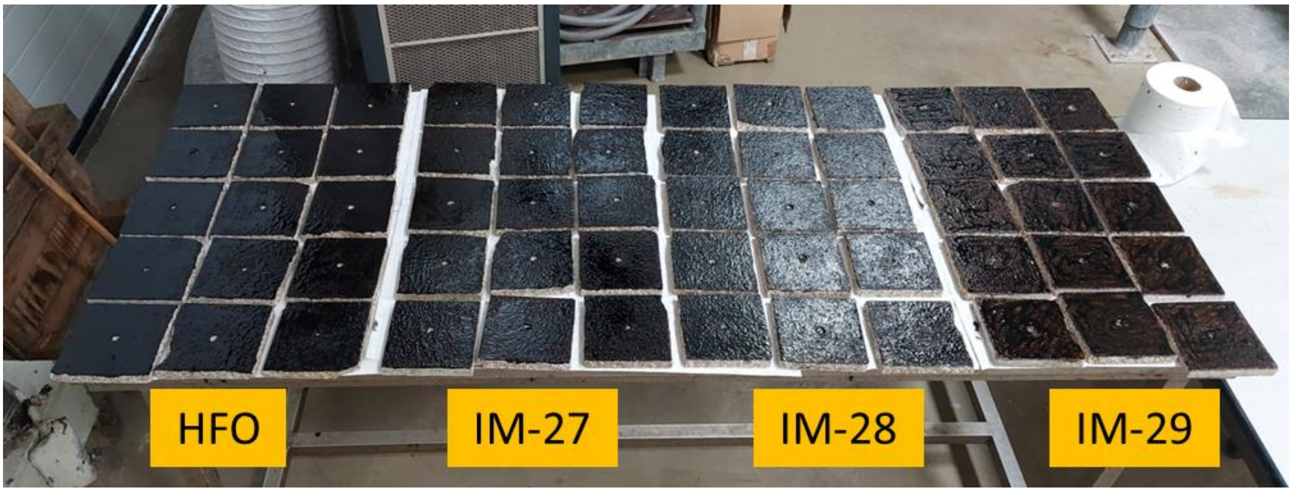


Figure 4 General view of the polluted tiles after oil spreading

The tiles were then placed in the washing robot and cleaned using tap water (Figure 5). Two conditions of temperature and pressure were studied: ambient temperature (~15°C) and 50°C, and pressure of 50 bars and 100 bars, leading to four washing experimental conditions: 15°C/50 bars, 15°C/100 bars, 50°C/50 bars and 50°C/100 bars. The strongest conditions (50°C and/or 100 bars) are used in the field to clean sites considered as not ecologically sensitive. The two conditions at 15°C (50 bars and 100 bars) were processed first, six days after the tile's pollution, following the classical protocol. The two conditions at 50°C (50 bars and 100 bars) were processed five months later, using manual high-pressure water washer as the device repair was not planned in due time. Control tiles representing polluted tiles not passed through the washing robot process were added to the test matrix. Triplicates were carried out for each condition, leading to a total of fifteen tiles for each oil. To ensure precise and repeatable washing conditions, tiles were washed three by three (triplicates of each conditions each time).

This protocol does not reproduce exactly shoreline clean-up technique as used in the field. In this study, only one water jet is used instead of multiple passages.

Figure 5 Installation of tiles in the washing robot

2.1.3 Quantification of oil remaining on tiles after cleaning

Following the cleaning process, the remaining oil was extracted by immerging the tiles (polluted face facing the crystalliser) in dichloromethane (rectapur® quality), in an ultrasonic bath for 10 minutes in order to remove the totality of the oil adsorbed on the tiles surface. After drying on sodium sulphate (activated at 400°C overnight) (Figure 6) the mass of recovered oil was measured by gravimetry after complete evaporation of the solvent.

This extraction step is time consuming. The tiles washed at 15°C (50 bars and 100 bars) were processed in a period between 1.5 and 2.5 months after tiles oiling. The tiles washed at 50°C (50 bars and 100 bars) were processed 5 months after the tiles oiling.

Extracted oil from those tiles allowed the calculation of the cleaning efficiency. This rate corresponds to the amount of oil extracted after the washing robot cleaning step divided by the amount of oil extracted from the control tiles. For each condition of washing, tests were performed in triplicates.

Figure 6 Oil extraction in dichloromethane and drying over sodium sulphate

- Results from Task 5.1 are presented in section 3.1 and Appendix 1.

2.2 Efficiency of cleaning agents (Task 5.2)

The objective of this task, performed by SINTEF (Norway), was to study the effectiveness of different shoreline cleaning agents on oil contaminated bedrock, using flushing as a countermeasure. Slate tiles were used. Flushing was performed using the Flushing Robot, an equivalent device to the Washing Robot at Cedre.

Three fresh low sulphur fuel oils (IM-27, IM-28 and IM-29) were used and the effectiveness of the two shoreline cleaning agents Aqua Delta (SCA 1) and Cytoclean (SCA 2) were tested. The effectiveness of flushing was studied with and without using shoreline cleaning agents (SCA).

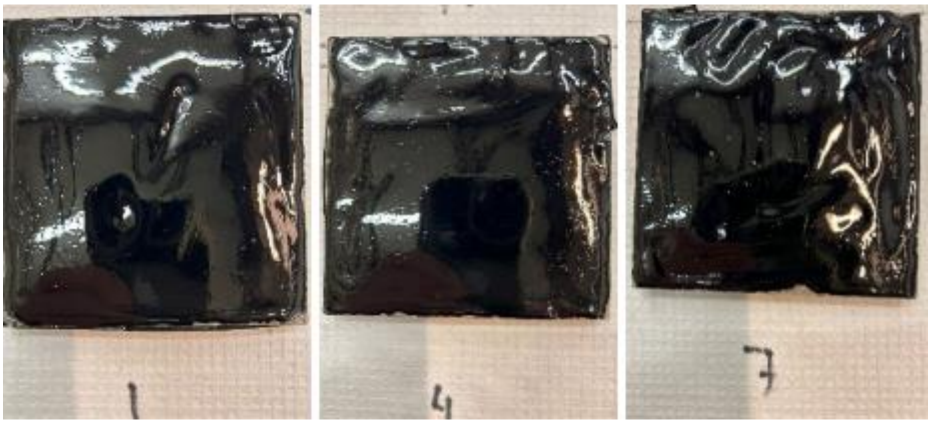
All the tests were performed in triplicates, at a test temperature of 15°C with a water flushing pressure of 50 bars.

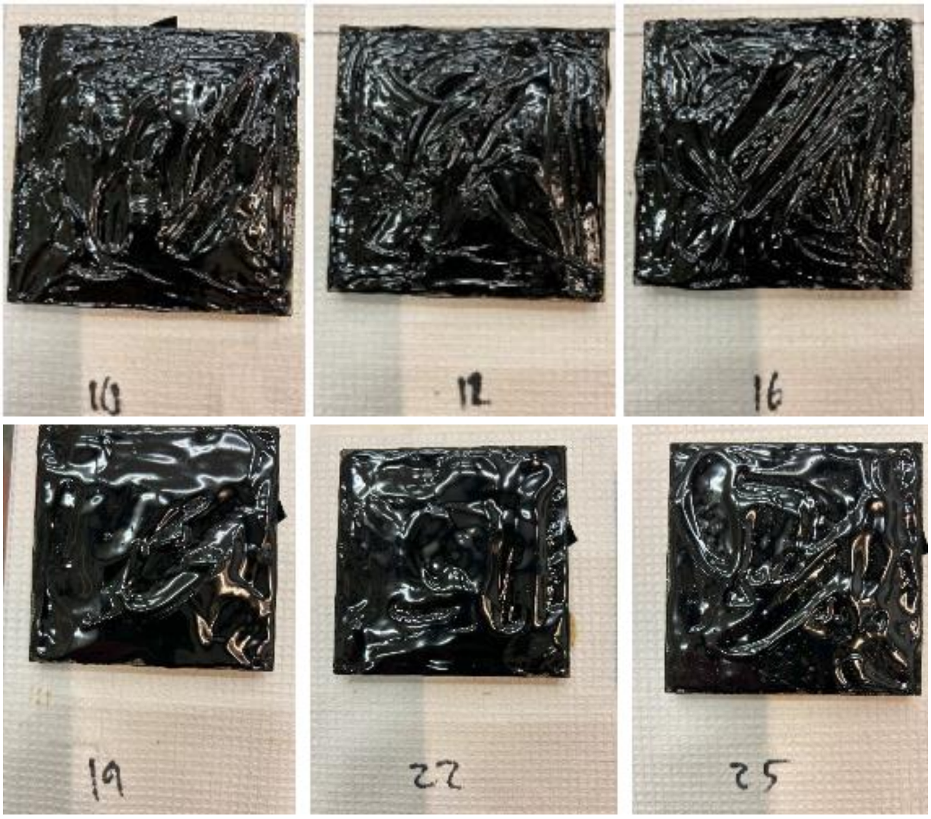
2.2.1 Tiles pollution

The edges of the slate tiles were masked with tape to avoid quantification of oil covering the edges. The tiles were also tempered to the study temperature of 15 °C before use. As a standard, 10 g +/- 0.25 g of weathered oil was applied to the bedrock tiles measuring 10 x 10 cm, representing an oil film thickness of 1 mm. The tiles were then stored horizontally in a temperature-controlled room at the test temperature of 15 °C for 1 day to let the oil settle and cover the tile evenly.

2.2.2 Addition of cleaning agents

The shoreline cleaning agents (SCA) were applied using a pipette, at an Agent to Oil (AoR) ratio of 1:5. The agent was then allowed to soak for 20 minutes before the tiles were mounted on the steel rack for flushing treatment. The tiles appearance before flushing is shown in Figure 7.

a) IM-27 



b) IM-28

c) IM-29

Figure 7 Tiles aspect before flushing. For each oil, the following treatment was applied: left: SCA1, middle: SCA 2, right: no SCA.

2.2.3 Flushing conditions

A flushing pressure of 50 bars, serving approximately 10 litres per minute at a water temperature of 9 °C (cold tap water), was applied.
After exposure, the tiles were placed horizontally at the test temperature for one day to dry off the last remains of water, before quantifying the remaining oil on the tiles gravimetrically. The tape on the edges was removed before quantification. The tiles were photo documented before and after exposure.
In addition, higher water flushing temperature (25 °C) was applied in extra tests using Aqua Delta on IM-27 and IM-28.
The effectiveness is given in percentage, and represents the oil removed during flushing, compared with the initial oil applied on the tile surface.

- Results from Task 5.2 are presented in section 3.2 and Appendix 2.

2.3 Release and toxicity of oil absorbed in rocks (Task 5.3)

The objective of this task, performed at Cedre, was to evaluate whether oil trapped in rocks by absorption could be released in seawater and induce an inhibition of algal growth and/or a mortality of copepods. Results from the different tests were compared one to each other and with a control (organisms exposed to the culturing media which as not be in contact with oil) to evaluate any impact of released soluble compounds, from the rocks to the seawater, on the organisms. Those tests, performed with a very limited volume of water, do not mimic natural exposition of marine organisms to polluted rocky substrates. They allow comparing the relative toxicity of different LSFOs with a traditional HFO and the effect of cleaning operations on the release of PAHs from rocks.

2.3.1 Pollution of tiles

Granite tiles identical to the ones used in the Task 5.1 (Rock cleaning, see Figure 2) were used to simulate the rocky shoreline. IM-27, IM-28, IM-29 and the comparative heavy fuel oil were added at the surface of two tiles each, following the same protocol as the one described in section 2.1.2, leading to eight polluted tiles. For each oil tested, one of the two tiles was washed with the high-pressure washer, at 50°C and 100 bar (Figure 8). It should be noted that different degrees of penetration for IM-29 in the two tiles used. The tile not cleaned with the high-pressure washer exhibited a much higher penetration.

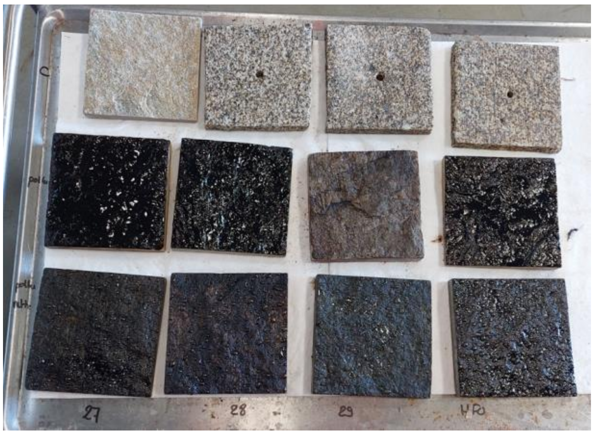


Figure 8 Pollution of the eight tiles used for ecotoxicology tests, after cleaning with the high-pressure washer of one of the two tiles per oil (bottom line) (note: the tile used with IM-29 that was not high-pressure washed shows a high degree of penetration)

The tiles polluted but not cleaned with the high-pressure washer were immerged in a tap water tank for three days to allow oil in excess to be released. One control tile (tile not polluted) was also tested to study its potential impact on the organisms.

2.3.2 Preparation of the test solutions

The nine tiles (one control tile not polluted, four polluted tiles and four polluted and cleaned tiles) were placed in individual crystallisers with 1.2 L of filtered seawater (0.45 µm). The water was gently mixed for 24 hours in the dark (by covering the cristallisers with a carboard) in order to release soluble compounds. The resulting water accommodated fractions "WAFs" (i.e. soluble fraction) were then collected, by taking care to place a sorbent sheet on the water surface to capture residual oil sheen.

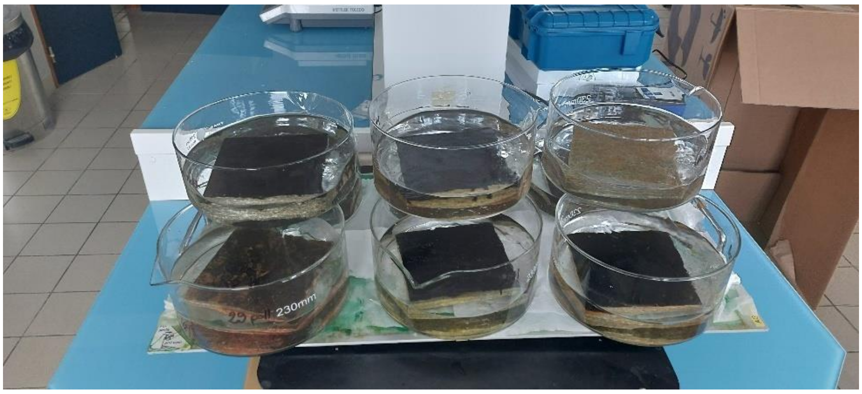


Figure 9 Adapted "WAFs" preparation

Nutrients and silica solutions were then added to these "WAFs". PAHs concentrations were determined by SBSE-TD-GC/MS analyses.

In summary, algae were exposed to a total of four "WAF" solutions coming from each polluted tiles (IM-27, IM-28, IM-29 and HFO) and four "WAF" solutions coming from each polluted and cleaned tiles (IM-27, IM-28, IM-29 and HFO). Algae were also exposed to a "WAF" solution coming from an unpolluted tile.

2.3.3 Ecotoxicity tests on algae

The tests were adapted from the ISO 10253: 2016 standard (Marine algal growth inhibition test with *Skeletonema costatum* and *Phaeodactylum tricornatum).*

An algal kit (Algaltoxkit) containing the test species *Phaeodactylum tricornatum* was used for the trials. Test organisms are incorporated in the kits in a "resting" or "immobilized" form, from which they can be activated "on demand" prior to the performance of the toxicity test. The transfer of the algal inoculum in an adequate growth medium reactivates the microalgae leading, within three days, to a culture in the exponential growth phase ready for the bioassay.

The nine "WAFs" were exposed to the algae at ~1.10^4 cell/mL. Controls containing only algal culturing medium and algae were prepared in triplicate.

Finally, a reference/positive test was also carried out with potassium dichromate ($K_2Cr_2O_7$) in triplicate. A dilution series was prepared for this reference test, with $K_2Cr_2O_7$ concentration ranging from 3.2 to 31.7 mg/L.

Algae were incubated for three days in an incubator at 20°C (+/- 2 °C) with a constant uniform illumination supplied by cool white fluorescent lamps (10 000 Lux sideway illumination).

Optical density (OD at 670 nm) was used to measure the biomass evolution, and consequently to calculate the algal growth inhibition, with measurements every 24 hours. The tests were performed in disposable spectrophotometric cells of 10 cm path-length ("long cells") as test vials, which allows direct and rapid scoring of the OD in any spectrophotometer equipped with a holder for 10 cm cells.

Optical density measurements of the algal suspensions at 670 nm wavelength in 10 cm long cells correlate very well with algal numbers and are hence in accordance with the prescription of ISO Guideline 10253 and other standard methods for the determination of algal densities.

Figure 10 Incubation of the algae

For a test to be considered valid, the following criteria should be met:

- The average growth rate in the control replicates shall be at least 1.4 d^{-1}. This growth rate corresponds to an increase in cell density by a factor of 67 in 72 h.
- The variation coefficient of the growth rate in the control replicates shall not exceed 5 %.

Algal growth calculated from the different conditions tested were compared to evaluate any impact of potential soluble compounds, from the rocks to the seawater, on the algal growth rate. The Regtox software for automatic data treatment was used to determine the EC_{50} for the test using the reference toxicant $K_2Cr_2O_7$.This allows ensuring algal growth rate is affected by a noxious chemical substance.

- Results from Task 5.3 (algae) are presented in section 3.3.1. and Appendices 3.

2.3.4 Ecotoxicity tests on copepods

Steps described in 2.3.1 and 2.3.2 were repeated for the ecotoxicity tests on copepods.

The study was conducted with the marine copepod *Acartia tonsa.* The procedure was adapted from the ISO 14669: 2003 standard (Determination of acute lethal toxicity to marine copepods).

The marine copepods *Acartia tonsa* were used in this test. The copepods were obtained from the Aquarium Oceanopolis in Brest, few days before the experiments, and were kept in acclimatisation tanks at 20°C until the beginning of the trials. They were fed with mixed algae diet until 24 hours before the experimentation.
3,5-Dichlorophenol (CAS: 591-35-5) at 1.0 $mg.L^{-1}$ was used as positive noxious substance. Filtered seawater (0.45 µm) was used as control.

5 mL solutions (seawater spiked or not with the reference and the test substances) were incubated in 6 mL flasks, with 4 replicates for each condition and 12 replicates for the blank (Figure 11). Five copepods were randomly distributed to each test vessel.

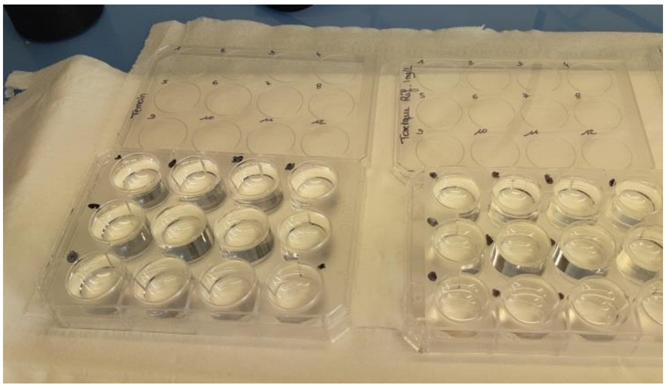


Figure 11 Preparation of the control and the positive substance flasks

Tests were run under continuous light from fluorescent tubes of universal natural white type, at a temperature of 20°C ± 2 °C. The copepods were then exposed to the tested substances for a period of 48 hours. Mortalities were recorded at 24 and 48 hours.

A test can be considered acceptable if the following conditions are fulfilled:
- The oxygen saturation at the end of the test should be ≥ 4 $mg.L^{-1}$;
- The mortality rate observed in the blanks should be ≤ 10 %;
- The toxicity of the reference substance (3,5-dichlorophenol) should be in an acceptable range, the mortality being between 20% and 80%.

In those adapted tests, the oxygen saturation was not followed due to insufficient volumes of water in the flasks.

Copepod's mortality, calculated from the different conditions tested, were compared in order to evaluate any impact of potential soluble compounds released from the rocks.

- Results from Task 5.3 (copepods) are presented in section 3.3.2 and Appendices 4.

2.4 Natural recovery and rock colonization by biota (Task 5.4)

The objectives of these trials were to evaluate the significance of the natural remobilisation of LSFOs from rocky shores, in various environmental conditions, as well as the colonisation of those substrates by biota. Three experimental sites, characterised by different environmental conditions, were selected: the North of Norway, the western part of France, and Malta.
Rocks were covered by a thin oil layer and installed on the experimental sites for natural weathering. Over time, rocks were regularly subsampled for analysis of residual oil and survey of biological recolonisation.

2.4.1 Description of the experimental set-up

2.4.1.1 France and Norway

The same protocol was applied in France and Norway. An adapted protocol, but following the same main steps, was applied in Malta.
Norway used slate tiles and France granite ones. Tiles of 15 x 15 x 2 cm were purchased, respectively from a local distributor in Norway (with local origin of the rock from a quarry in Alta) and a local landscaper store (with origin of the granite from a quarry in Spain) (Figure 12).

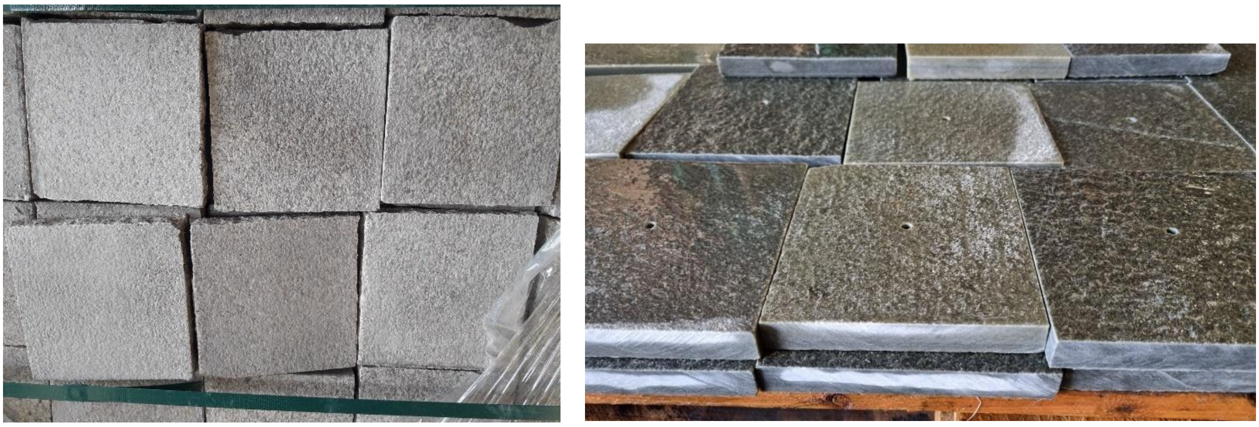


Figure 12 Receipt of the tiles respectively at Cedre (left) and NCA (right)

Three grams of the LSFOs IM-27, IM-28, IM-29 and of the heavy fuel oil, previously heated the night before, were added to the tiles surface thanks to a weighted syringe. Oils were then spread with the finger (with gloves), trying to be as consistent as possible from one tile to the other (Figure 13).

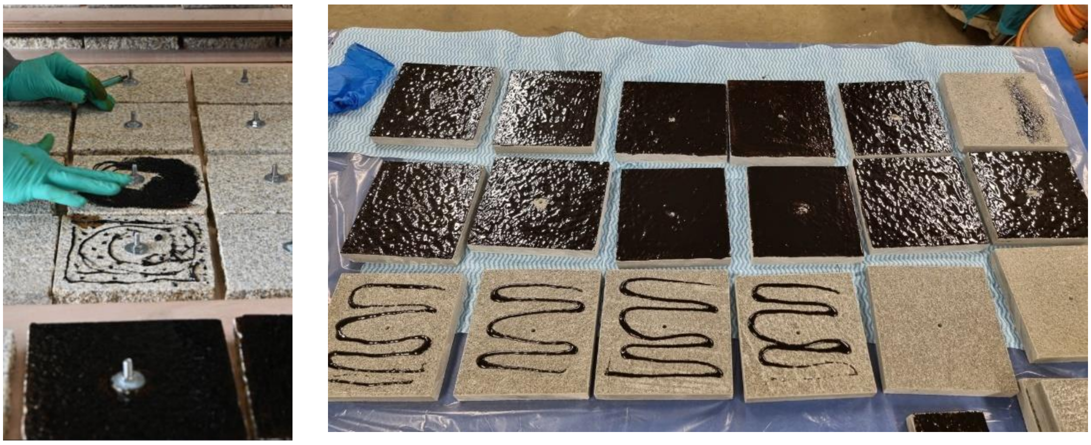


Figure 13 Addition of 3 grams of oil on the tiles at Cedre (left) and NCA (right)

Tiles, fixed on wooden frames, were then let horizontally for ~60 hours in order to allow spreading process and then vertically for 96 hours to ensure oil flow and the removal of excess oil, as well as drying. Tiles were then immerged in a water basin for ~24h in order to allow light weathering (recovery of sheen). Once the tiles were removed from the basin, three of them per oil tested were picked up for T_0 measurement in triplicate. Each of those tiles was fully wrapped with a sheet of aluminium foil, carefully labelled, and placed in a freezer (-20°C) until analyses. Cleaned tiles were also added to the wooden frames and served as control tiles.

Wooden frames were then installed on the experimental sites for several months (section 2.4.2) and tiles were collected at different time steps. Initial similar theoretical time steps were planned between the two sites but some changes occurred due to weather conditions and accessibility to the experimental sites (Table 2 and Table 3).

Table 2 Tile's sampling time steps in France

Time Step	T1	T2	T3	T4	T5	T6
Exposure time	+ 15 days	+ 1 month	+ 3 months	+ 6 months	+ 9 months	+ 11 months

Table 3 Tile's sampling time steps in Norway

Time Step	T1	T2	T3	T4	T5
Exposure time	+ 15 days	+ 1 month	+ 4 months	+ 6 months	+ 8 months

At each time step, three tiles of each oil tested were subsampled. Triplicates of control tiles (tiles not recovered with oil) were collected once recolonisation by biota started. Each sampled tile was fully wrapped with a sheet of aluminium foil, labelled, and stored in a freezer (-20°C) until analyses.

2.4.1.2 Malta

As no mass production of tiles representing Maltese coastline was identified, it was decided to use rock samples obtained from quarries and construction sites (Figure 14). The two predominant rocks representing the Maltese coastline were used: Globigerina limestone and Upper coralline limestone (Figure 19).

Due to negligible tides in Malta and to the fact that each tile should be alternatively below and above the water surface, only two lines of rocks were fixed on the wooden frames. Duplicates of each oil were added on the two rock types. This constrained the number of rocks that could be monitored during the trials as the available linear on the quay was limited. Consequently, no time steps for rock subsampling were performed. Trials consisted in visual observations and on comparison of the initial and final states.

Figure 14 Rocks selected to perform the trials in Malta

Three grams of the same oils tested in Norway and in France (IM-27, IM-28, IM-29 and HFO) were added and spread on the top of the rocks (Figure 15). Each oil was spread on the two natures of rock.

Figure 15 Addition of oil on the rocks used for the trials in Malta

After oil addition, plywood frames were let for drying horizontally for 60 hours and then vertically for 96 hours. Plywood frames were then immerged in a freshwater basin for 48 hours, before installation on the experimental site (Figure 16).

Figure 16 Wooden frames supporting the rocks recovered with the studied oils

Changes based on visual observation of natural degradation and biota colonisation were recorded over the course of the experiment, and at the end of the survey, rocks were sent to Cedre for qualitative chemical analyses (section 2.4.4.2).

2.4.2 Description of the experimental sites

Three sites were chosen for those experiments, in France, Norway and Malta.

2.4.2.1 Experiment in France

Experiment took place on the two faces of a quay located on the French Island "Ile des Morts" (South-West part of the Bay of Brest, Brittany, France). This island is a military site and public access is prohibited. These trials were made possible thanks to the support of the Ceppol[1], who enabled us to obtain the necessary authorisations. Similar trials already occurred at the same location in 2001 – 2004[2]. The Northern side of the quay is exposed to the long swell entering in the Bay. The Southern side of the quay is much more sheltered than the North side. It is also more exposed to solar radiation.
Wooden frames supporting the granite tiles were attached at a height allowing water covering twice a day (Figure 17).

[1] centre of practical expertise in pollution response of the French navy

[2] Jézéquel, 2005 : « Pollution d'un littoral par fiouls lourds : Etude de l'influence des paramètres environnementaux sur la persistance et l'évolution chimique du polluant », thèse de doctorat de l'Université de Bretagne Occidentale

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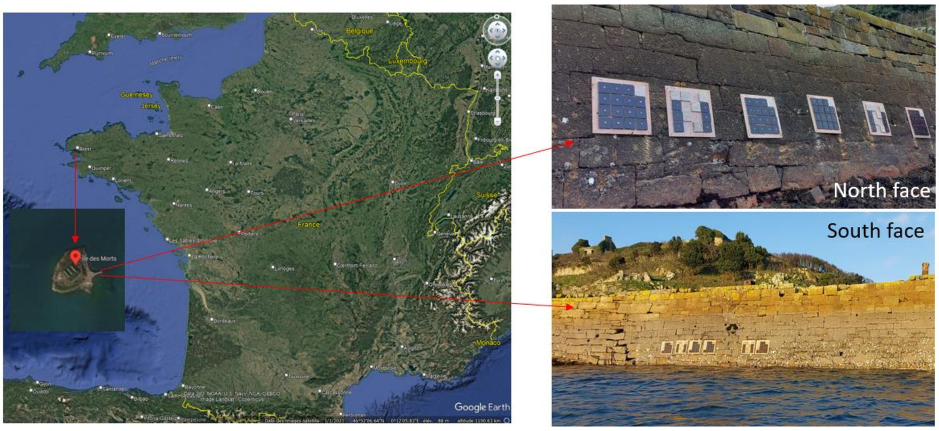


Figure 17 Location of the experimental site on the French Island "Ile des Morts"

2.4.2.2 Experiment in the North of Norway

Experiment took place on a private quay of the Port of Tromsø (Northern part of Norway). Wooden frames supporting the slate tiles were attached at a height allowing water covering twice a day (Figure 18).

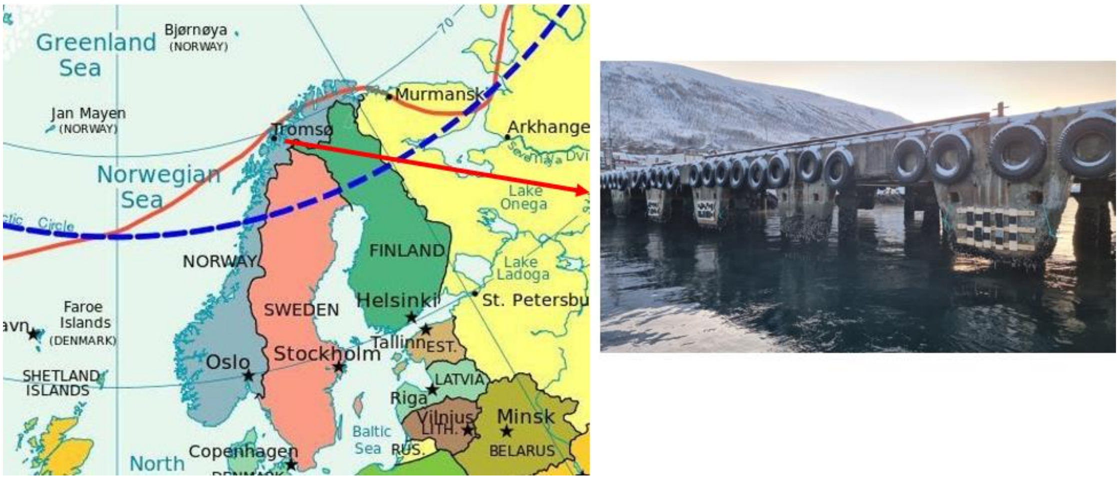


Figure 18 Location of the experimental site in North of Norway

2.4.2.3 Experiment in Malta

Experiment took place on a quay of the port of Valletta in Malta (Figure 19). The wooden frames were secured by ropes so that they can be adjusted according to the level of the sea as the tide in Malta is negligible. To do so, each rock is in and out the water every day.

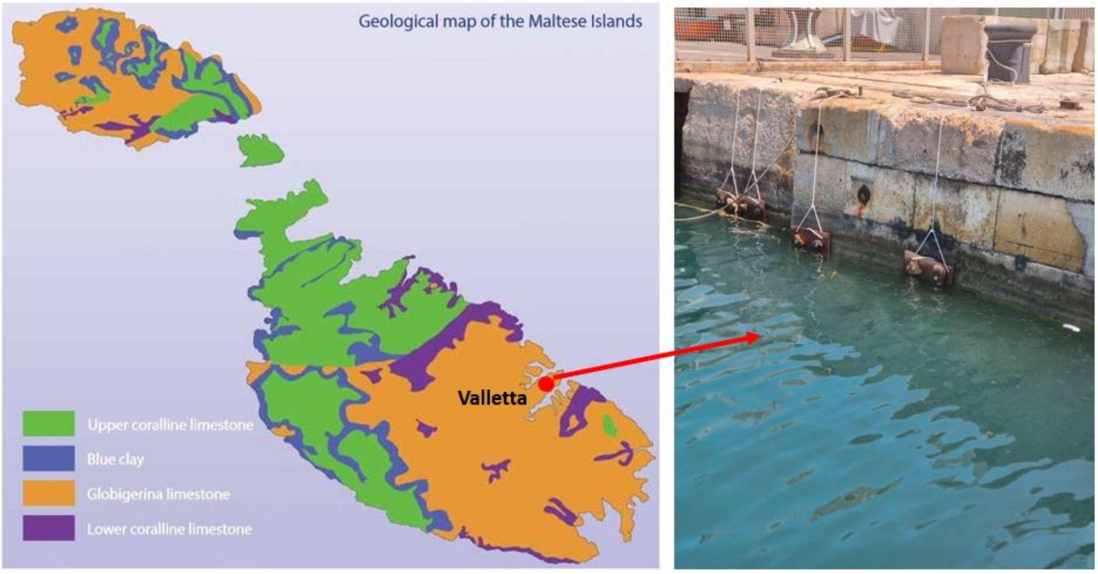


Figure 19 Location of the experimental site in Malta

2.4.3 Monitoring of living organisms

The main organisms developing on the rocky shores of France and Norway are barnacles. Monitoring and counting of living organisms was thus performed on this organism (Figure 20).

Barnacles are small crustaceans (*phylum arthropoda*) surrounded by hard calcareous shells and fixed on different types of substrates such as rocks, quay pillar or ship hull.

Figure 20 Juvenile Elminius modestus on a granite tile coming from the French site in April 2025

The upper orifice is closed by two mobile plates at the centre of which the animal is fixed on its back, which is made up of a mass of tissue and organs enclosed in a limestone structure from which six pairs of thoracic legs emerge, used for sensory perception, nutrition and reproduction. Some species reproduce throughout the year, while others peak in July and August. Barnacles can be distinguished by the shape of their calcareous plates and their size, which generally varies from 4 mm to 2 cm (Jézéquel, 2005).

The fertilized eggs hatch in early spring and the nauplii larvae are released into the water masses. The larvae swim freely in the water (as plankton), and depend on phytoplankton to grow. When they have grown big enough, they will settle down by attach themselves by the shoreline and become barnacles. The rate of development of the eggs appears to be temperature dependent, particularly in the first period (Jézéquel., 2005).

The choice of attachment sites varies from species to species and depends on a number of environmental parameters such as light, depth, substrate roughness and exposure to waves and currents. The substrate chosen is always rough, not too sunny and swept by waves. The crevices in the substrate are preferred.

During the experiment, in addition to the polluted tiles, unpolluted tiles were placed on the experimental site. They enable comparison of biota colonisation with polluted tiles.

Before extracting the oil persisting on the tiles, the density of colonising organisms was assessed using a method adapted from Lewis (1964)[3] and Thompson *et al*. (1996)[4], which consisted of counting the number of barnacles present in 10 squares of 1 cm^2 distributed randomly over the surface of each tile (Figure 21).

Figure 21 Frame used to evaluate the number of barnacles

Colonisation by algae and/or organisms was also assessed on the rocks exposed to the Mediterranean conditions.

2.4.4 Chemical analyses

Tiles from the Norwegian and Maltese experiments were shipped to Cedre where all the chemical analyses were performed.

[3] Lewis, J.R., 1964 : « the ecology of rocky shores », The English Universities Press LTD, Londonn, p.323.

[4] Thompson, R.C, Wilson, B.J ., Tobin, A.S., Hawkins,S.J. 1996 : « Biologically generated habitat provision and diversity of rocky shore orgnaisms at a hierarchy of special scales », J. Exp. Mar. Biol. Ecol., Vol.202, p.73-84.

2.4.4.1 Oil quantification

In order to study the natural removal of oil in the real environment, the residual oil on each tile was extracted and quantified following the same protocol as the one described in section 2.1.3.

2.4.4.2 Oil composition

Chemical composition of the oils collected on the tiles at each time step were analysed with Gas Chromatography coupled to Mass Spectrometry detection (GC/MS).

Determination of the four families Saturates, Aromatics, Resins and Asphaltenes (SARA) was performed on the fresh oils and on the final time step.

For each time step, alkanes and PAH were quantified in hopane unit, with GC-MS.

Detailed protocols are described in Appendix 1 of the Deliverable D3.1.

- Results from Task 5.4 are presented in section 3.4 and Appendices 5, 6 and 7.

2.5 Interaction with sediments (Task 5.5)

A series of qualitative tests were performed to assess the oil adhesion on different substrates. Tests were conducted at Cedre with the shoreline test bench (Figure 22).
This equipment is composed of an oscillating table comprising twelve tanks (40 cm long, 20 cm wide, 30 cm high) equipped with a pneumatic cylinder to recreate different hydrodynamic conditions. The table's movements are set to create a water surface agitation. The tidal simulation system is composed of a stationary tidal water distribution pipe and a mobile water collection pipe. The mobile pipe is mounted on a pneumatic cylinder supplied by a compressed air system *via* a solenoid valve. During those trials, the swing between low and high tide was manually operated due to a mechanical failure to fill the tanks with the same water output. A simplified tidal cycle was applied: High tide was set up in the morning (~10 am) and low tide in the evening (~5 pm). Sand-filtered natural sea water (taken from the bay of Brest) was used to fill the tank.

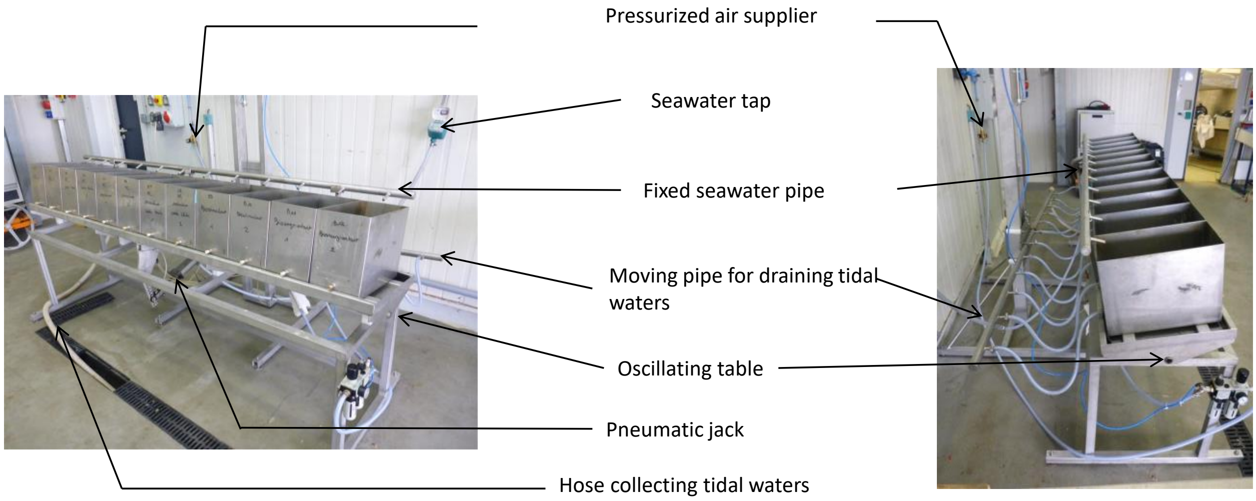


Figure 22 The Shoreline Test Bench

The adhesion of oil on sediments was assessed on the fresh LSFOs IM-27, IM-28 and IM-29 and on the comparative heavy fuel oil. Three types of sediments, characterized by different granulometry, were studied (Figure 23):

- Rocky sediment: granulometry 50/70
- Cobble sediment: granulometry 2/10
- Sandy sediment: granulometry 0/2

Figure 23 sediments used in IMAROS 2 trials

Around 2.4 kg of sand and gravel and 5.5 kg of pebbles were poured in the tanks and approximately 400 g of oil previously heated at 50°C were added to the sediments, following two conditions: oil deposited on wet sediment and oil deposited on dry sediment. The goal was to simulate a spill occurring close to the shoreline, with the oil arriving fresh on the coast. Two tanks for each type of sediment were used for the condition “oil deposited on wet sediment”, one tank per sediment for condition “oil deposited on dry sediment”. The tidal cycle was then activated.

Trials were performed in June 2025, with an air and water temperatures of 20-25°C.

The assessment of the oil stickiness/penetration to the sediments was performed before and after each tidal swing, during 4 days.

- Results from Task 5.5 are presented in section 3.5 and Appendix 8.

2.6 Observations on practical cleaning techniques (Task 5.6)

The task consisted of different small-scale tests, a main test in a beach cleaning container and a test of cleaning of weathered oil. The small-scale tests were conducted to get a first impression on how the oils would behave, also based on earlier experiences with heavy fuel oils. The small-scale tests were also conducted to determine if it was necessary to adjust the conditions and test procedure for the main container test.

2.6.1 Small-scale tests

2.6.1.1 Small-scale test 1 and 2 – frozen surroundings

At the onset of the Godafoss oil spill in Norwegian waters in February 2011, ambient air temperatures ranged from -22 °C to -3 °C. Sea surface temperatures were close to 0 °C, with visible ice present on the water. The spilled substance was a heavy fuel oil (IFO380).

During the initial response, it was observed that the oil largely drifted past the shoreline with minimal beaching. In areas where oil did strand, it could be manually removed from smooth rock surfaces by rolling it off, often leaving the rock completely clean. This behaviour was consistently noted as long as air temperatures remained below approximately -3 – -4 °C. Based on these observations, the assessments were:

The shoreline likely had a thin ice layer that prevented the oil from adhering to the surface, resulting in immediate remobilization of the oil back into the water.
In cases where oil did strand, it is probable that a thin icy layer existed between the oil and the bedrock. This layer may have been present prior to stranding or may have formed as a result of the emulsion within the oil freezing upon contact with the cold surface, effectively creating a barrier that limited adhesion.
Based on the observations during the Godafoss incident, we wanted to study how oil interacts with sediments in cold climates. Specifically, we aimed to investigate:

- How frozen sediments influence the adhesion of oil to rock surfaces.
- The effectiveness of oil removal from frozen substrates.
- Whether there are observable differences in oil behaviour between dry and wet rock surfaces under cold conditions.

The rock used in the test was quite smooth pebbles (river stones) with a diameter of 3-5 cm (Figure 24). They were not flat, as you might observe on beaches in the Mediterranean.

Figure 24 Smooth pebbles (3-5 cm) used in the small-scale tests

- **Small-scale test 1 (Dry frozen rocks):** 4 small plastic containers, each containing 5 dry rocks (pebbles) where frozen down to -18°C for 24 hours. The rocks were then covered with oil and frozen once again. Different cleaning techniques were applied as described below (table 1).
- **Small-scale test 2 (frozen wet rocks):** 4 small plastic containers, each containing 5 rocks (pebbles) that were dipped in water, where frozen down to -18°C for 24 hours to create a thin ice layer. The rocks were then covered with oil and frozen once again. The same cleaning techniques were applied as in test 1, described below (table 1).

All rocks were weighed before cleaning started.

Cleaning methods were applied step by step according to table 1, see also Figure 25.

Table 4 Techniques applied in small-scale tests

Step 1 (rock 1)	"Pull" off the oil by hand, if possible, alternatively scrape it off with a wooden spatula
Step 2 (rock 2)	Rub/polish with oil bark by hand
Step 3 (rock 3)	Lower the rock in 25°C water bath. Observe for 5 mins
Step 4 (rock 3)	Wash the rock in the 25°C water bath (if needed)
Step 5 (rock 3)	Scrub the rock in the 25°C water bath with a toothbrush (if needed)

The rocks were then put into small glasses of diesel for 3 weeks, in order to remove any (potential) remaining oil on the rocks before control weighing.

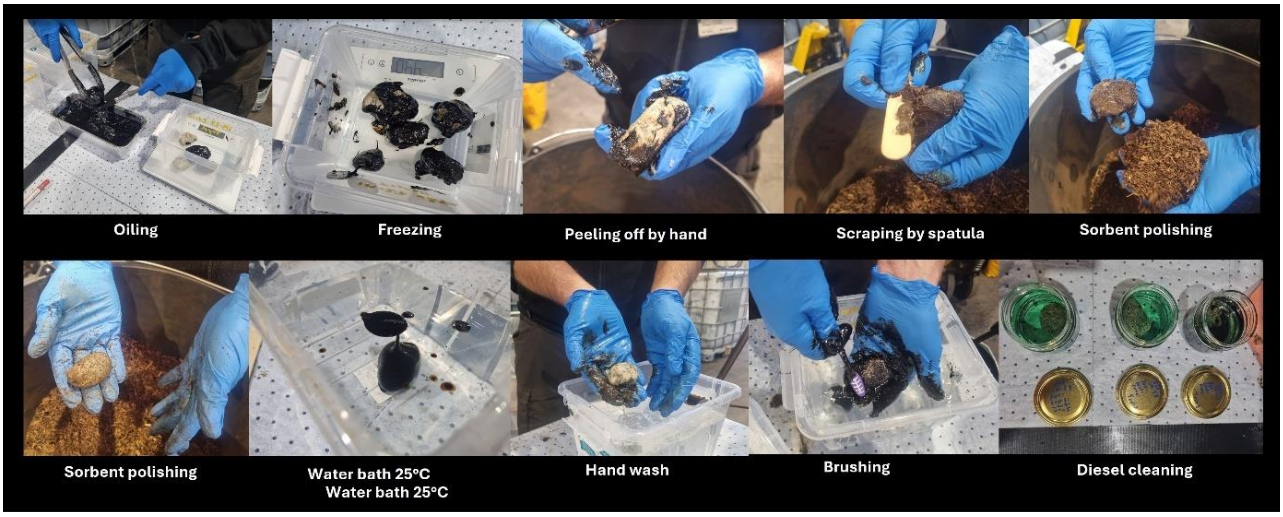


Figure 25: Illustration of applied cleaning techniques.

2.6.1.2 Small-scale test 3 – water baths

The primary objective of this test was to determine the temperature threshold at which oil begins to detach from pebbles without the application of external energy. This insight was intended to inform expectations for upcoming tests and to establish appropriate temperature parameters for future experiments.

The test was conducted using smooth river stones (pebbles) with diameters ranging from 3 to 5 cm (Figure 24).

Following initial WP4 skimmer tests, observations from small-scale tests 1 and 2, and prior experience with various IFO bunker oils, we developed hypotheses regarding the behaviour of the three LSFO test oils. To evaluate these, oiled pebbles were submerged in seawater at different temperatures to observe oil release characteristics. The expectations were as follows:

- **IM-27**: Anticipated to "melt" at relatively low temperatures (>25°C), releasing from the stones in warm water. Its lower "shorter" compared to IFO bunker oil suggested easier removal.
- **IM-28**: Expected to be less adhesive than IFO bunker oil, but more challenging to remove than IM-27 and IM-29. It was hypothesized that IM-28 might require temperatures of 40°C or higher for effective release.
- **IM-29**: As an emulsion with a "short" consistency, it was expected to be the easiest to remove, potentially releasing at temperatures below 20°C.

Four boxes were prepared for each oil type, each containing 20 pebbles and approximately 200 g of oil. After oil application, around 1.5 liters of seawater was added to each box. The initial water temperature was approximately 10°C (Figure 26).

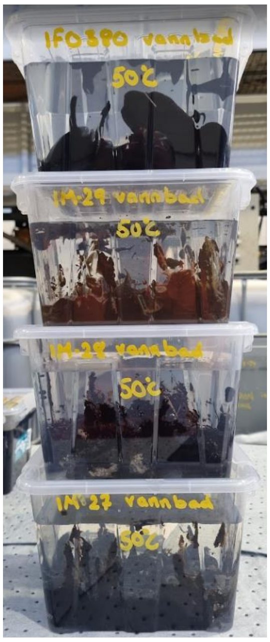


Figure 26: Boxes with pebbles for small scale test 3.

The boxes were then stored under the following conditions:

- One box per oil type at 5°C (refrigerated)
- One box per oil type at room temperature (~15°C)
- One box per oil type in a heating cabinet set to 25°C
- One box per oil type in a heating cabinet set to 50°C (actual measured temperature: 42–44°C)

All boxes were weighed prior to testing to quantify the combined weight of rocks and oil. After approximately 24 hours, the water and any floating (released) oil were decanted, and the boxes were reweighed to determine the amount of oil removed from the pebbles.

2.6.1.3 Small-scale test 4 – concrete mixer

The same type of rocks was used in this test; smooth river pebbles with diameters ranging from 3 to 5 cm. Approximately 20 kg of pebbles were placed into a concrete mixer, followed by the application of liquid oil at a temperature of 24–25°C. The mixer was run briefly to ensure even distribution of the oil across the stone surfaces. The mixture was then allowed to cool to ambient temperature (16–18.5°C) for approximately 30 minutes. Only the three LSFO test oils were used in this procedure. Water was added to fully submerge the pebbles, and the mixer was operated for about two minutes. Water temperature varied depending on the oil type being tested and was based on the findings from the small-scale tests 1, 2 and 3.

Following the tumbling process, the contents were transferred to a large mason bucket. Floating oil was skimmed from the surface, residual water was removed, and the bucket containing wet stones was weighed. The stones were then left to dry for a final control weighing. The procedure is illustrated in Figure 27.

The control weighing revealed a reduction in mass. This was attributed to the presence of sand remnants in the original stone mixture, which was washed out during mixing, as well as the loss of small stone fragments due to mechanical impact. As a result, weighing was deemed unreliable as a control measure for subsequent concrete mixer tests. Visual inspection was instead adopted as the primary method for evaluating cleaning effectiveness.

Figure 27: Small-scale test 4 - oiling and tumbling of pebbles in a concrete mixer.

2.6.2 Container test

This test was conducted in a container produced for the purpose of beach cleaning tests and training (Figure 28). IM-27, IM-28 and IM-29 and a IFO380 reference sample were tested at 3 different water temperatures: 15°C, 20°C and 25°C.

The container can be equipped with artificial shoreline in both ends. In this test set-up, only one of the of the sides was prepared, leaving the other side with a water table of approximately 70 cm of water. The waterside of the beach can be hoisted or lowered to keep the lowest rock submerged.

The beach frame consists of eight fenced in sections. Three different beach types were prepared (Figure 29):

- Pebbles (3-9 cm diameter) ;
- Smooth rock slopes (bedrock) made of flagstones (40*40 cm granite) ;
- Cobbles (6-20 cm diameter).

*Figure 28: Container (12*2,5*2,5m) produced for the purpose of beach cleaning tests and training. Size in accordance with transport rules and prepared for trailer transport if needed.*

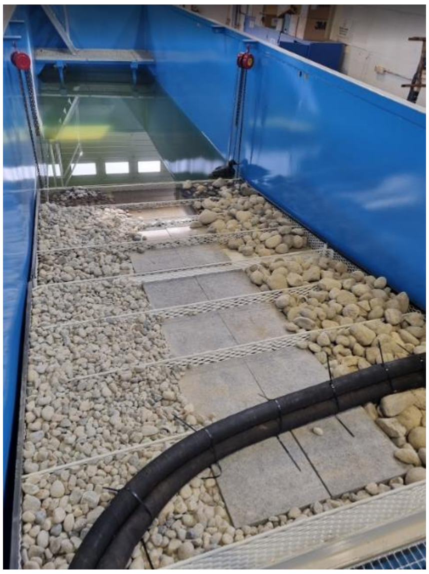


Figure 29: Different types of shorelines

A flooding system with a pierced through hose was installed in the upper part of the beach.
All surfaces except the rocks are painted metal plates or grid. This means that added oil and water must flow “through” the beach and into the water at the lower end of the beach. Water temperature inside the container is controlled with a diesel driven heater system. The tests were conducted in the period 25-28.03.2025 and 31.03-02.04.2025.
After application of oil (Figure 30), the following methods were used:

- Step 1: 30 mins flooding (Figure 31)
- Step 2: high pressure washing with firehose (Figure 32)

If no or little effect:

- Step 3: Polishing with sorbents (bark) (Figure 33)
- Step 4: Shoreline cleaning agent Aqua delta (Figure 34)

Figure 35 illustrates the condition after cleaning.

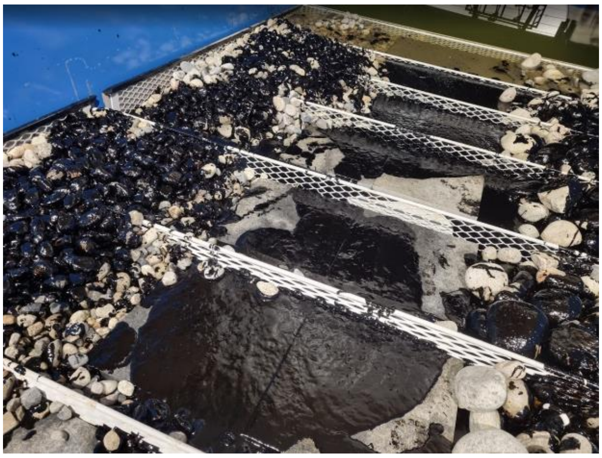


Figure 30: Oiled Beach

Figure 31: Step 1 - flooding

Figure 32: Step 2 - flushing

Figure 33: Step 3 - Application of sorbents

Figure 34: Step 4 - Application of Shoreline Cleaning Agent

Figure 35: Cleaned beach

2.6.3 Cleaning after long time weathering

The aim was to evaluate how the stones responded to cleaning after having been exposed to sunlight, rain, and wind over an extended period outdoors.

- Does the oil dry out over time, making it easier to remove during cleaning?
- Does the oil adhere more strongly over time, making it increasingly difficult to remove during cleaning?
- Does solar heating cause it to migrate further into the sediment layers?

We constructed four “homemade” beach sections inside a metal container with a perforated bottom leading to an internal tank, approximately 2x2 meters in size. The sections were separated using wooden dividers covered with white garden fabric to prevent sand from falling into the tank below. A layer of sand approximately 10 cm thick was then added, followed by the placement of small and larger stones (ranging from 3 to 20 cm in diameter) on top of the sand.
Finally, each individual beach section was treated with a well-concentrated application of oil, using each of the four oil types (Figure 36).
The “beach” was then placed outdoors, covered with a mesh to prevent birds and other animals from coming into contact with the oil, while still allowing exposure to sunlight, wind, and rain. The oil was never in contact with seawater, and consequently not exposed to tidal movements or wave energy. In practice, the setup simulated an oil spill that had been thrown well above the shoreline - such as during a storm - and subsequently remained undetected or deprioritized for beach cleaning over an extended period.

The plan was to attempt cleaning the stones after several months using a concrete mixer, various water temperatures, and, if necessary, shoreline cleaning agents.

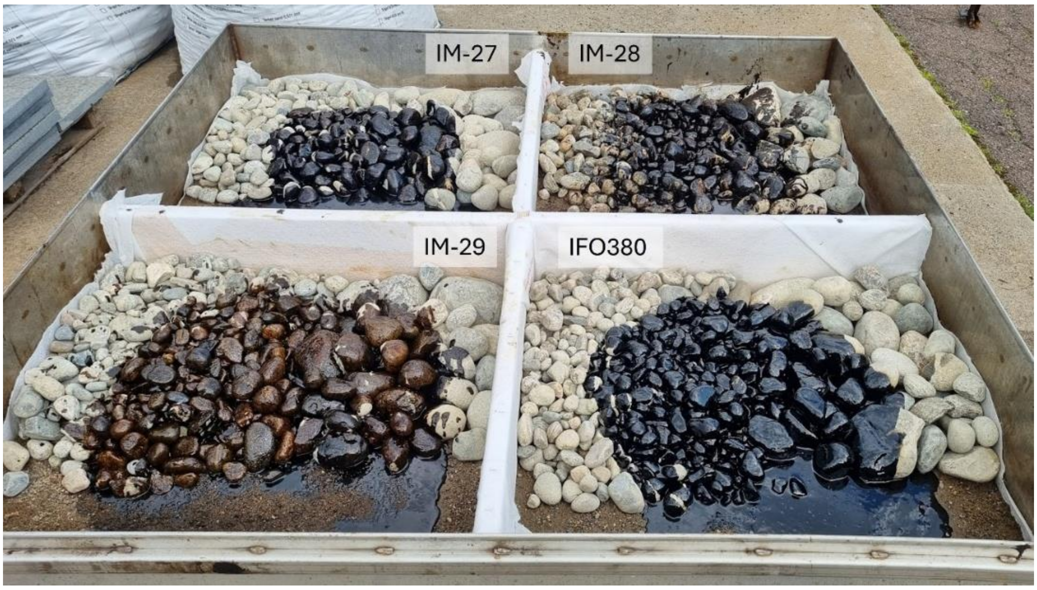


Figure 36: Beach sections contaminated with the different test oils.

Each batch of oiled rocks was treated the following way (see Figure 37):

1. Tumbling in concrete mixer in approx. 13°C water for 2 mins. > 10 pebbles picked out for drying.
2. Tumbling in concrete mixer in approx. 19°C water for 2 mins. > 10 pebbles picked out for drying.
3. Tumbling in concrete mixer in approx. 25°C water for 2 mins. > 10 pebbles picked out for drying.
4. Tumbling in concrete mixer in approx. 40°C water for 2 mins. > 10 pebbles picked out for drying.
5. Remaining pebbles sprayed with shoreline cleaning agent.
6. Tumbling in concrete mixer in approx. 13°C water for 2 mins. > 10 pebbles picked out for drying.
7. Remaining pebbles sprayed with shoreline cleaning agent.
8. Tumbling in concrete mixer in approx. 19°C water for 2 mins. > Remaining pebbles picked out for drying.

Figure 37: Different steps of the treatment.

- Results from Task 5.6 are presented in section 3.6.

3 RESULTS

As a reminder, the main physical-chemical characteristics of the oils tested in this work package are detailed in the Table 5.

Table 5 Physical-chemical characterisation of the oils tested in the WP5. Pour point indicated is the pour point provided by the oil suppliers. Values into brackets are the minimum and maximum values obtained from SINTEF in-depth pour point analysis (See deliverable D3.3 for more details)

Samples	Nature	Viscosity 50°C, 10 s^{-1} (mPa.s)	Viscosity 15°C, 10 s^{-1} (mPa.s)	Density 15°C	Pour point (°C)
IM-27	VLSFO	262	16 600	0.96	12°C (9-24°C)
IM-28	VLSFO	109	54 813	0.94	27°C (21-30°C)
IM-29	VLSFO	11	10 559	0.89	27°C (15-24°C)
HFO	-	nd	79 733	nd	nd

3.1 Rock cleaning (Task 5.1)

3.1.1 Oil penetration/absorption

As already observed during the first IMAROS project, a penetration of some LSFOs occurred during the drying time of the experiments performed with the granite tiles. Figure 38 shows this phenomenon, after five months of drying.

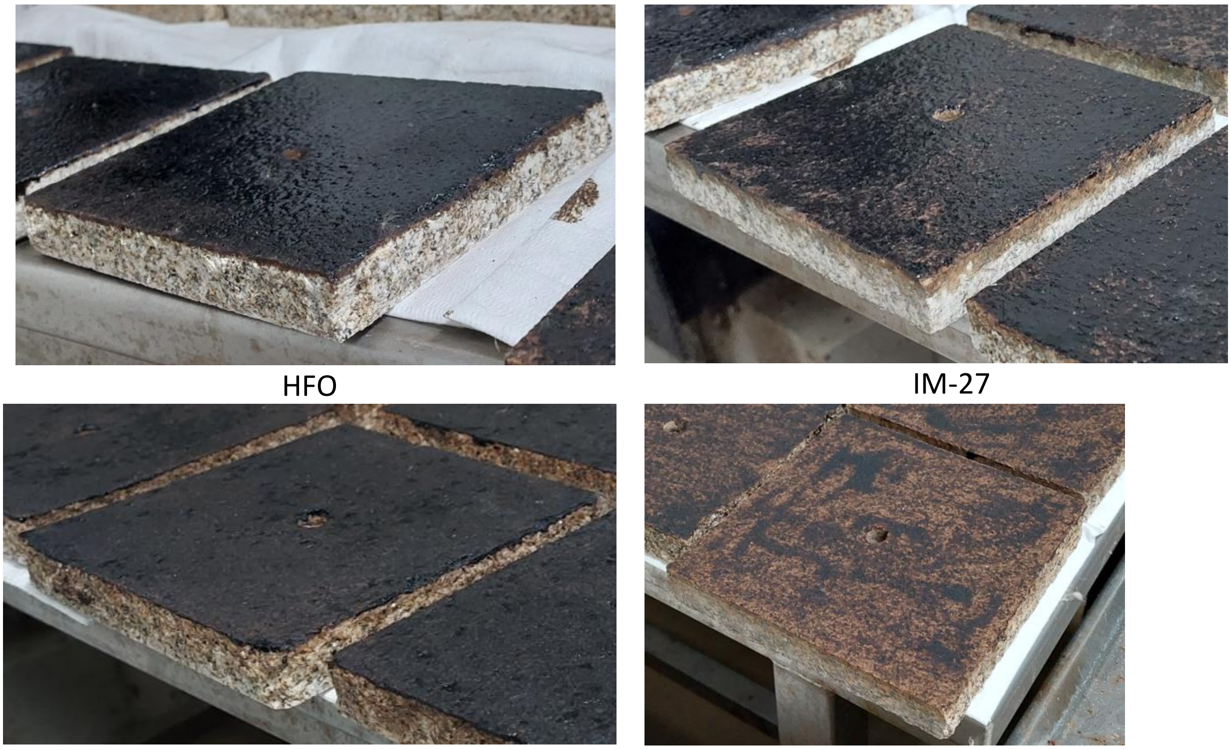


Figure 38 Pictures of the tiles after 5 months drying time

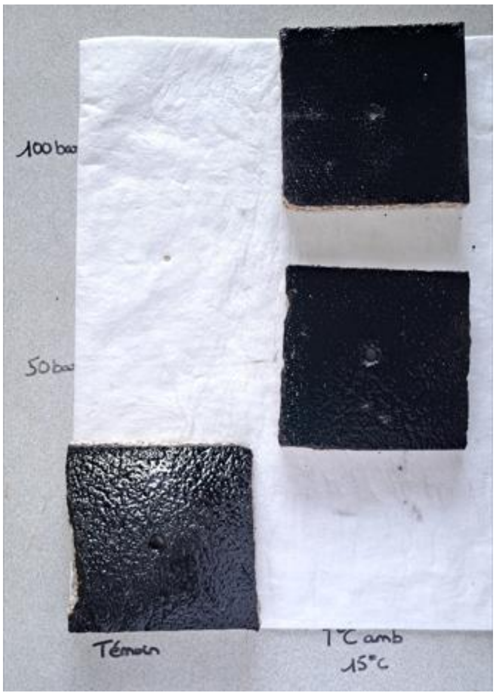
3.1.2 Washing efficiency

Oil extraction from the control tiles led to significant lower mass than the three grams added: 2.5g for HFO, 2.2 g for IM-27, 1.0 g for IM-28 and 0.6 g for IM-29, confirming a loss, probably by absorption in the rocks, especially for IM-29.
Comparative pictures of the control tiles (not having washed with the high-pressure washer) and the tiles washed at 15°C (50 and 100 bars) are presented in the Table 6. The visual difference between the different treatment is not obvious.
Figure 39 presents the results of the washing efficiency for the 3 LSFOs and for the reference oil (HFO). Those results take into account the oil "lost" by absorption, explaining the low efficiency calculated. It should also be remained that the tiles were let for drying for a much longer period that initially planned before extraction at the laboratory (between 7 and 10 weeks for the control and 5 months for the 50°C conditions). The oil could thus have formed a hard and dry layer more difficult to clean, explaining also the low efficiency obtained.

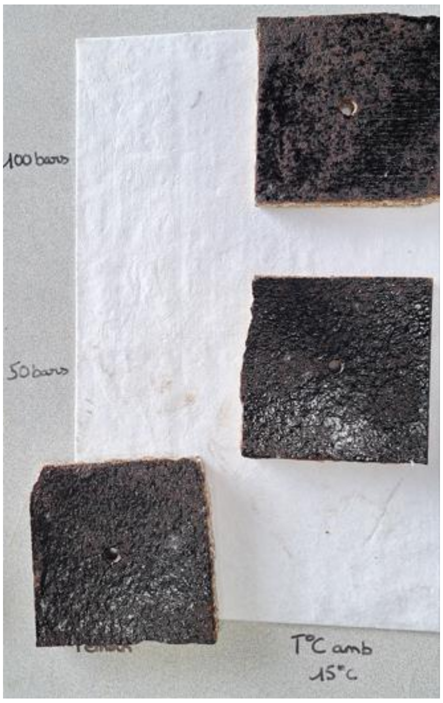
Considering the reference oil (HFO), increasing the water temperature at 50°C is the only possibility to measure an effect of the cleaning. The washing efficiency is however very limited, with the highest efficiency measured with the condition 50°C – 50 bars (17 ± 7%).
IM-27 shows the highest washing efficiency, with increasing washing efficiency for combined conditions of temperature and pressure. However, the maximum efficiency of 37 ± 3%, obtained for the condition 50°C – 100 bars, is limited.
IM-28 shows a very limited increase of the washing efficiency at 50°C or 100 bars compared to the control, increasing from 5 ± 4% to 11 – 13%. For the combined conditions of temperature and pressure (50°C – 100 bars), efficiency was null. This could be due to heterogeneity of the rocks that leads to different penetration degree. Penetration could have been more pronounced for the three tiles tested with this condition.
Finally, the same observation is made for the IM-29 oil, that exhibits high variability of washing efficiency and some efficiency null, even for the combined conditions of temperature and pressure.

From the first IMAROS project, low washing efficiencies were calculated for oils exhibiting high degree of penetration. However, a combined effect of high pressure and high temperature (50°C-100 bars) seemed to led to the best washing efficiencies.

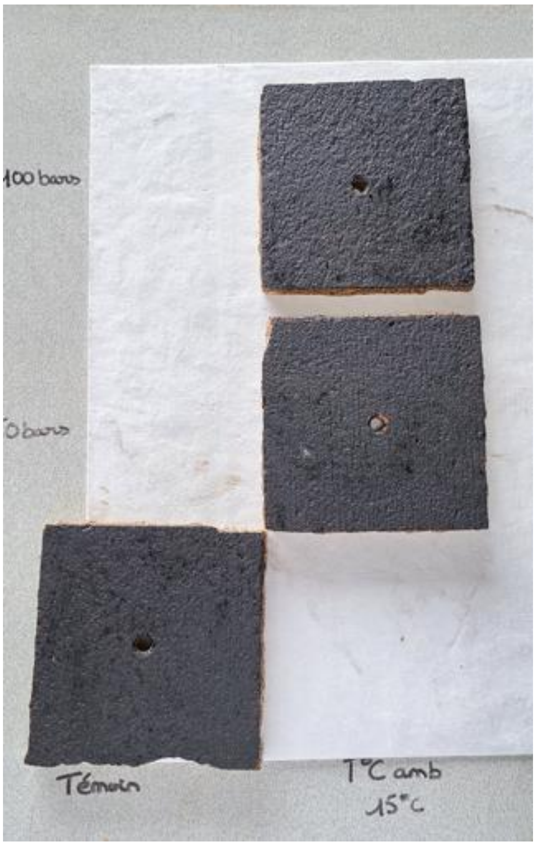
Table 6 Comparative pictures of the control tiles (not having been processed with the washing robot, bottom left on each picture) and the tiles cleaned at 15°C (100 and 50 bars, up and down, right on each picture).



HFO



IM-27



IM-28

IM-29

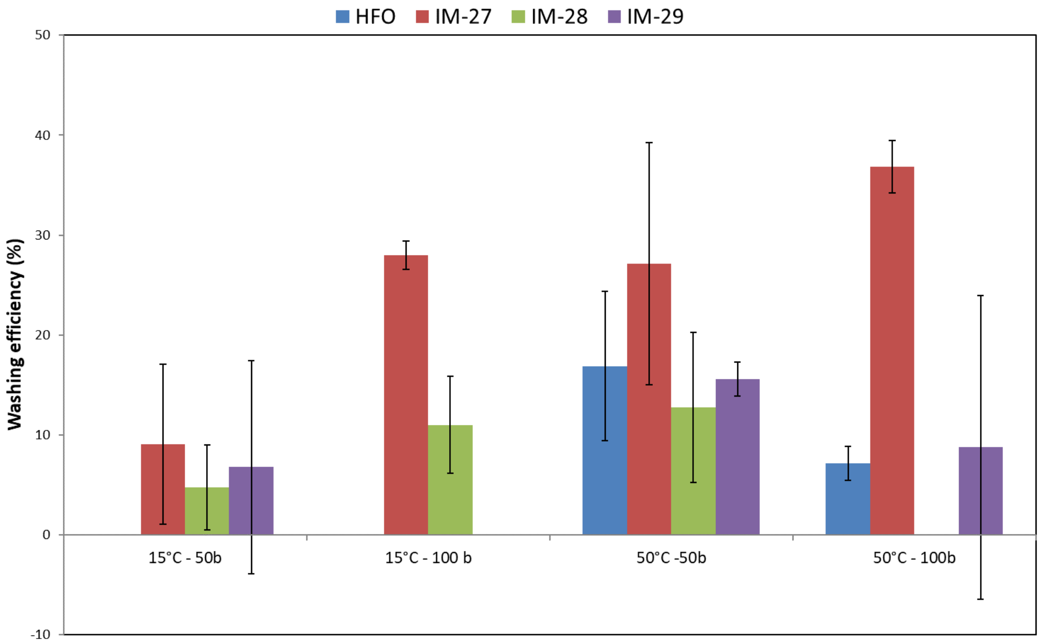


Figure 39 Washing efficiency of the of high -pressure washer, following different conditions of temperature and pressure, on granite tiles polluted with IM-27, IM-28, IM-29 and HFO

As a conclusion, taking into account the four oils tested, granite tiles covered with a thin layer of those oils and let for drying and penetration processes will be very difficult to clean with a high-pressure washer, even with the combined effect of temperature (50°C) and pressure (100 bar). Rock tainting will persist and no significant difference with the comparative heavy fuel oil appears.

Appendix 1 details the results obtained during those trials.

3.2 Efficiency of cleaning agents (Task 5.2)

Within the conditions of those tests, no penetration in the slate tiles was observed for the three oils tested.

Results are presented on Figure 40, 41 and 42. For IM-27 and IM-28 using cold tap water (9 °C), there was an effect of the SCAs compared with only water flushing, and the effectiveness of Aqua Delta (SCA 1) was slightly higher than for Cytoclean (SCA 2). However, the effectiveness of both SCAs were between 10% and 17%.
For the IM-29 oil, the water flushing using cold tap water was very effective (close to 100%), but using water without SCA was as effective as applying SCAs.
Using a water flushing temperature of 25 °C resulted in an increase in the effectiveness of Aqua Delta on IM-27 from 17% to 60% (without SCA from 5 to 39%). On IM-28 the effectiveness increased from 16% to 26 % (from 2 to 13% without SCA). Hot water was not tested on IM-29.

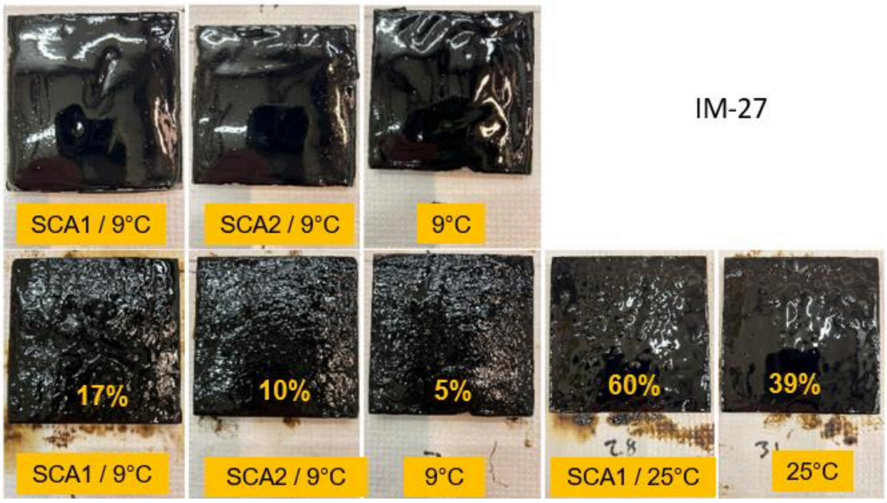


Figure 40 Effectiveness of water flushing (50 bar) and use of SCA with water temperatures of 9°C and 25°C, on IM-27

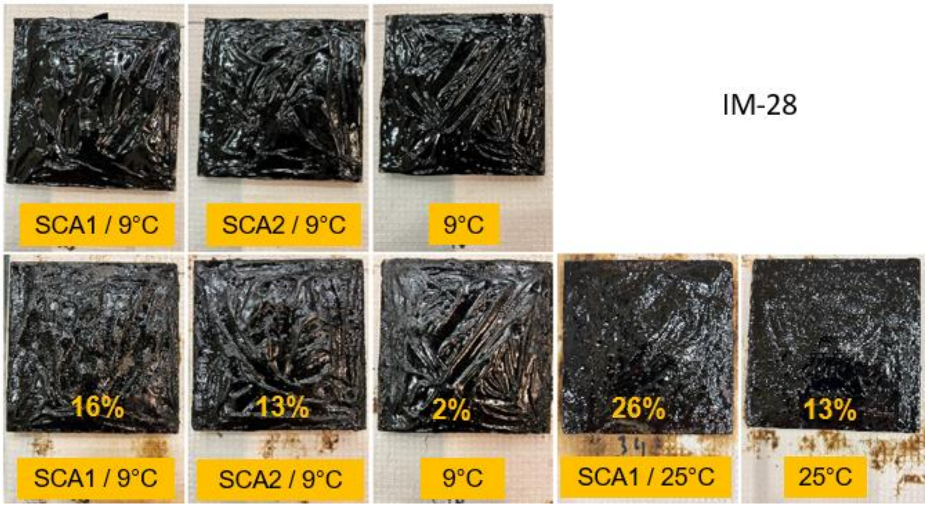


Figure 41 Effectiveness of water flushing (50 bar) and use of SCA with water temperatures of 9°C and 25°C, on IM-28.

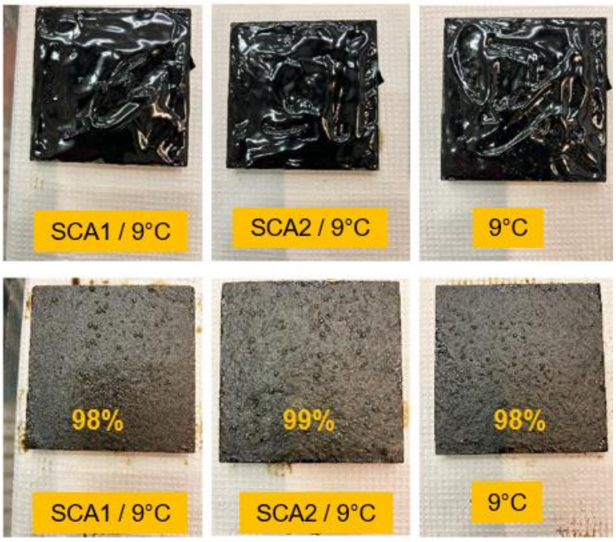


Figure 42 Effectiveness of water flushing (50 bar) and use of SCA with water temperatures of 9°C, on IM-29.

On fresh and thick layers of LSFOs deposited on slate tiles, washing will be very efficient for fluid oils. Washing efficiency will highly decrease for viscous or semi-solid LSFOs. Addition of shoreline cleaning agents and increase of the water temperature will improve the washing but results will still be limited. It must be noted that these results cannot be directly compared to the ones obtained at Cedre (Task 5.1). In particular, the oil penetration was not observed for the substrate used by SINTEF.

- *The full SINTEF report is presented in Appendix 2.*

3.3 Release and toxicity of oil absorbed in rocks (Task 5.3)

3.3.1 Ecotoxicity tests on algae

3.3.1.1 Validation of the test

The mean of the growth rate in the control replicates at 72h is 1.4 d^{-1} which is the lower limit for criteria acceptance. The variation coefficient of the growth rate in the control replicates is below 5% (0.22%).

The increasing concentrations of the positive substance ($K_2Cr_2O_7$) induce an algal growth rate decrease (Figure 43).

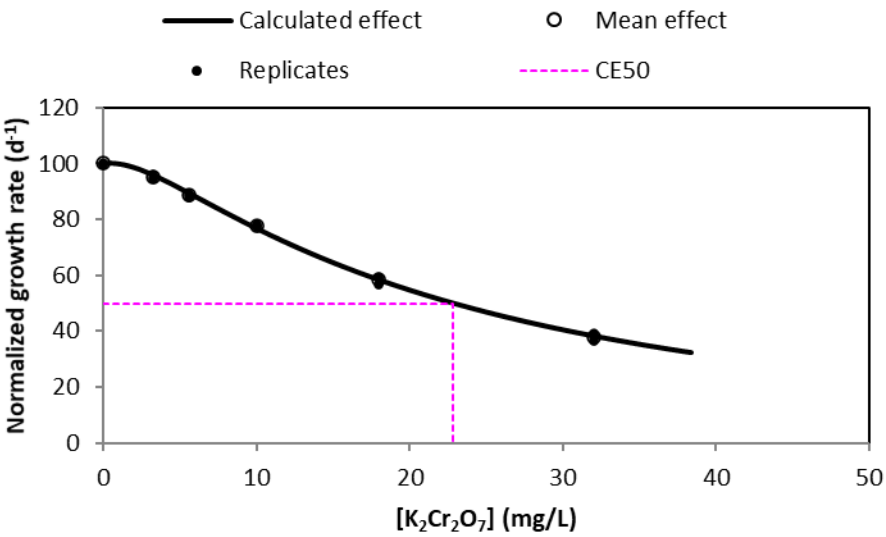


Figure 43

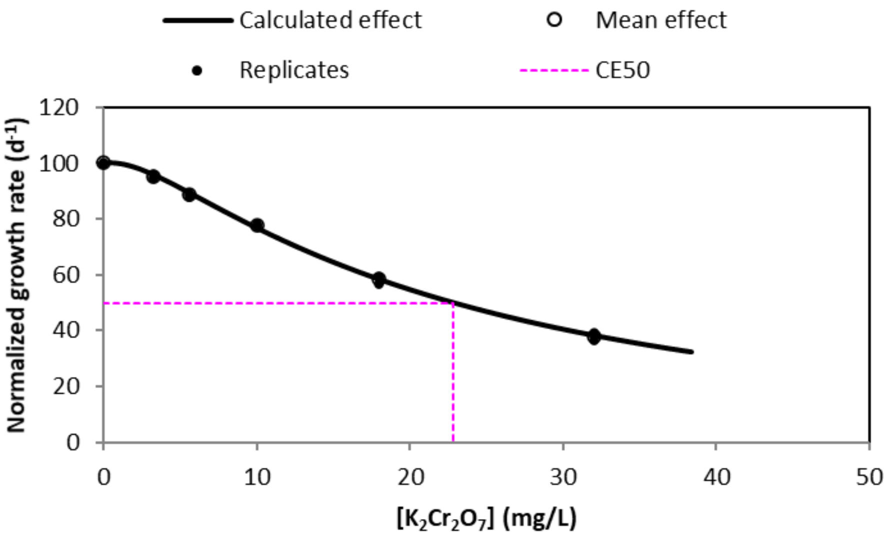


Figure 43 Normalised growth rate (in d^{-1}) calculated with the positive substance $K_2Cr_2O_7$ and determination of the EC_{50} with the Regtox programme

Regtox programme allowed the calculation of a EC_{50} for this substance ($K_2Cr_2O_7$). This calculated concentration is 22.8 mg/L. Interlaboratory exercise (using *Phaedodactylum tricornutum* as algae and $K_2Cr_2O_7$ as positive control) based on the ISO 10253 standards was performed by ten laboratories and led to the determination of an EC_{50} of 20.1 ± 5.3 mg/L (n = 7). The result obtains during this study is in accordance with those values.

The test acceptance criteria are thus fulfilled.

3.3.1.2 Comparison of the composition of the adapted WAFs

As a comparison, in the frame of the first IMAROS project, regular WAFs were prepared and the PAH concentrations varied from 13 to 156 µg/L.

Figure 44 presents the concentrations of PAH for the different adapted WAFs that were prepared. A notable difference is observed between the “Control” (seawater) and the “Control tile” (adapted WAF having been in contact with a clean tile) conditions, with an increase of PAH concentrations from 50 to 1 841 ± 86 ng/L. This increase of concentration could not be explained. Concentrations increase then progressively from IM-27, IM-29, IM-28 and HFO. The comparative HFO is thus the oil exhibiting the more important solubilization of PAH in the adapted WAFs.
No major difference was noticed between the two treatments “Tile: polluted + cleaned” and “Tile: polluted”. This is in agreement with the low washing efficiency measured in the Task 5.1. Surprisingly HFO exhibits even higher concentrations for the tile that has been washed. Giving those results, no major difference of algal growth is expected between those two conditions.

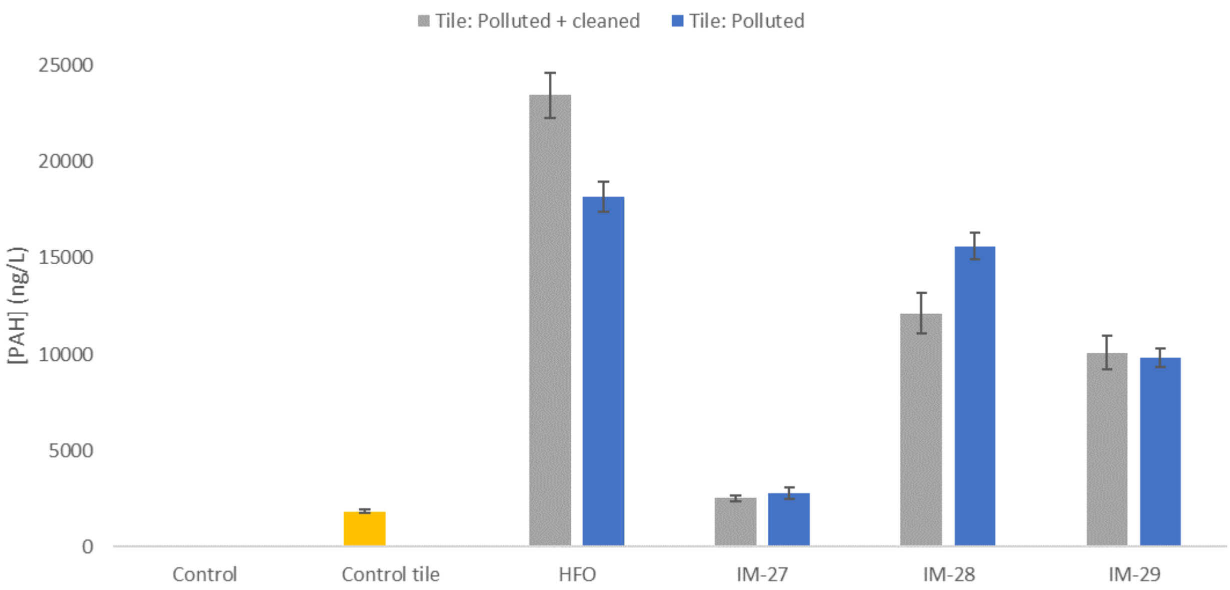


Figure 44 PAH concentrations (in ng/L) in the different adapted WAFs prepared

3.3.1.3 Comparison of the algal growth rates

The average specific growth rate µ, for each test culture, was calculated using the following equation:

$$\mu = \frac{\ln(N_1)-\ln(N_0)}{t_1-t_0} \qquad \text{(Eq. 1)}$$

with μ the specific growth rate (in d^{-1}), N_x the number of cells at the time x, and $(t_1 - t_0)$ the number of days between t_1 and t_0 . Growth rates at 24 hours, 48 hours and 72 hours, are presented in *Appendix 3*.

Figure 45 presents the specific growth rates calculated for all the tests performed. A small decrease of the growth rate, from 1.37 ± 0.00 d^{-1} to 1.15 ± 0.02 d^{-1} is observed between the two tests "Control" and "Control tile". Tests performed with the four oils were compared to the "Control tile" one as a tile was present in all the tests and it was assumed that the same "tile effect" was observed for all of them.

Except for the test performed with the HFO (tile: polluted and cleaned) that exhibit a slight growth rate decrease (0.94 ± 0.02 d^{-1}), all the growth rates were in the same range (1.14 – 1.20 d^{-1}). This observation implies that, in the conditions of those tests, PAH concentrations in the adapted WAFs below 20 000 ng/L do not affect the algal growth. The lowest growth rate calculated for HFO ("Tile: Polluted + cleaned") seems in relation with the highest concentration of PAH (23 461 ± 1 157).

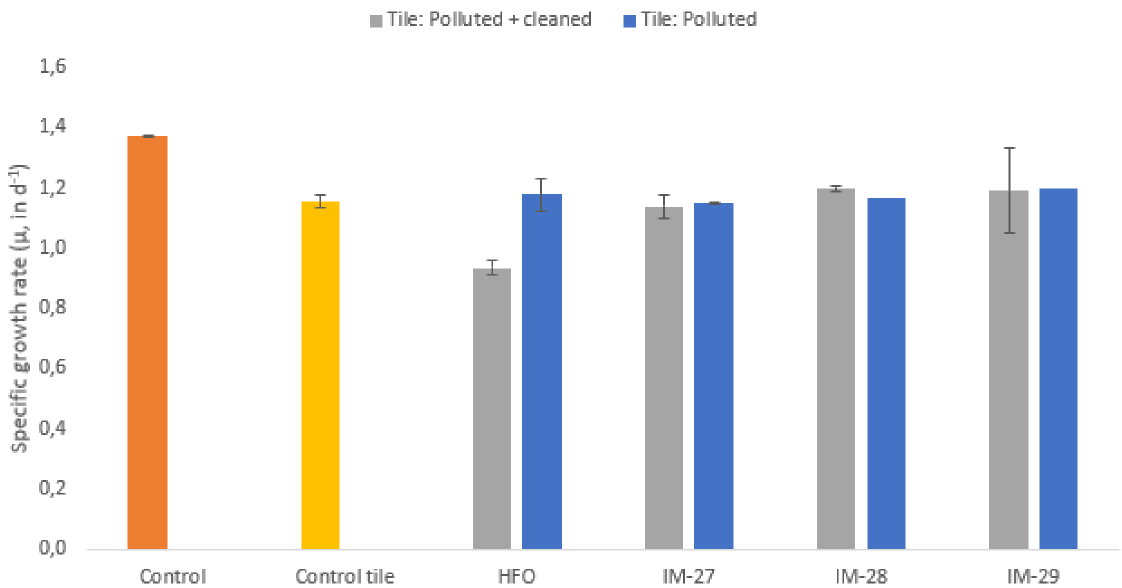


Figure 45 Specific growth rate µ (in d-1) at 72h calculated for all the 9 "WAF" and the control experiment

- *Detailed results obtained during those trials are presented in Appendix 3.*

3.3.2 Ecotoxicity tests on copepods

3.3.2.1 Validation of the test

Considering the controls, the mean mortality increases from 0% after 24 hours to 7% after 48 hours, leading to mortality above the acceptable threshold value (10%) at the end of the test.
Considering the positive control, the mean mortality increases from 23% after 24 hours to 65% after 48 hours, leading to mortality in the range of the acceptable threshold value (20 - 80%) at the end of the test.

3.3.2.2 Comparison of the composition of the adapted WAFs

Figure 46 presents the concentrations of PAH for the different adapted WAFs prepared. LSFOs do not exhibit higher concentrations than the comparative HFO. Here again, no major differences between the two treatments applied to the tiles (cleaned or not after pollution) are observed. Only the adapted WAFs prepared with the tiles covered with IM-29 shows lower concentrations when the tile was washed with the high-pressure washer. Globally, the same WAF compositions were obtained between the trials performed with the algae and the copepods.

As a comparison, in the frame of the first IMAROS project, regular WAFs were prepared and the PAH concentrations varied from 12 to 163 µg/L.

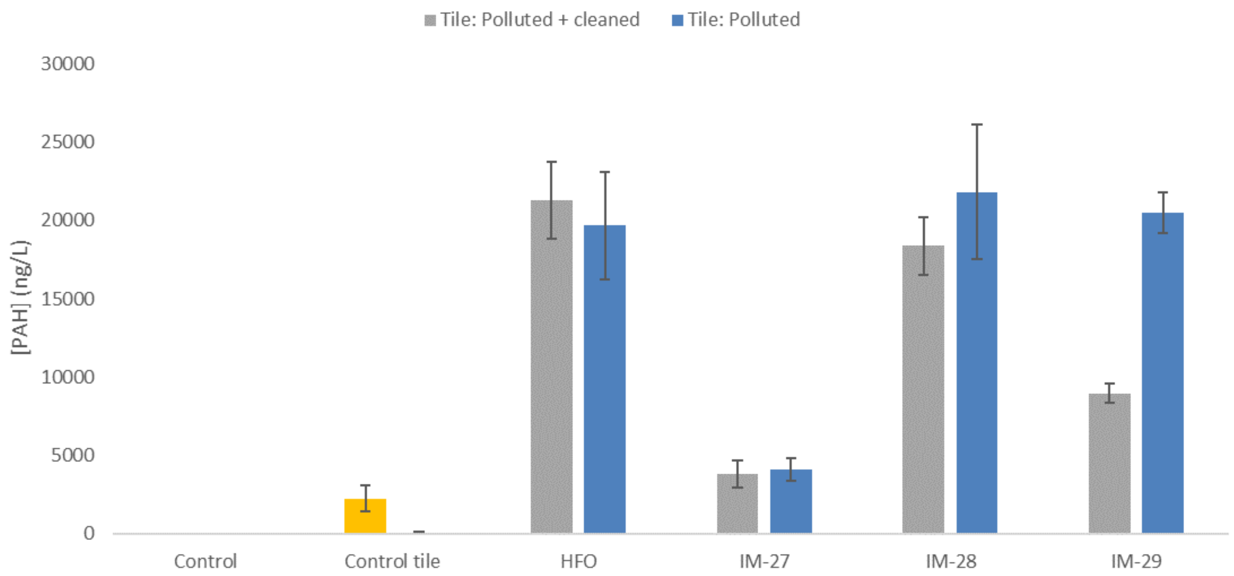


Figure 46 PAH concentrations (in ng/L) in the different adapted WAFs prepared

3.3.2.3 Comparison of the mortality

Responses obtained for the controls, the reference substance (3,5-Dichlorophenol) and the four oils are detailed in Apppendix 4.

The mortality rate obtained with the adapted WAF prepared from the control tile (not polluted) is not statistically different from the one obtained with the control (seawater), even if the concentration of PAH is clearly higher. Mortality rate increases as soon as oils were added on the tiles. Due to the limited volumes of culture medium and so of copepods (between 4 and 12 in each flask) the standard deviations are quite important. Here again the comparative HFO seems to have one of the biggest effects on the copepods with mean mortality exceeding 80%. Globally a correlation between mortality rate and PAH concentration can be observed (Figure 48).

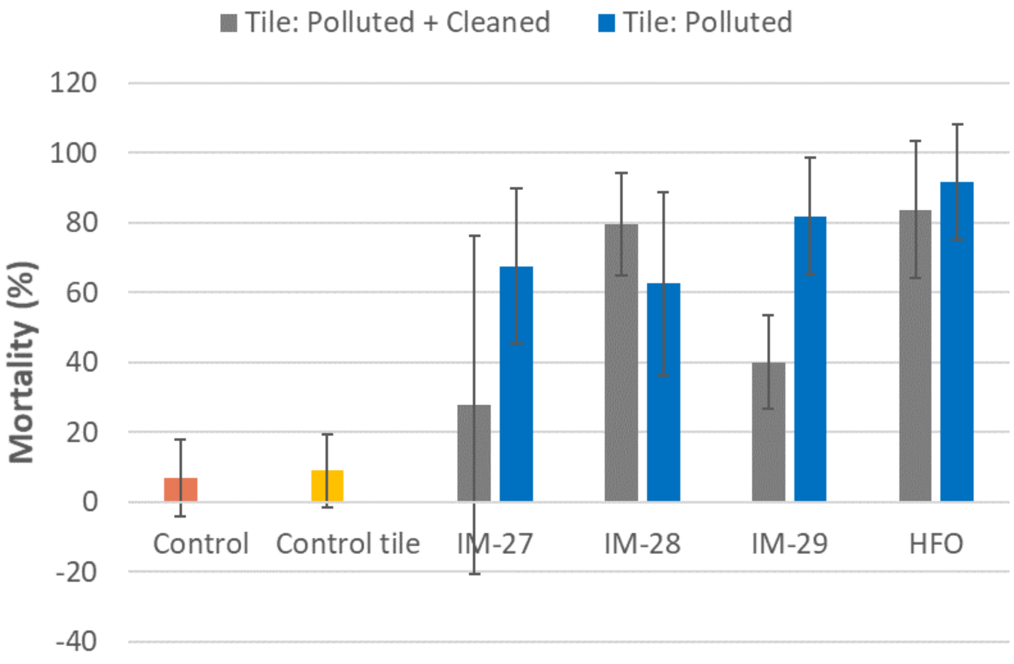


Figure 47 Average mortality of copepods exposed to adapted WAFs prepared with water having been in contact with tiles characterised by different treatment

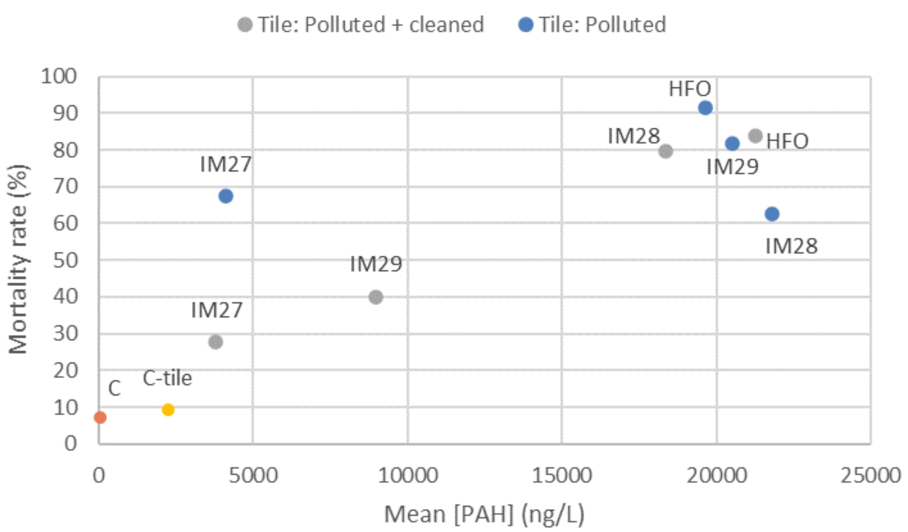


Figure 48 Mortality rate (in %) in function of the mean concentration of PAH

- *Detailed results obtained during those trials are presented in Appendix 4.*

3.3.3 Main conclusion from Task 3.3

LSFOs tested showed similar or lower PAHs concentrations than the traditional HFO tested. Algal growth rate was not affected by those PAHs, at least below a value of 20 000 ng/L that could represents a threshold, as no difference was observed with the control. Increasing mortality of copepods was observed with increasing PAH concentrations in the adapted WAFs, the highest mortality rate being observed with the HFO. Those results are in agreement with a study from SINTEF, in the frame of the IMAROS project, that showed that LSFOs were not more toxic than traditional HFO[5]. Polluted tiles having been cleaned with a high-pressure washer release sufficient amount of PAH to induce an effect on the copepod mortality. However, those tests performed with a very limited volume of water (1.2L par tile) do not mimic natural exposition of marine organisms to polluted rocky substrates. They allow to compare the relative toxicity of different LSFOs with a traditional HFO and the effect of cleaning operations on the release of PAHs from the rocks.

[5] Liv-Guri Faksness and Per S. Daling, Chemical composition of fuel oils, IMAROS, 2022, ISBN 978-82-14-07516-8

3.4 Rock colonization by biota / Natural recovery (Task 5.4)

After tile's pollution and drying period, penetration of some LSFOs, especially IM-29, was observed on the three sites and the different rocks. This phenomenon was most pronounced on the granite tiles used in France.

3.4.1 Experiment in France

3.4.1.1 Visual observation with time

Pictures of the initial and final time steps are presented below. Appendix 5 presents pictures of each time step.

North face

A clear reduction in oil visibility over time was observed, with notable differences among the oils tested. After eleven months of exposure, oil was almost no longer visible on the tiles treated with IM-29 (see Figure 50 and Figure 52). The tiles exhibited increasing coloration for HFO, followed by IM-27, while IM-28 remained relatively dark. Additionally, barnacles colonized all tiles—both control and polluted—starting from the fourth time step (after six months of exposure, in April). These barnacles are visible in Figure 52 and Figure 53 as small white dots.

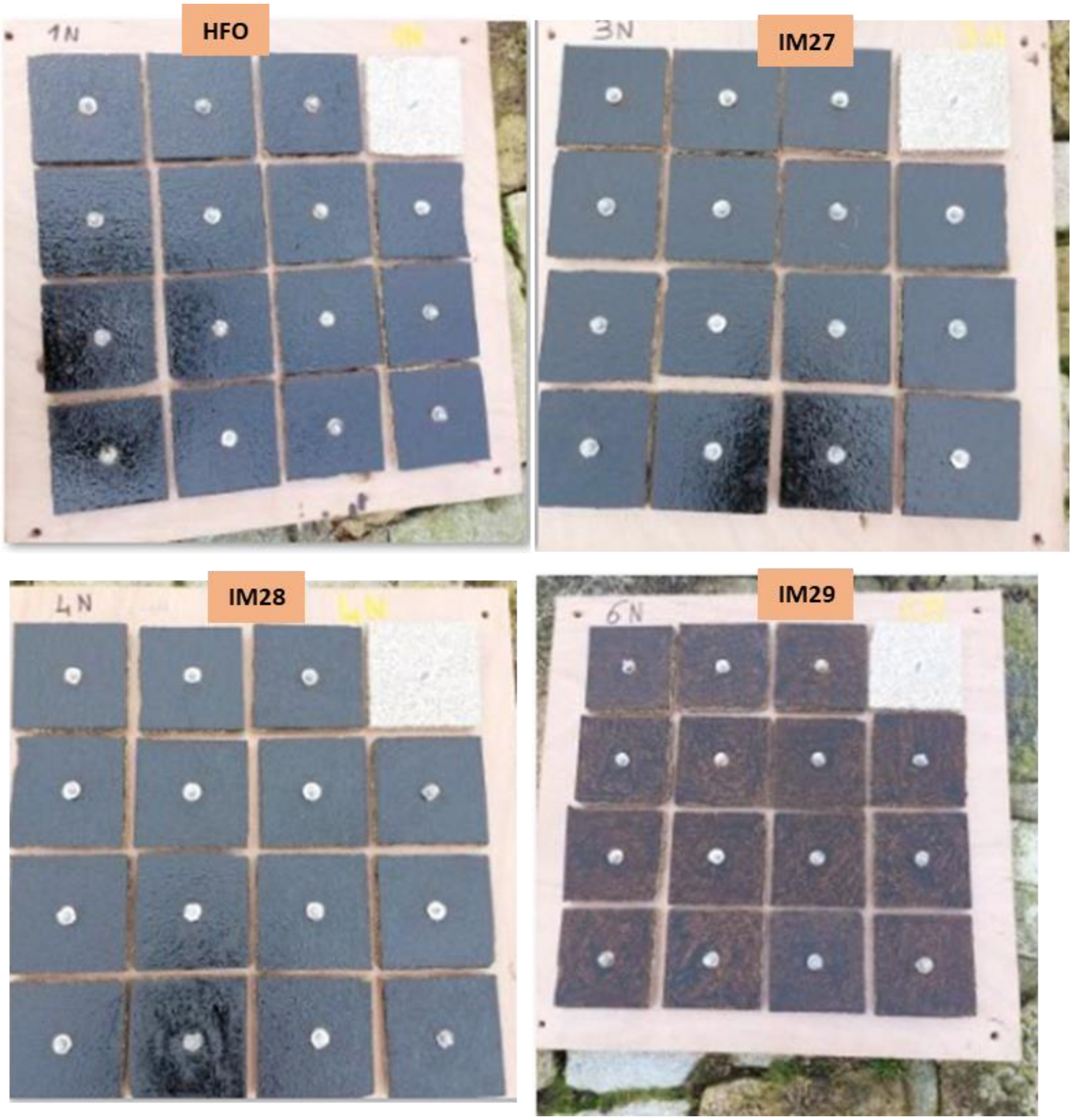


Figure 49 Pictures of the wooden frames installed on the North face of the quay, at T0

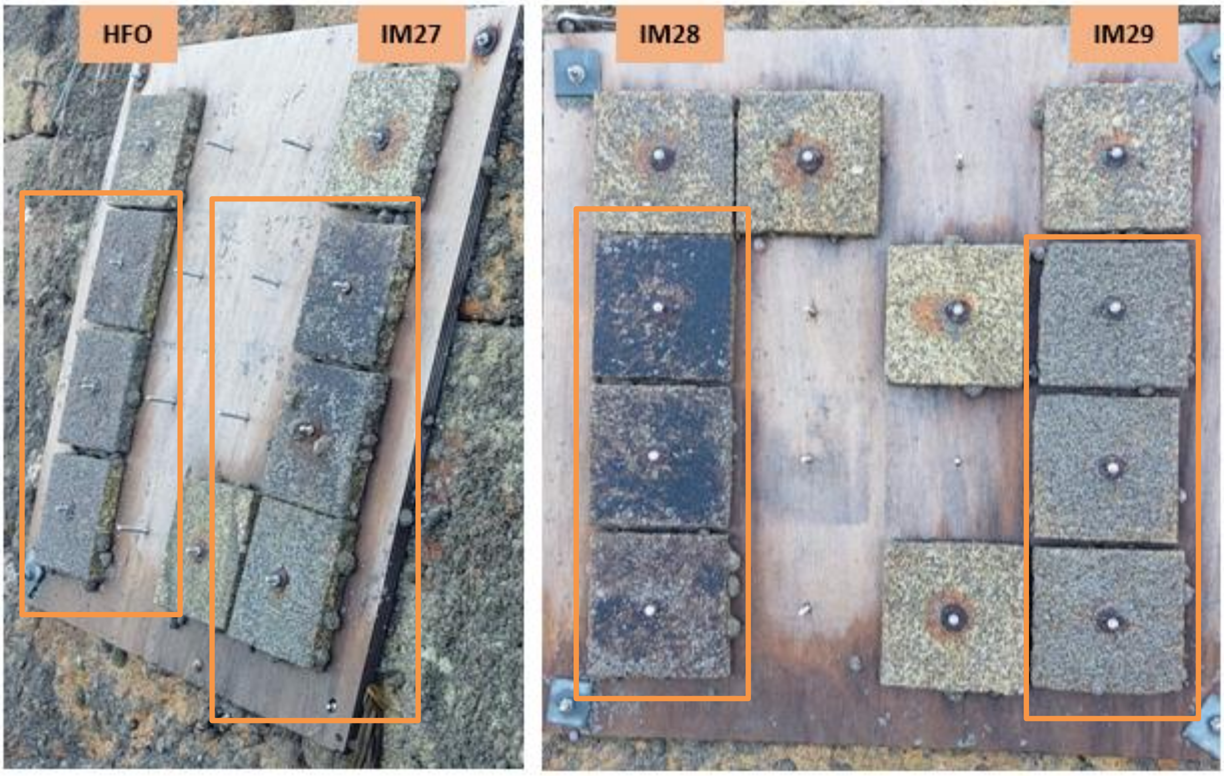


Figure 50 Pictures of the wooden frames installed on the North face of the quay, after 11 months of exposure. Clearest tiles, not included in the orange boxes, are control tiles (not polluted).

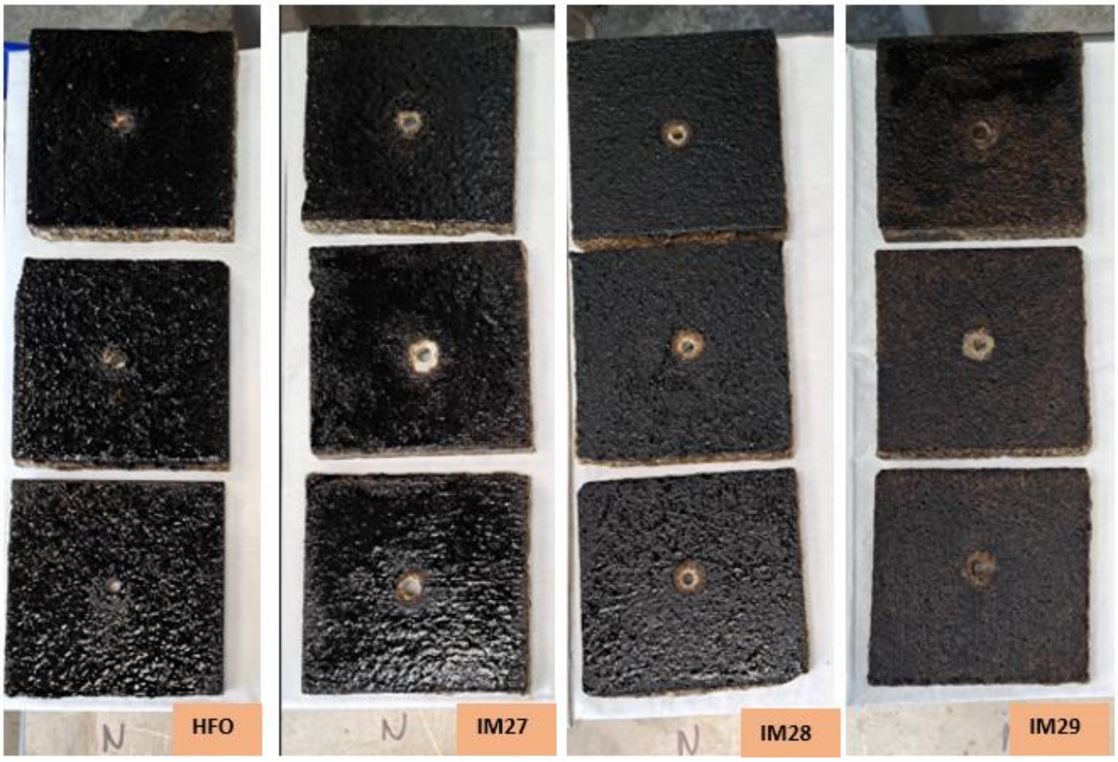


Figure 51 Pictures of the polluted tiles from the North face of the quay, at T0, at the laboratory before extraction

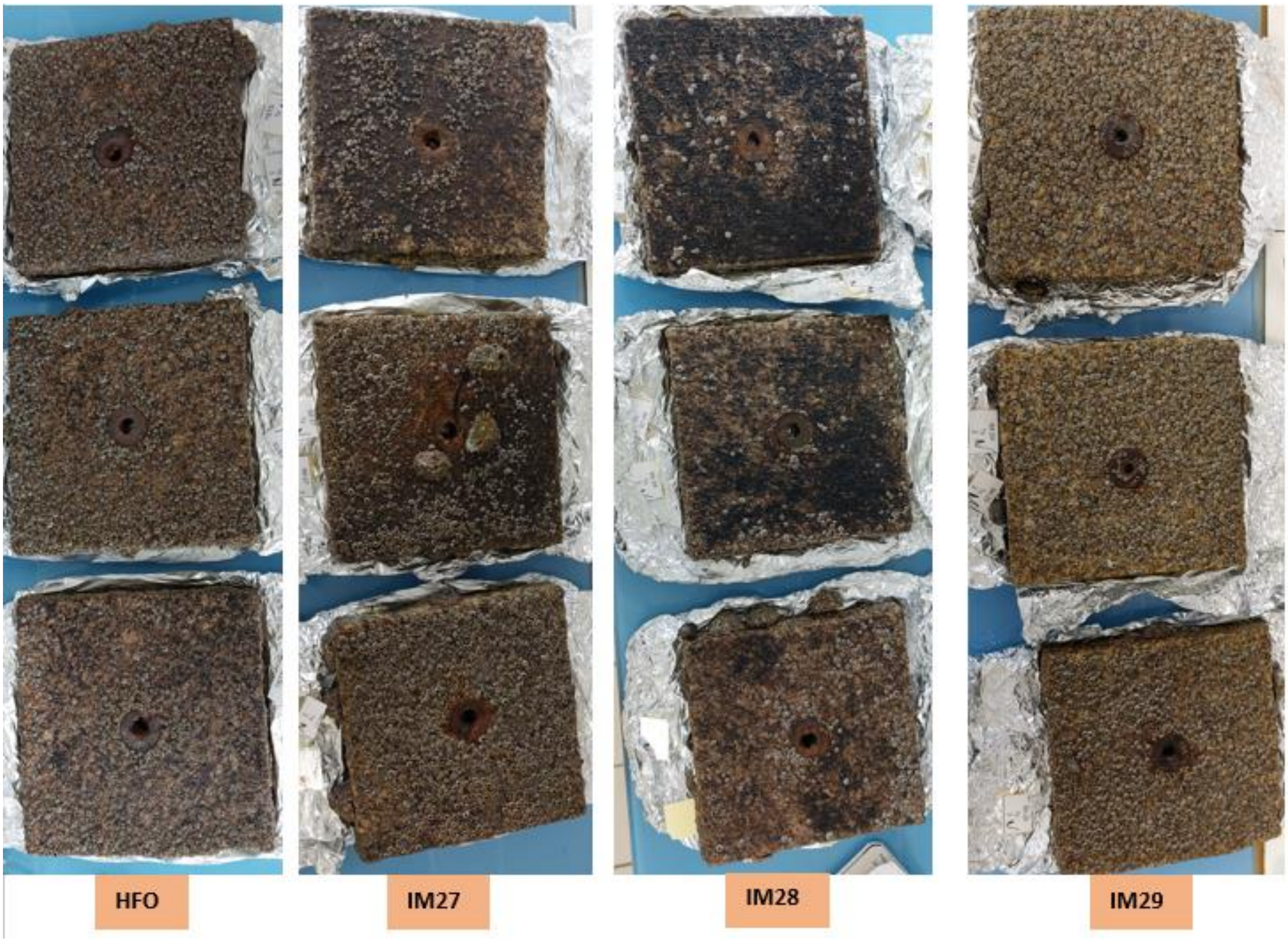


Figure 52 Pictures of the polluted tiles from the North face of the quay, after 11 months of exposure, at the laboratory before extraction

Figure 53 Pictures of the control tiles from the North face of the quay, after 11 months of exposure, at the laboratory before extraction

South face

As observed on the north-facing side, oil removal was significantly advanced after eleven months of exposure for tiles polluted with IM-29 and HFO (Figure 57). In contrast, IM-27—and especially IM-28—demonstrated greater persistence. Notably, no barnacle colonization was observed on either the control or polluted tiles on this side of the quay (Figure 57 and Figure 58).

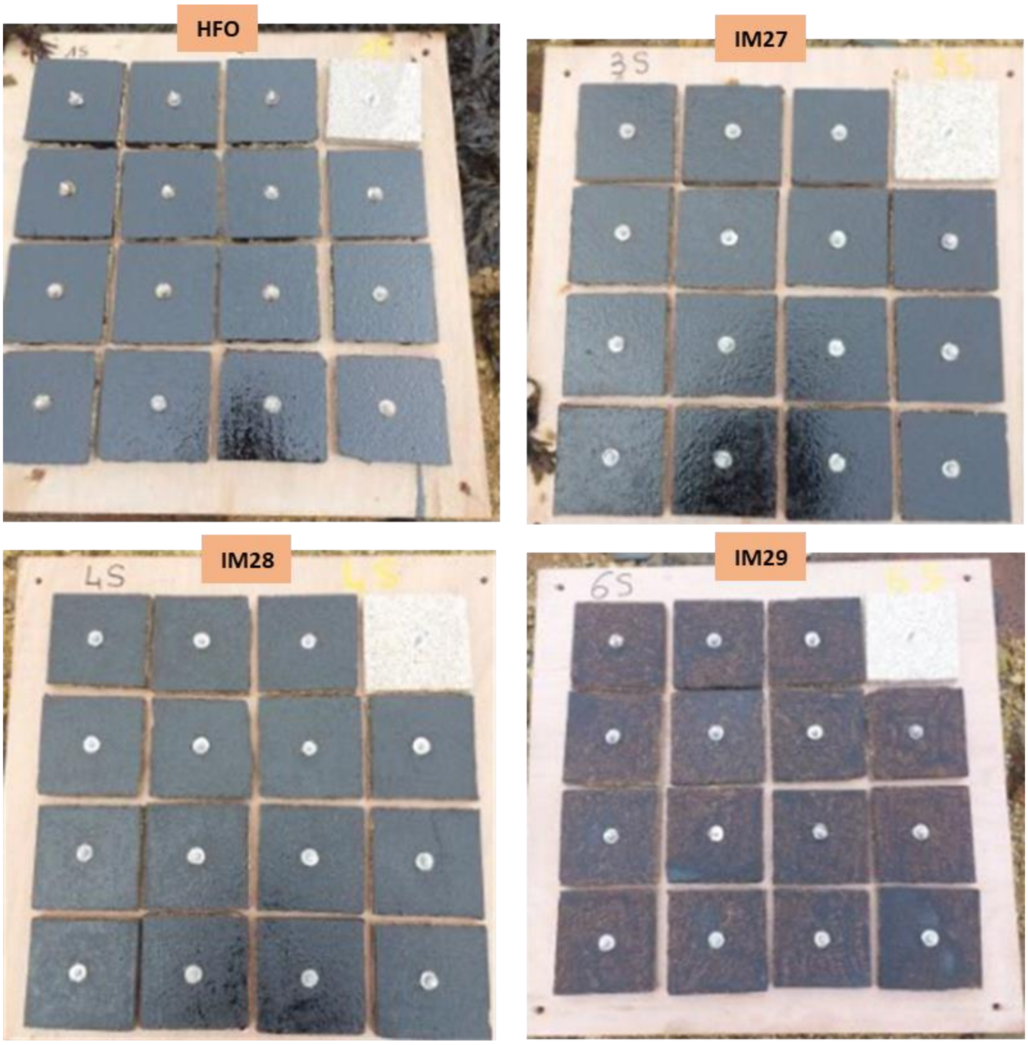


Figure 54 Pictures of the wooden frames installed on the South face of the quay, at T0

Figure 55 Pictures of the wooden frames installed on the South face of the quay, after 11 months of exposure

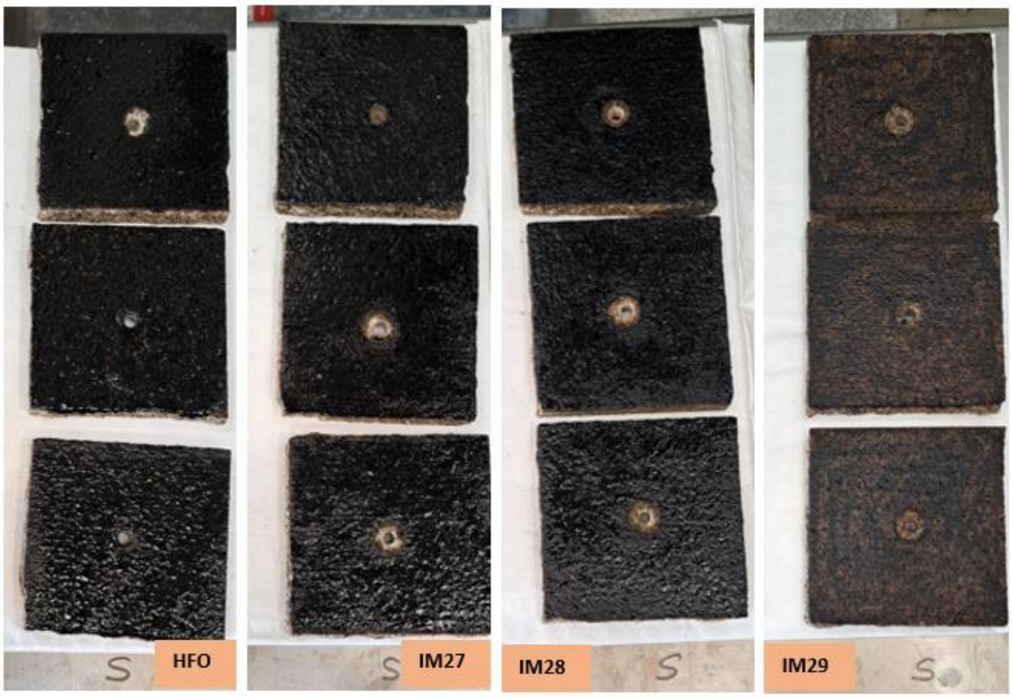


Figure 56 Pictures of the polluted tiles from the South face of the quay, at T0, at the laboratory before extraction

Figure 57 Pictures of the polluted tiles from the South face of the quay, after 11 months of exposure, at the laboratory before extraction

Figure 58 Pictures of the control tiles from the South face of the quay, after 11 months of exposure, at the laboratory before extraction

3.4.1.2 Quantitative degradation

At each time step, the tiles collected were extracted in order to quantify the remaining oil. Figure 59 exhibits the evolution, with time, of the averaged remaining quantity of oil on the tiles. Data are presented in Appendix 5.

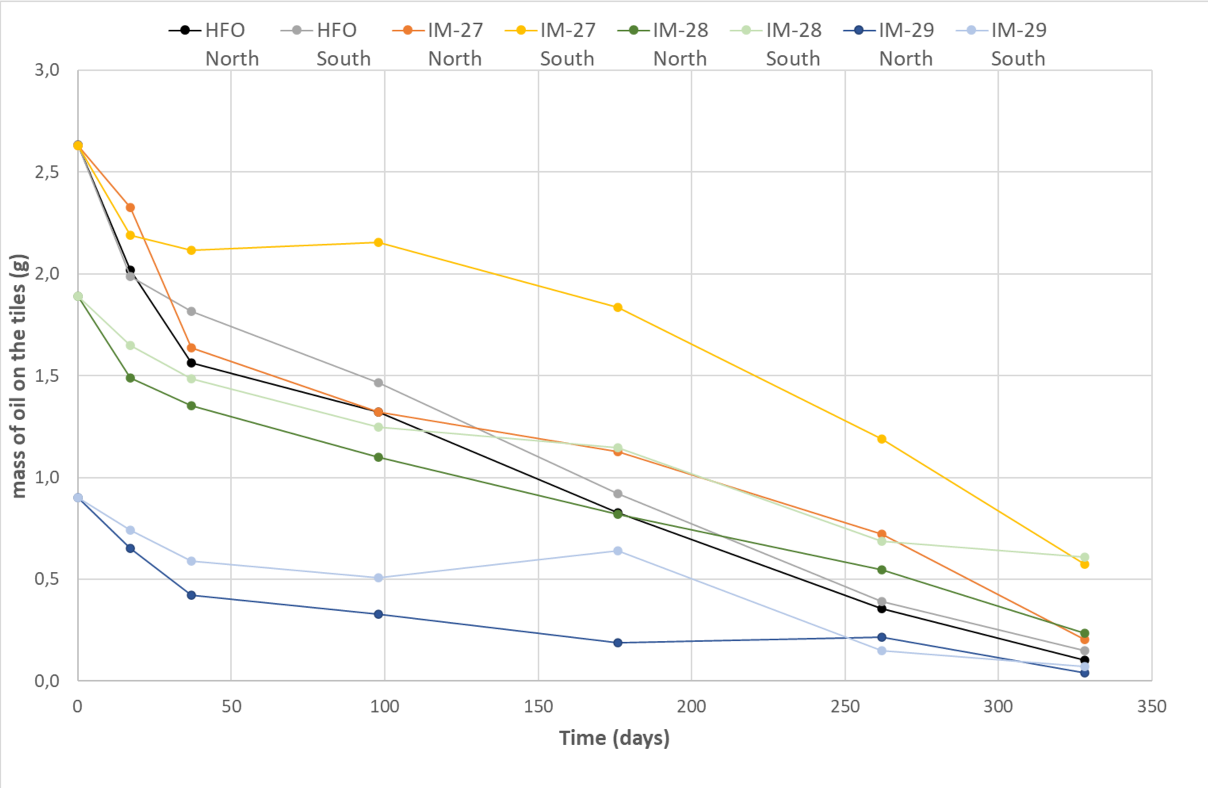


Figure 59 Evolution with time of the averaged quantity (in g) of oil extracted on from the tile's surface

The difference noted between the oils for the initial masses is due to losses by absorption in the rock, especially observed for IM-29. The quantity of oil decreases with time for all the oils and for the two conditions tested. Regarding IM-29, final quantities of 0.04 g (North) and 0.07 g (South) were measured. Highest quantities were recovered on tiles covered with IM-28 and IM-27, for the "South face" condition. For each oil tested, the kinetic of degradation is faster for tiles set up on the North face of the quay, face exposed to more dynamic conditions (wave action). Those data are in agreement with the visual observation (Figure 52 and Figure 57). However, after eleven months in the field, remaining oil on the tiles covered with HFO and IM-29 is similar regardless of the condition tested.

After eleven months of exposure to natural conditions, tiles set up on the North face of the quay exhibit a loss of oil ranging from 87% (IM-28) to 96% (IM-29 and HFO). Tiles set up on the South face of the quay exhibit a loss ranging from 69% (IM-28) to 94% (HFO).

3.4.1.3 Tiles recolonization

During the eleven months of monitoring, no barnacles or algae were observed on the tiles installed on the South face of the quay on the polluted tiles or on the control ones (see Figure 57 and Figure 58).

On the North face of the quay, thick layers of green algae were observed on the tiles (polluted and not polluted) between the time steps six and nine months (See Appendix 5). Barnacle's colonisation started end of April, after six months in the field. The organisms were, at this stage, difficult to see and their presence was limited to few individuals.

After eleven months of exposure, and five months of growth, barnacles were clearly visible on the control and the polluted tiles (Figure 52 and Figure 53).

Figure 61 presents the estimation of barnacle's abundance on the tiles subsampled at T4, T5 and T6. Globally, compared to the control tiles, tiles covered with IM-28 exhibit less barnacles. On the contrary, tiles covered with IM-29 exhibit more of them. This is in agreement with the visual observations (Figure 52 and Figure 53). Tiles covered with IM-27 and HFO are more variable and closest from the results obtained with the control tiles.

In the conditions of those trials, a thin layer of LSFO on granite tiles can induce a decrease or an increase of barnacle's fixing, depending on the oil's nature.

Figure 60 left) Tile covered with HFO, at T4 (6 months), the little white dots are barnacles, right) picture taken with the binocular loupe in Cedre's laboratory

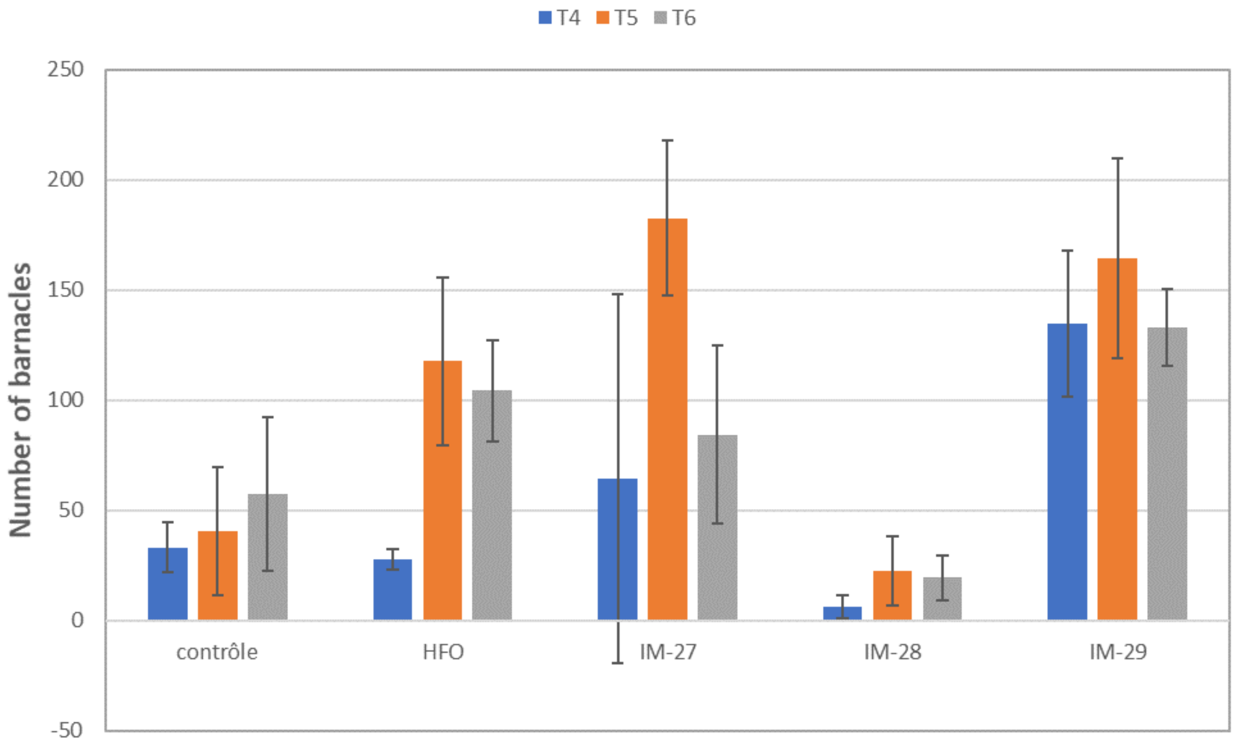


Figure 61 Evaluation of the number of barnacles, using the frame (see Figure 21), on the north tiles

3.4.1.4 Chemical composition of the oils

All the data are presented in Appendix 7. The abundances are normalized to a non-weathered compound, hopane (compound 30ab) in order to compare samples despite their different concentrations. This allows a comparison of the different samples with time.

Degradation rate of PAH

A high decrease of PAH is observed between the fresh oils (taken from the bottles at the laboratory) and the T0 (tiles sampled just before setting up in the field, after fifteen days of drying and soaking in water tanks at Cedre) (data shown in Appendix 7). A loss of 21%, 29%, 46% and 68% is respectively calculated for IM-27, IM-28, HFO and IM-29. This decrease is due to evaporation and dissolution processes before set up in the field.

After setting up in the environment, a decrease of PAH is observed with time for the four oils tested. (Figure 62). Regarding IM-27 and HFO, the kinetics of degradation seems slightly more important for the tiles exposed to the South face of the quay. This is in agreement with the results obtained by Jézéquel et al. (2005). The two different expositions (North and South) do not affect the PAH degradation of IM-28. Finally, PAH degradation of IM-29 is more variable and no trend can be raised between the two expositions. However, at the end of the trials, the differences between the two conditions tested (North and South faces of the quay) are quite similar for the four oils.

Over the eleven months of trials, a maximum loss of PAH of ~96% was calculated forIM-28. The minimum loss calculated for HFO, was of ~75%.

This result should be related to the global concentration of PAH in the oils. PAH quantification was performed on the four fresh oils. It appears that the comparative heavy fuel oil exhibits significant higher concentrations (107 mg/g) than the three LSFOs (12 mg/g for IM-27, 26 mg/g for IM-28 and 50 mg/g for IM-29).

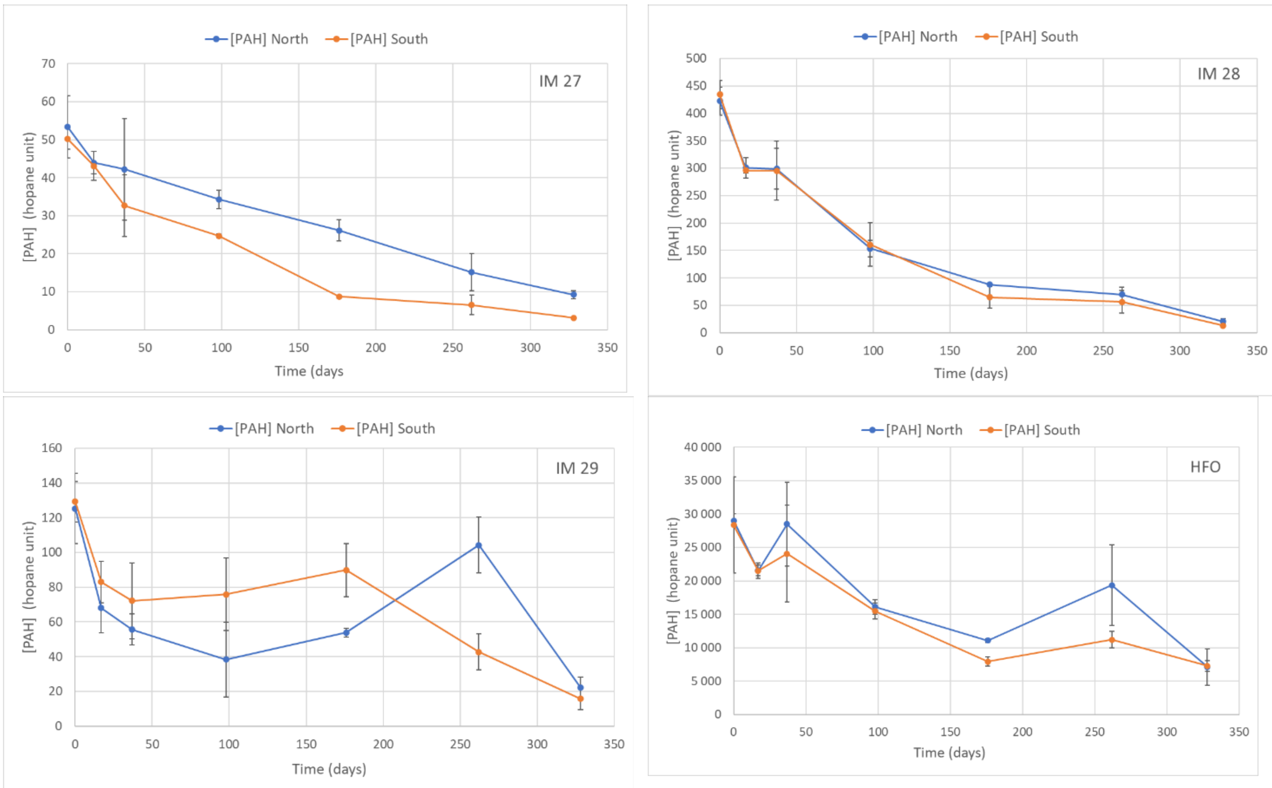


Figure 62 Evolution with time of the sum of the abundances of PAH (normalized on the hopane compound 30ab)

<u>Degradation rate of n-alkanes</u>

The high decrease observed for the PAH between the fresh oils (taken from the bottles at the laboratory) and the T0 (tiles sampled just before setting up in the field, after fifteen days of drying and soaking in water tanks at Cedre) is not observed for the n-alkanes (Appendix 7). Only the comparative HFO exhibits a loss of 44%.

After setting up in the environment, a decrease of n-alkanes is observed with time for the four oils tested (Figure 63).

Regarding IM-27 and IM-28, the n-alkanes degradation is more important for the tiles exposed to the North face of the quay. This is in agreement with the results obtained by Jézéquel et al. (2005)[6]. The impact of the different exposition on the quay is globally not observed on the IM-29 oil. Finally, regarding the comparative heavy fuel oil, a higher degradation is observed on the North face during the four first time steps but similar abundances are finally reached at the end of the trial.

Regarding the North face, an important loss of n-alkanes of between 81% and 88% was calculated for the four oils.

[6] Jézéquel, 2005 : « Pollution d'un littoral par fiouls lourds : Etude de l'influence des paramètres environnementaux sur la persistance et l'évolution chimique du polluant », thèse de doctorat de l'Université de Bretagne Occidentale

Regarding the South face, the loss of the same compounds is more variable between the oils tested. It ranges from 16% for IM-28 to 80% for the comparative fuel oil. IM-27 and IM-29 exhibit intermediate degradation rates of respectively 35% and 69%.

Jézéquel et al (2005) explained the higher degradation rates obtained for the tiles located on the North face of the quay by an enhanced bacterial development in shaded areas. Among several hypotheses detailed in its study, he listed the presence of a bacterial biofilm that boosts the biodegradation of n-alkanes and the secretion of organic matter by barnacles which could enhance the bacterial development. In our study, algae and barnacles were observed on the North face. This could explain the highest n-alkanes degradation observed on the tiles located on this face of the quay.

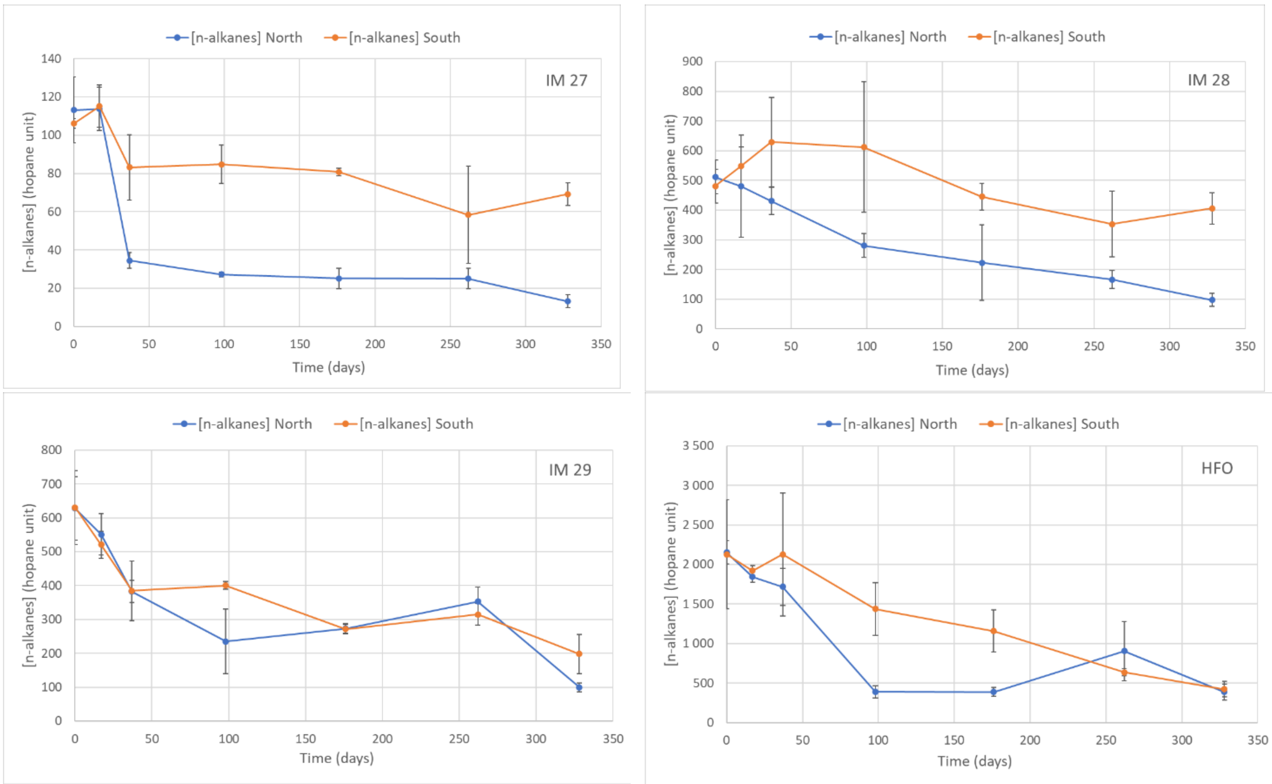


Figure 63 Evolution with time of the sum of the abundances of n-alkanes (normalized on the hopane compound 30ab)

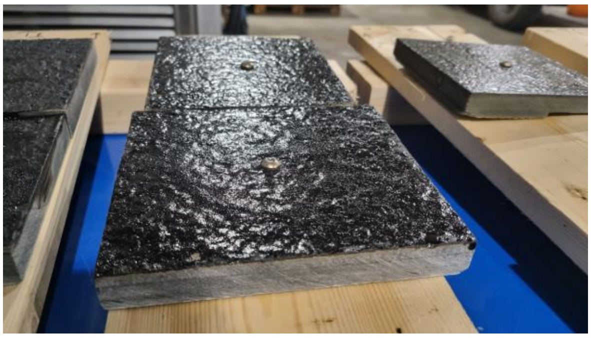
3.4.2 Experiments in Norway

3.4.2.1 Visual observation

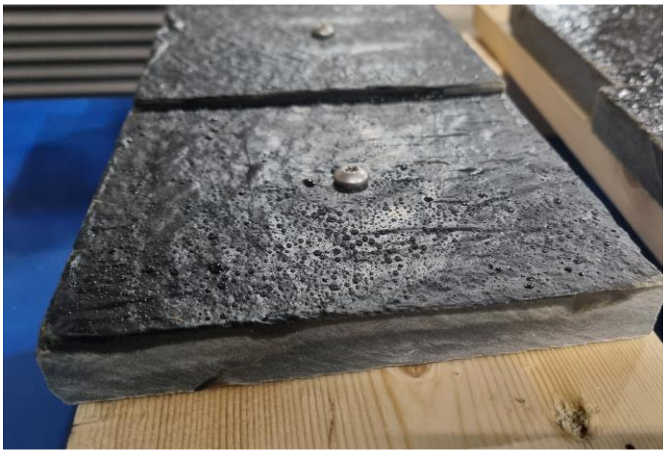
Pictures of the initial (T+15 days) and final time steps are presented on Figure 64 - Figure 67. Appendix 5 presents pictures of each time step.

Visual changes were noticed three months after the beginning of the experiments (end of May) and were enhanced with time. Tiles covered with HFO and IM-29 seem to exhibit the highest removal rates. However, the oils are much more persistent than in the experiment performed in France.

Figure 64 Picture of the tiles after 15 days of exposure



HFO IM-27



IM-28 IM-29

Figure 65 Picture of the sampled tiles, collected after 15 days of exposure

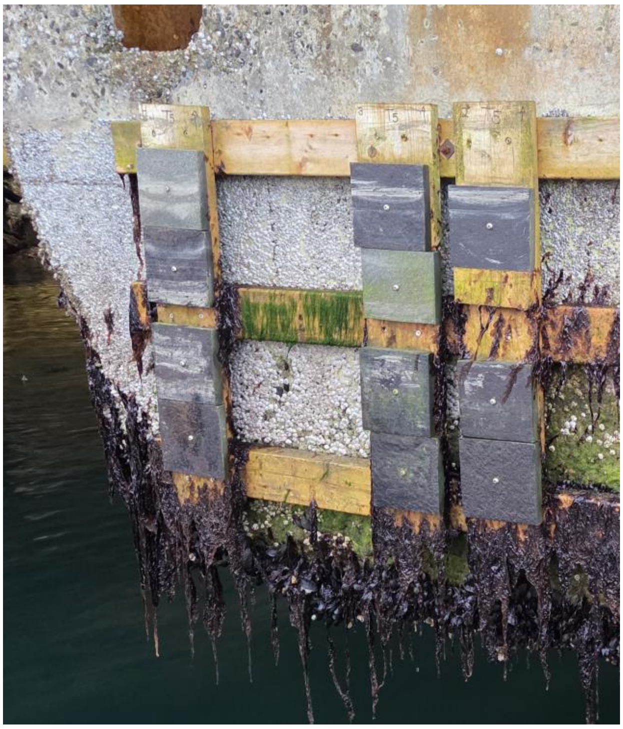


Figure 66 Picture of the tiles after 8 months of exposure

HFO IM-27 IM-28 IM-29

Figure 67 Picture of the sampled tiles, collected after 8 months of exposure

3.4.2.2 Quantitative degradation

At each time step, the tiles collected were extracted in order to quantify the remaining oil. Figure 68 exhibits the evolution, with time, of the remaining quantity of oil on the tiles. The detailed masses from each tile as well as the standard deviations are presented in Appendix 5 (Section II – Experiment in Norway). It should be noted that the last time step for HFO and IM-27 was removed from the graph as the quantity extracted was not realistic (much higher than the initial masses added). This result could not be explained.

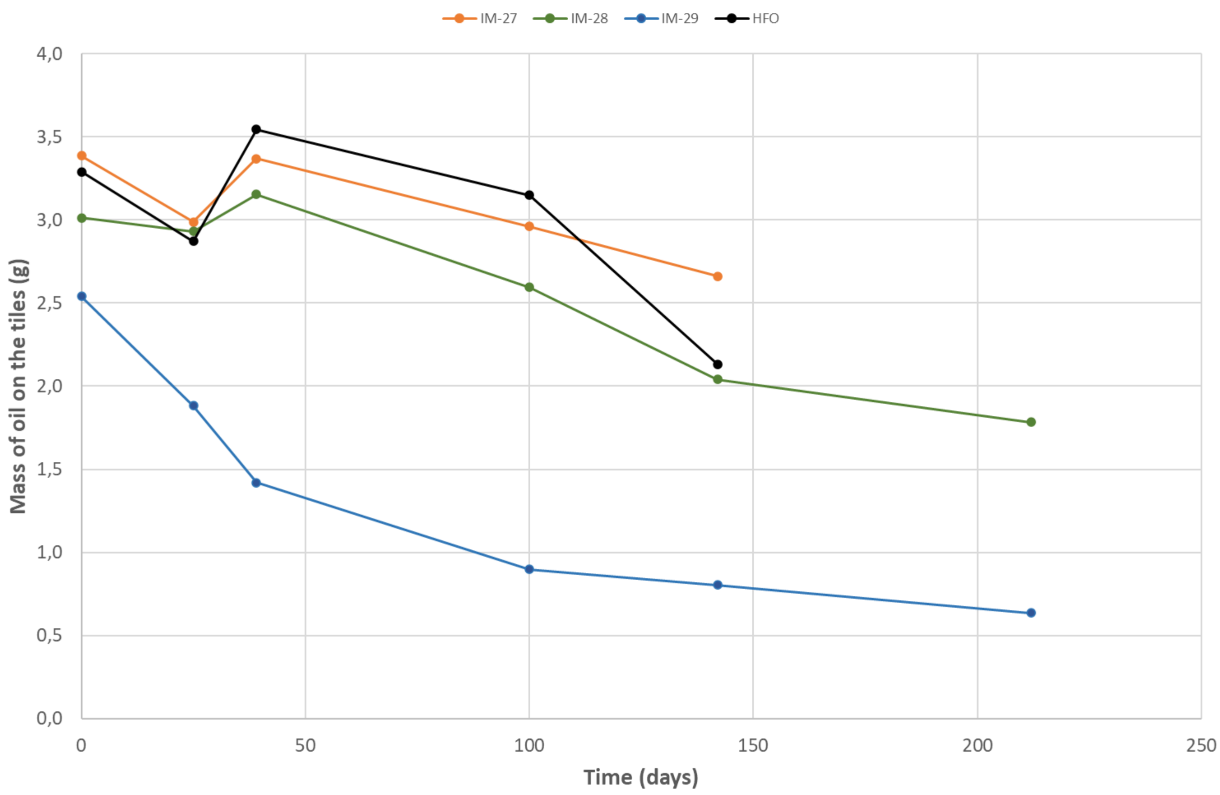


Figure 68 Evolution with time of the averaged quantity (in g) of oil extracted on from the Norwegian tile's surface

As previously documented in the experiment conducted in France, the discrepancies in initial masses primarily result from oil absorption into the substrate, a process most pronounced for IM-29. However, this absorption phenomenon was less marked in the current study compared to the French trials, likely due to differences in rock's nature—specifically, the use of slate in Norway versus granite in France.

The behavior of IM-29 mirrored that observed in France, with a rapid mass loss occurring within the first three months of weathering. This pattern suggests a combined effect of oil removal and absorption. In contrast, the remaining three oils (HFO**,** IM-27, and IM-28) exhibited delayed oil removal, initiating only between time steps 2 and T3 (100 days, late May). For these oils, penetration into the substrate appeared minimal, and the observed mass reduction was attributed solely to surface oil removal, a process accelerated during spring and summer conditions.

After eight months of exposure under natural conditions, oil loss reached 75% for IM-29 and 41% for IM-28, while HFO and IM-27 recorded losses of 35% and 21% (calculation on the T4 time step). These results indicate slower degradation kinetics compared to the French experiment, consistent with the influence of colder climatic conditions on oil weathering processes.

3.4.2.3 Tiles recolonization

After six months of weathering, in July, a total of two barnacles was observed on control tiles. After eight months of weathering, some growth of green algae on the control tiles and the tiles covered with IM-29 was reported but no barnacles were observed on the tiles (polluted or not). The effect of the LSFOs on the rock's recolonisation could thus be followed.

3.4.2.4 Chemical composition of the oils

All the data are presented in Appendix 7.

Degradation rate of PAH

After setting up in the environment, and as it was already observed during the experiments performed in France, a decrease of PAH was observed with time for the four oils tested (see Appendix 7, Section II experiment in Norway). A loss of PAH of 55% was calculated for the heavy fuel oil. The loss of PAH is higher than 92% for the three LSFOs tested.

Evolution of the abundances between the French and the Norwegian experiments was compared. Figure 69 presents the results obtained for the IM-27 oil. After 100 days, data are in the same range between the two sites.

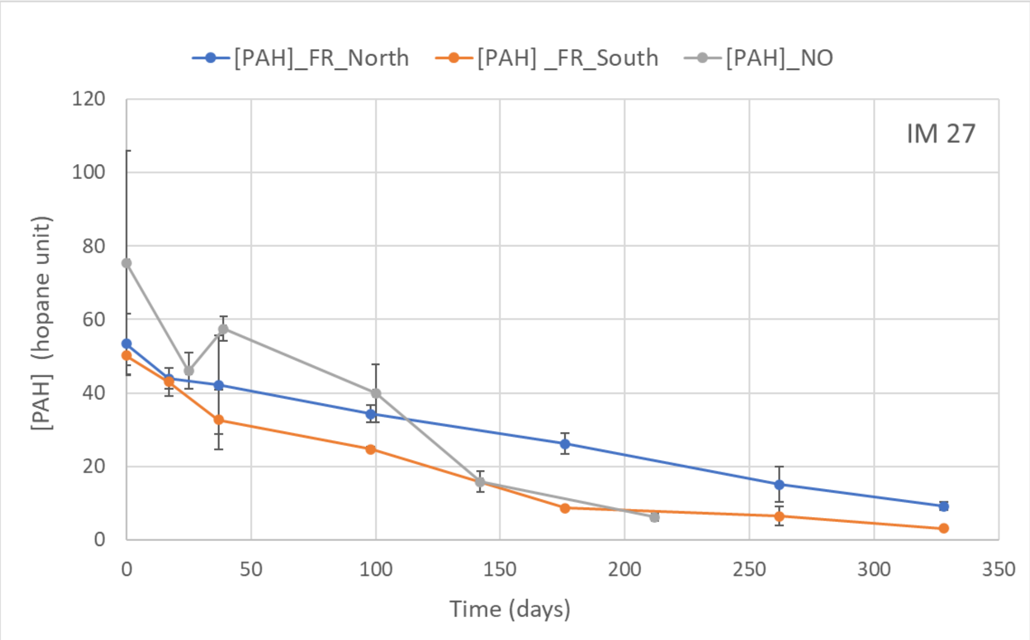


Figure 69 Comparison of the evolution with time of the sum of the abundances of PAH (normalized on the hopane compound 30ab) between the French (in blue and orange) and Norwegian (in grey) experiments.

Degradation rate of n-alkanes

No evolution of n-alkanes was observed between the initial and the final time steps of the Norwegian trials (See Appendix 7, Section II experiment in Norway).

As with PAH, evolution of the n-alkanes abundance between the French and the Norwegian experiments was compared. Figure 70 presents the results obtained for the IM-27 oil. After 39 days of weathering a clear difference is noticed between the Norwegian and the French trials and indicates different biodegradation processes at the two sites.

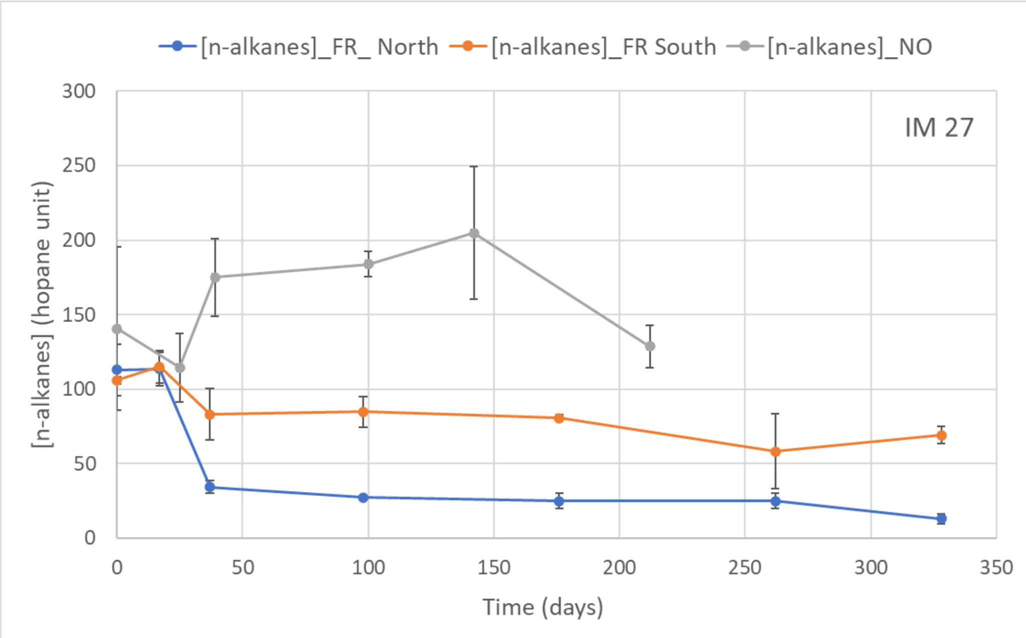


Figure 70 Evolution with time of the sum of the abundances of n-alkanes (normalized on the hopane compound 30ab) (Norwegian experiment)

3.4.3 Experiments in Malta

3.4.3.1 Visual observation

Figure 71 and Figure 72 show the rocks appearance at the beginning and at the end of the trials. At the beginning of the experiment, some differences were noticed between the different oils tested. Rocks covered with IM-29 were clearer than the other ones. Some differences were also noticed for each oil tested, between the different rocks used, as can been shown on Figure 71 for the IM-27 oil. At the end of the trials, some rocks were lost and others were broken. The remaining rocks were sent to Cedre for deeper visual observation and chemical analyses. No extraction was performed for oil quantification for those simplified trials as the rocks were not calibrated as the rock tiles in France and Norway.

Figure 71 Wooden frames with polluted rocks before setting up in the harbour

Figure 72 Wooden frames withdrawal after three months at sea

After three months of exposition to Mediterranean conditions, oil was hardly visible for the three LSFOs tested and the two types of rocks tested, except at the location of some metallic washers. The rocks were fully recovered with different types of algae/organic matter.

3.4.3.2 Tiles recolonization

Figure 73 shows a detailed view of rocks polluted with IM-28 and IM-29, respectively. All the visible black patches have been attributed to algae after observation at the microscope.

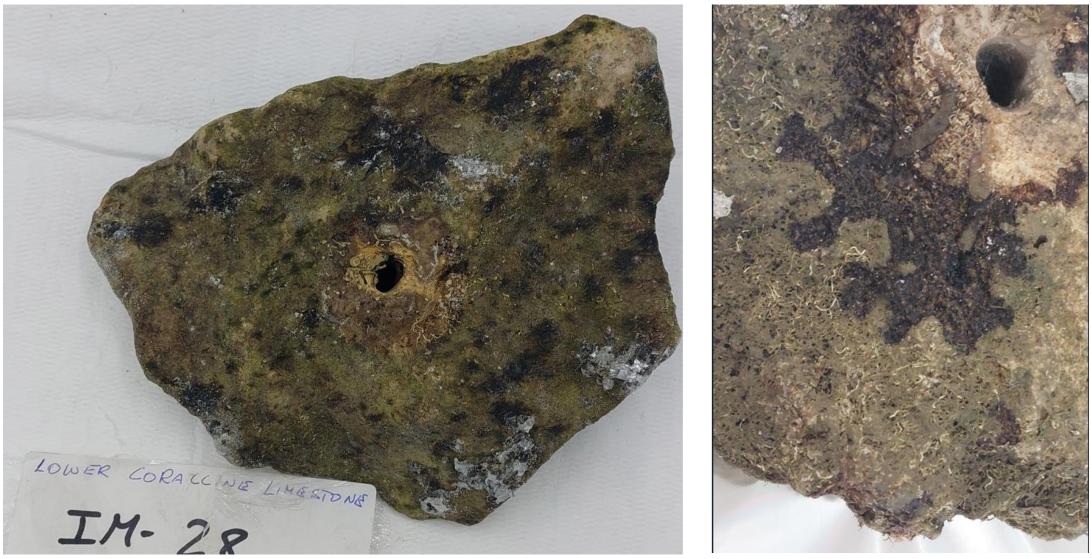


Figure 73 Black patches of algae covering rocks polluted with IM-28 (left) and IM-29 (right) respectively.

Large part of the rocks was covered with a thick layer of greenish/whitish algae and organic matter. Below this layer, a dark colouring was observed but could not be associated to oil or algae (Figure 74).

Figure 74 Zoom on a thick layer of organic matter on the top of a rock. The nature of the black colour seen below this layer is not identified (oil or algae).

At the end of the trials, in terms of covering with organic matter, no difference was observed between the top polluted faces and the sides not polluted (Figure 75).

Figure 75 (left) Rock polluted with IM-28 on the top side. (right) same rock, other view on a side not polluted: no differences are noticed between the polluted face and the other faces

3.4.3.3 Chemical composition of the oils

All the data are presented in Appendix 7.

A high decrease oh PAH and n-alkanes was observed for the four oils and the two rocks tested. Over the three months of experiments, a loss ranging from 81% (IM-28 -Lower Coralline Limestone) and 98% (IM-29 – Lower Coralline Limestone) was calculated regarding the PAH. Regarding the n-alkanes a loss ranging from 80% (IM28 - Lower Coralline Limestone) and 99% (IM-29 – Lower Coralline Limestone and HFO) was calculated. Those results reflect the importance of the photo-oxidation and biodegradation processes affecting the chemical composition of the oils in such environmental conditions.

Regarding the trials performed in France, Noway and Malta, the following main conclusions can be drawn:

- **Natural degradation is temperature dependent with higher removal rates in warm environments ;**
- **In cold climate, even if oil removal is visible and quantifiable, tiles are still highly coloured. Biota recolonisation was not observed on the polluted tiles or on the clean ones.**

- **In temperate environment, natural removal is more pronounced, especially for tiles exposed to dynamic environmental conditions. Barnacles' growth was observed on all the tiles, with differences noticed between the oils.**
- **In warm climate, even after only three months of exposure, oil is hardly visible and rocks are all covered with a thick layer of organic matter. However, oil could be extracted from all the rocks tested and indicate a high degree of PAH and n-alkanes degradations.**

3.5 Interaction with sediments (Task 5.5)

All the tests were performed at ambient temperature. Trials were performed in June. Air and water temperatures were around 20-25°C.

3.5.1 Main observations

- *Detailed results obtained during those trials are presented in Appendix 8.*

On sandy beaches, some LSFOs (such as IM-29), fresh or naturally emulsified oils thanks to successive tidal cycles and agitation, can fully penetrate in the sediment or lay down, like frozen (such as IM-28) on the top of the sediment (Figure 76). IM-29 remained fluid over the several days of experiments. IM-27, IM-28 and HFO slowly emulsified and turned more viscous. IM-27 exhibited an intermediate behaviour, with progressive full penetration observed at low tide as the oil weathers.

IM27

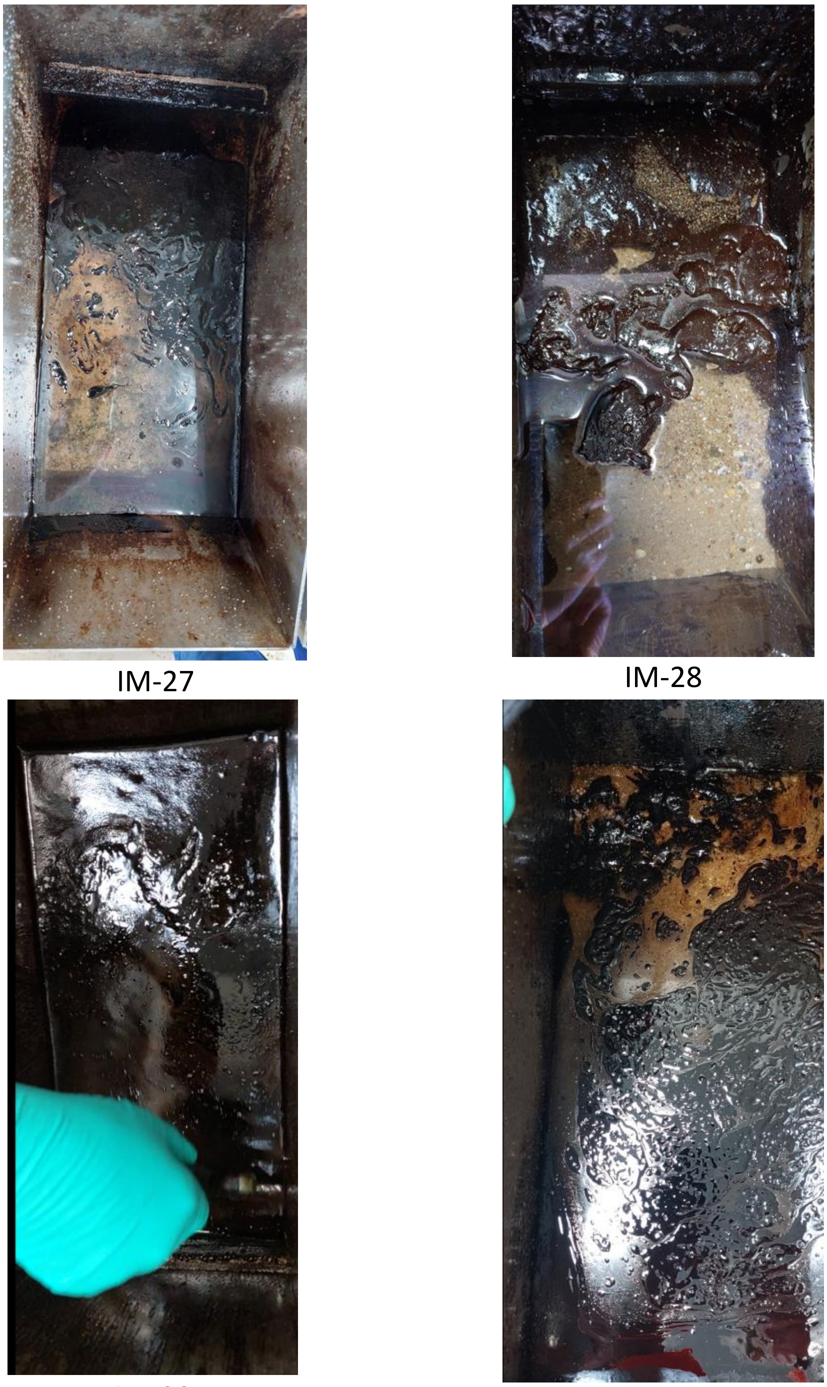
IM28

IM29

HFO

Figure 76 Pictures taken after several days of low and high tides and agitation

Slow addition of water on the sand leads to an immersion of the pollutant, that stays on the top of the sediment. Agitation of the water is needed to allow the remobilisation of the oil from the surface of the sediment (Figure 77). Remobilisation of highly viscous oil such as IM-28 can still be limited and oil needs time to resurface. Vigorous manual mixing of the sediment itself allows the remobilisation of the oils trapped in the sediment.



IM-27 IM-28

IM-29 HFO

Figure 77 Oil resurfacing after water addition and agitation

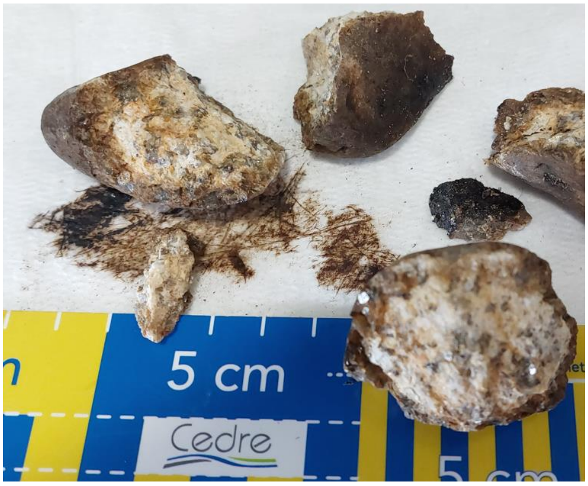
The comparative HFO exhibits a behaviour close to the one of IM-28, with, at low tide, limited penetration and possibility to roll it with low incorporation of sand and a very high tendency to stick to the tank walls and to the tools.

On the gravels and the pebbles, behaviours of the oils are nearly the same. Oils (poured at 50°C) seep into the sediment (dry or wet). Slow addition of water on the polluted sediments leads to an immersion of the pollutant, that stays on/in the sediments. Only fluid LSFOs such as IM-29 exhibit a remobilisation of some slicks on the water surface. Agitation of the water is needed to remobilise the oil layer covering the sediment, leaving the surface of the sediment almost clean. Manual agitation of the sediment allows a remobilisation of the trapped oil, leaving cleaned sediments.

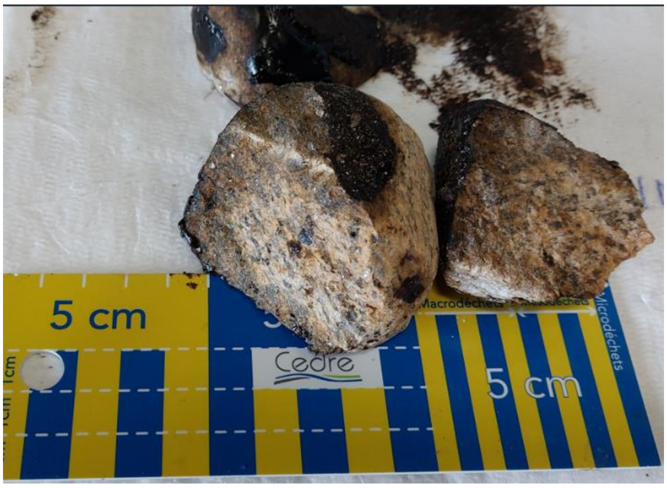
Regarding response options, based on those pilot-scales trials, some recommendations can be drawn. Surfwashing operations with recovery of the oils by nets could be recommended on polluted exposed sandy beaches, depending on their geomorphology and the local wave strength. Some highly viscous oils, also characterized by a high pour point, could be recovered directly on the sand, with shovels or earthmoving equipment, with limited sand aggregation.
Taking into account the ecological sensitivity of the polluted sites, regarding rocky shores, flushing or concrete mixer with recovery of effluents seem to be efficient techniques. Vigorous energy of the sediments themselves leads to an effective remobilisation of the oils.
More cleaning tests were performed by NCA part of the Task 5.6.

3.5.2 Penetration of the LSFOs in the pebbles

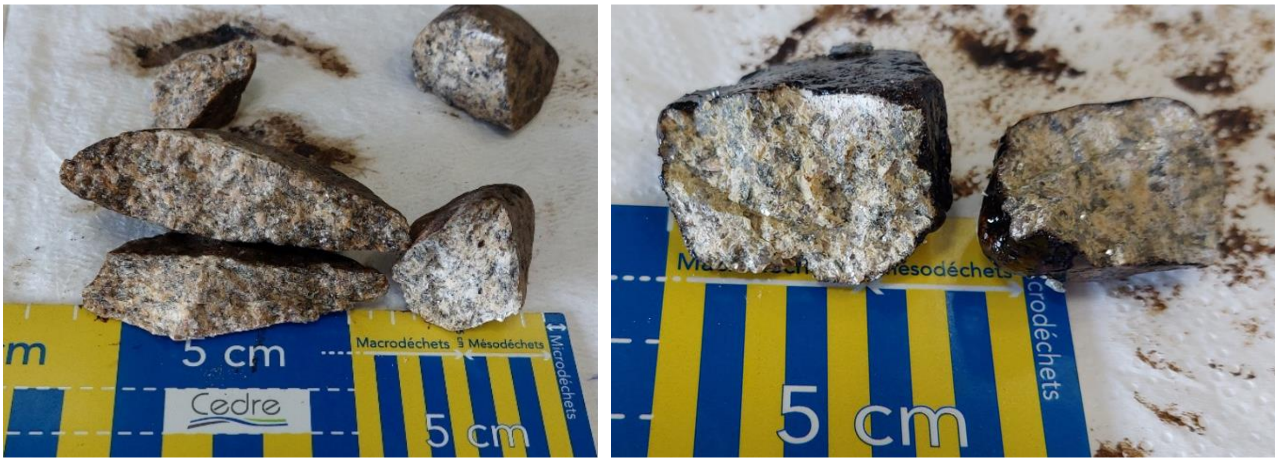
At the end of the trials, selected pebbles were broken to investigate oil penetration. Consistent with observations from the granite tile experiments, visible oil penetration was evident in pebbles exposed to the three low-sulphur fuel oils (LSFOs: IM-27, IM-28, and IM-29), but not in those exposed to the heavy fuel oil (HFO).



IM-27



IM-28



IM-29 HFO

Figure 78 Pictures of pebbles collected in the tanks at the end of the trials, showing the oil penetration for the three LSFOs

3.6 Observations on practical cleaning techniques (Task 5.6)

- *Detailed results obtained during those trials are presented in Appendix 9.*

3.6.1 Small-scale tests

3.6.1.1 Small-scale test 1 and 2 – frozen surroundings

The primary objective of the tests was to determine whether the "Godafoss effect", the observed ease of oil removal from cold, icy shorelines, could be measured and documented under controlled sub-zero conditions. A particular focus was placed on whether oil would be easier to remove from wet, frozen rock surfaces compared to other conditions.

The results showed no significant difference in oil adhesion between dry and wet pebbles under the test conditions. However, some variation was observed depending on the texture of the rock surface. As expected, oil adhered more easily to rougher surfaces, indicating that surface structure plays a more critical role than the wet or dry surface in influencing oil retention on frozen substrates. Among the cleaning methods evaluated, polishing with sorbents consistently proved to be the most effective in terms of cleanliness. Although this approach generates additional waste, it facilitates direct transfer of oil into the sorbents without contaminating gloves or other equipment.

All tested oils demonstrated a moderate to high potential for release from pebbles when submerged in a water bath at 25°C, even without the application of external energy. When mechanical energy was introduced—such as hand washing or brushing—the cleaning efficiency increased significantly. Overall, the three LSFO test oils were easier to remove from the pebbles compared to the IFO380. Of the LSFO samples, IM-29 was the easiest to clean off, followed by IM-27, while IM-28 showed similar adhesion characteristics to IFO380.

Based on these observations and test results, we assess that water temperatures in the range of approximately 20–25°C, combined with mechanical energy (e.g., flushing, surf washing, tumbling, or manual scrubbing), are likely sufficient to remove oil from pebbles and cobbles. These findings also allowed us to refine the planned water temperature parameters for the next round of testing. During initial testing, challenges were encountered in getting the emulsified LSFO test oils to adhere to the cooled pebbles prior to re-freezing. This could indicate that the tested oil emulsions are less likely to stick to the shoreline under cold conditions. Findings indicate that all test oils exhibit substantially lower stickiness in emulsion form compared to their fresh counterparts, furthermore, fresh IM-27 also appears to be less adhesive than traditional bunker oils.

All three oils—particularly IM-27 and IM-29—demonstrated a stronger tendency to adhere to nitrile gloves than to the rock surfaces, indicating potential differences in surface affinity.

For detailed results and observations related to each oil and test condition, please refer to the test forms for small-scale tests 1 and 2, included in the appendix at the end of the report.

3.6.1.2 Small-scale test 3 – water baths

In tests conducted without the addition of mechanical energy – relying solely on temperature – we observed that IM-27 began to release from the pebbles at the lowest temperature, with minor detachment already visible at approximately 15°C. The experiment is illustrated in Figure 79.

Throughout the test range, IFO380 consistently exhibited a higher degree of oil release compared to the three LSFO test oils. IM-28 and IM-29 showed no significant release at lower temperatures, with noticeable detachment only occurring at the highest temperature range (42 – 44°C).

Interestingly, the release temperature for IM-29 was considerably higher than anticipated, while IM-27 responded at a much lower temperature than expected. These deviations may be related to the specific test setup or methodology. Despite this, we still expected IM-29 to respond at lower temperatures in upcoming tests (3.6.2), and that IM-27 may require more mechanical assistance than initially assumed.

We anticipate that the introduction of mechanical energy – such as high-pressure washing, tumbling, or agitation – will enhance oil removal and lead to observable effects at lower temperature threshold.

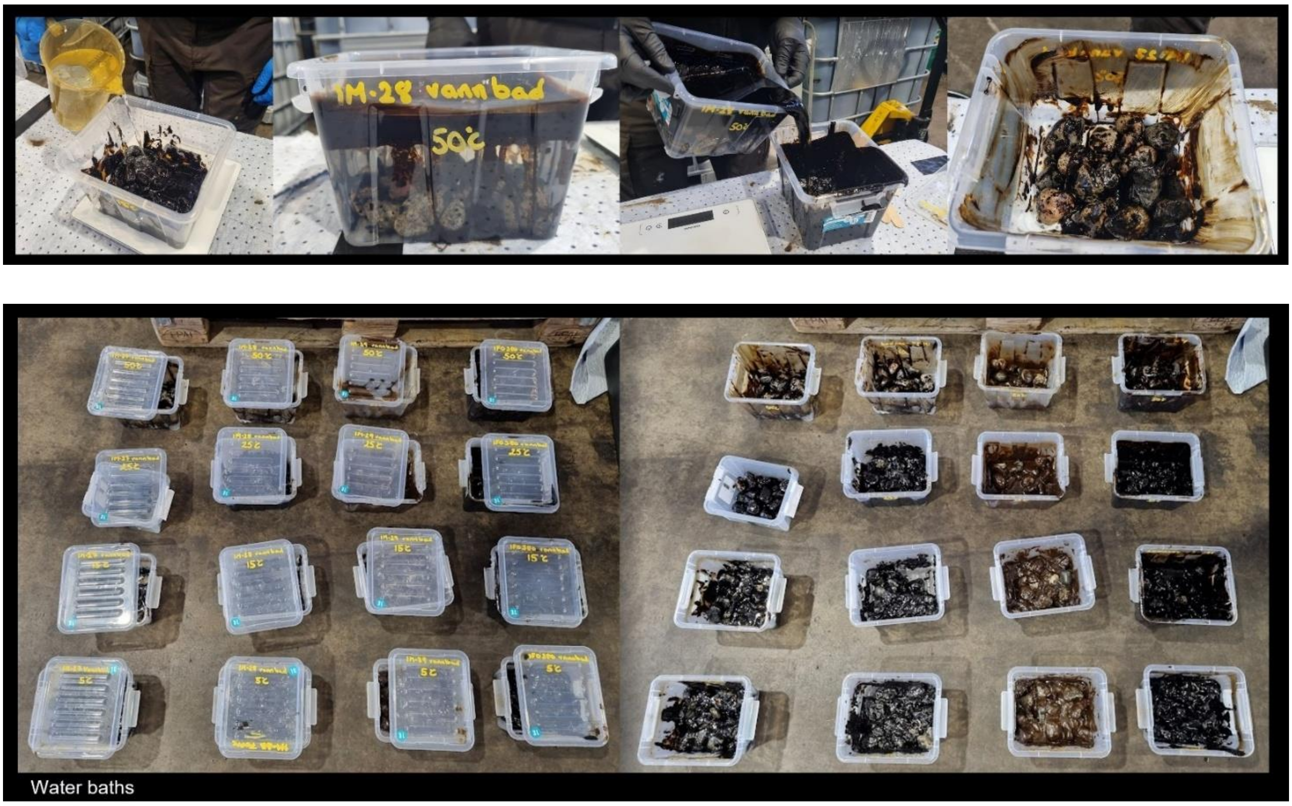


Figure 79: Small-scale test 3 - release of oil at different water temperatures.

3.6.1.3 Small-scale test 4 – concrete mixer

Co-funded by the European Union

During the tumbling process in the concrete mixer, we observed that the oiled pebbles – particularly those with IM-27 and IM-29 – began releasing water from the oil emulsions almost immediately. This likely originated from water pockets within the emulsions. Remarkably, this led to partial self-cleaning of the pebbles after only a short period of tumbling, even without the addition of water. However, the released oil subsequently adhered to the inner surface of the mixer drum and was then redistributed onto the pebbles, resulting in re-contamination.

At lower temperatures, IM-28 caused the pebbles to adhere to the drum surface, effectively halting the intended mechanical action – namely, the friction between pebbles and between pebbles and the drum wall. This significantly reduced the cleaning efficiency, indicating that the method is ineffective unless water temperatures are sufficiently high.

Despite these limitations, the technique is considered effective under the following conditions:

- IM-27 and IM-29: Effective cleaning observed at water temperatures as low as 13°C.
- IM-28: Effective at 25°C, with some effect noted at 20°C.
- IM-28 with shoreline cleaning agent: Effective at 11°C.

We also noted that the mason bucket used for collecting the mixer contents post-tumbling did not provide sufficient water volume to prevent reattachment of oil to the pebbles. A larger water volume—such as releasing the mixture into the wave zone within a boom barrier—could mitigate this issue. However, this approach introduces challenges related to oil skimming, as previously identified in WP4.
An alternative solution could involve a closed cleaning station equipped with a receiving pool of higher water volume. This would allow for better control of water temperature and facilitate the use of shoreline cleaning agents more effectively (see Figure 81 and Figure 82).
Overall, the concrete mixer method is considered a viable approach for cleaning pebble beaches, provided that water temperature is appropriately adjusted to match the oil type (See Figure 80).
Additional tests using sorbents (e.g., bark) demonstrated effective cleaning of the pebbles. However, due to the high degree of oiling in the test setup, a large volume of sorbents was required relative to the number of pebbles, making the method inefficient for use inside the mixer at this stage. Nevertheless, this technique remains promising as a finishing or polishing method, particularly when oil contamination is limited (see also section 3.6.3).

Figure 80: Cleaned pebbles after tumbling in concrete mixer.

3.6.2 Results - container test

Detailed results from all tests are presented in Appendix 9.

The three LSFO test oils demonstrated behaviour that deviates from typical expectations based on experience with conventional fuel oils such as IFO180 and IFO380:

- **IM-27** showed characteristics similar to traditional IFO oils. It responded well to flushing as a cost-effective cleaning method, provided the water temperature exceeded 20–22°C. At lower temperatures, additional cleaning measures were required. Polishing with sorbents and the use of shoreline cleaning agents yielded acceptable results even under cooler conditions. IM-27 also performed better than IM-29 when using small disc skimmers, although vacuum skimmers were also effective when applied within a water/oil settling system.
- **IM-28** was clearly the most challenging oil to manage. Its extreme stickiness caused it to behave similarly to IM-29 at low temperatures (coagulated/lumpy), but it adhered more aggressively upon contact with surfaces. Although flushing could release the oil, it quickly reattached. During high-pressure washing tests – conducted at temperatures up to 80°C – even after applying beach cleaning agents, the oil had to be manually “guided” to the drainage system, as it did not flow freely with the water. Once the flow slowed, the oil reattached immediately.
- **IM-29** appeared to be the easiest oil to clean. It was less adhesive than traditional bunker oils and could be flushed out to sea for collection at temperatures as low as 15°C, and likely even lower. However, it proved difficult to skim from the water surface (see WP4 summary report). If flushed into a boom-enclosed area, a handheld vacuum skimmer could be an effective collection method. This would require a field-based settling system to separate water from oil before transporting the recovered oil to waste handling facilities. At low

temperatures, the oil coagulates, and manual tools such as a metal hoof are recommended for retrieval.

Across all tests, the oils demonstrated a stronger affinity for man-made surfaces – such as metal, painted surfaces, plastic, and nitrile gloves – than for natural substrates like pebbles, cobbles, or rock slopes.
Common seawater temperatures (5–28°C) are unlikely to provide sufficient energy to release the oils from shoreline substrates. Therefore, additional mechanical energy – such as water pressure, agitation, or surf washing – is necessary to achieve effective removal.
Due to the variability in behaviour among LSFOs, it is not feasible to draw general conclusions applicable to all low-sulphur fuel oils. The key takeaway is the importance of conducting systematic initial method testing in the event of an LSFO spill. Further details regarding the methods and specific oil types (IM-27, IM-28, IM-29) are provided in the appendix 9.

Operational Considerations
Flushing LSFOs into the sea presents challenges, as some LSFOs are difficult to recover mechanically. Additionally, highly adhesive oils may reattach to surfaces, reducing the effectiveness of flushing or surf washing.

One promising approach for managing sticky, short oils on contaminated pebble beaches is the use of a closed in-situ washing system, constructed from readily available equipment (see Figure 81 and Figure 82). The setup can be adapted on what you have in stock. This setup allows for elevated water temperatures and the use of shoreline cleaning agents without direct impact on the shoreline.

To manage the contaminated wash water, settling in an IBC container or similar system prior to discharge may offer a cost-effective solution. This method enables oil separation and minimizes waste generation.

Figure 81: Example of a "sealed off" in-situ washing station: high pressure washer with heater, concrete mixer for tumbling/washing, vacuum pump skimmer for skimming the washing pool and an IBC container for collecting washed out oil from the pool and for settling of water /oil.

Figure 82: Simple version of in-situ washing station, without heated water or vacuum skimmer (if water temperature and tumbling is enough).

3.6.3 Cleaning after long time weathering

The “beach” was outside for more than 4 months, from 11th June to 23rd October. As shown in Figure 83, Figure 84 and Figure 85, the oil surfaces were drying out over time, shifting colour to from black to brown and losing the shining appearance which they had at the start. All the rocks were smearing on the fingers if touched to a different degree, but all the oil types had at “dry” feel to it in different degrees.

Figure 83: 11. June 2025.

Figure 84: 11. August 2025.

Figure 85: 23. October 2025.

IM-27 observations

The pictures shows that the weathering affects the oil layer om the rocks on the top side (Figure 86). The oil had penetrated the sand approximately 5 cm but some of this would have happened already when the oil was poured onto the beach.

Figure 86: Weathering of IM-27.

We followed the planned cleaning procedures and left everything to dry over night for picture taking. The visual aspect after the different cleaning temperatures etc is shown in Figure 87.

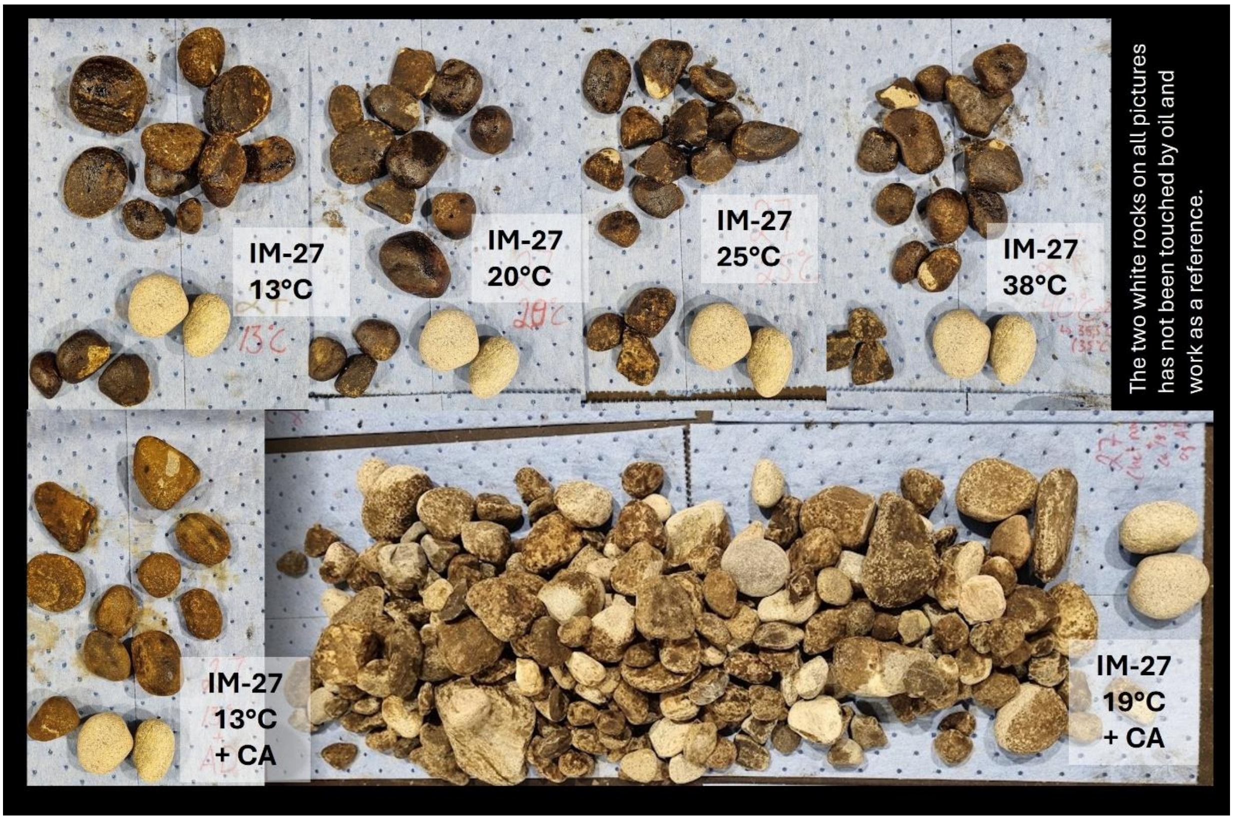


Figure 87: Rocks with weathered IM-27 after treatment.

None of the tested water temperatures, with or without the use of shoreline cleaning agents, resulted in a 100% clean outcome. Compared to the initial condition, the stones became significantly cleaner after just two minutes of tumbling, even at a water temperature of 13°C. However, all stones still showed oil smearing upon contact. Surprisingly, there was little difference in cleaning

effectiveness between tumbling at 13°C and the three other temperatures. A noticeable improvement was only observed when a shoreline cleaning agent was used.
Depending on the intended use of the area, the stones might be considered sufficiently clean even at only 13°C. Nevertheless, regardless of the achieved level of cleanliness, it is recommended to place the stones in the surf zone afterwards to allow for continued natural surf washing. In fact, surf washing alone might have been sufficient without prior tumbling, provided there are no time constraints. In time-sensitive situations, tumbling with the aid of a shoreline cleaning agent followed by placement in the surf zone is recommended.
It was also evident that the stones were visibly discoloured, and even the areas not originally contaminated with oil became stained during tumbling. It is assumed that this discoloration will gradually diminish through natural surf washing, although it remains uncertain whether it will disappear completely.

IM-28 observations
The pictures shows that the weathering affects the oil layer om the rocks on the top side (Figure 88). A lot of oil had gathered in between the rocks and the sand, and a thick layer remained there. Up to a 2 cm oil layer was remaining on top of the sand. The oil had penetrated the sand approximately 2 cm but some of this would have happened already when the oil was poured onto the beach.

Figure 88: Weathering of IM-28.

We followed the planned cleaning procedures and left everything to dry over night for picture taking. The visual aspect after the different cleaning temperatures is shown in Figure 89.

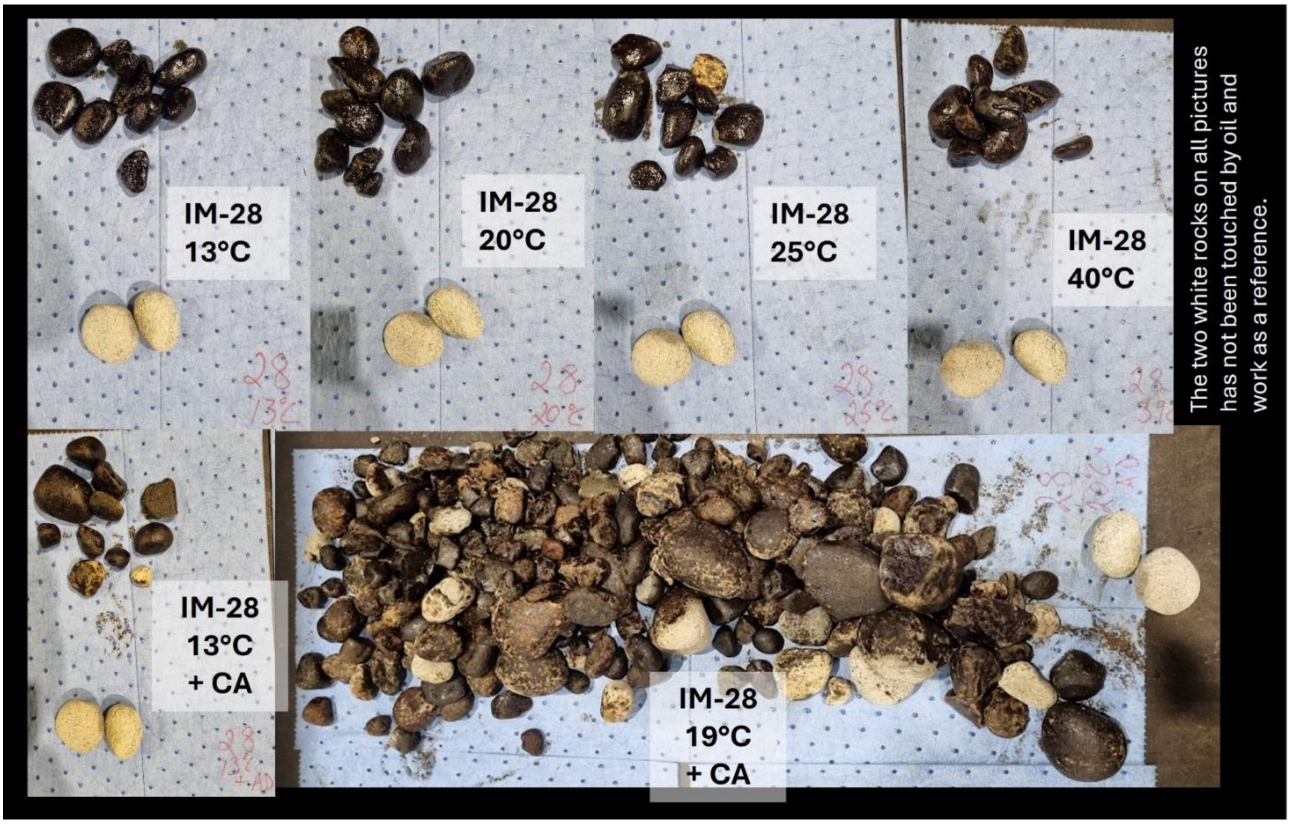


Figure 89: Rocks with weathered IM-28 after treatment.

Although we observed that some oil was removed from the stones during tumbling, the results were far from satisfactory. There was minimal noticeable effect until the water temperature was increased to 40°C, and even then, the cleaning effect remained limited.

When shoreline cleaning agents were added and the stones were tumbled at 13°C, the cleaning effect was significantly more pronounced, though still not sufficient in our assessment. Tumbling with shoreline cleaning agents at 19°C produced an acceptable result, provided that the next step would be surf washing.

In our view, relying solely on surf washing would not be advisable. We would recommend increasing the temperature to 40°C in combination with shoreline cleaning agents, followed by surf washing as a final cleaning step.

Some discoloration was observed, although not to the same extent as with IM-27 and IM-29.

IM-29 observations

The pictures shows that the weathering affects the oil layer on the rocks on the top side (Figure 90). The oil had penetrated through the sand at least 10 cm all the way to the bottom. Some of the penetration would have happened already when the oil was poured onto the beach.

Figure 90: Weathering of IM-29.

We followed the planned cleaning procedures and left everything to dry over night for picture taking. The visual aspect after the different cleaning temperatures is shown in Figure 91.

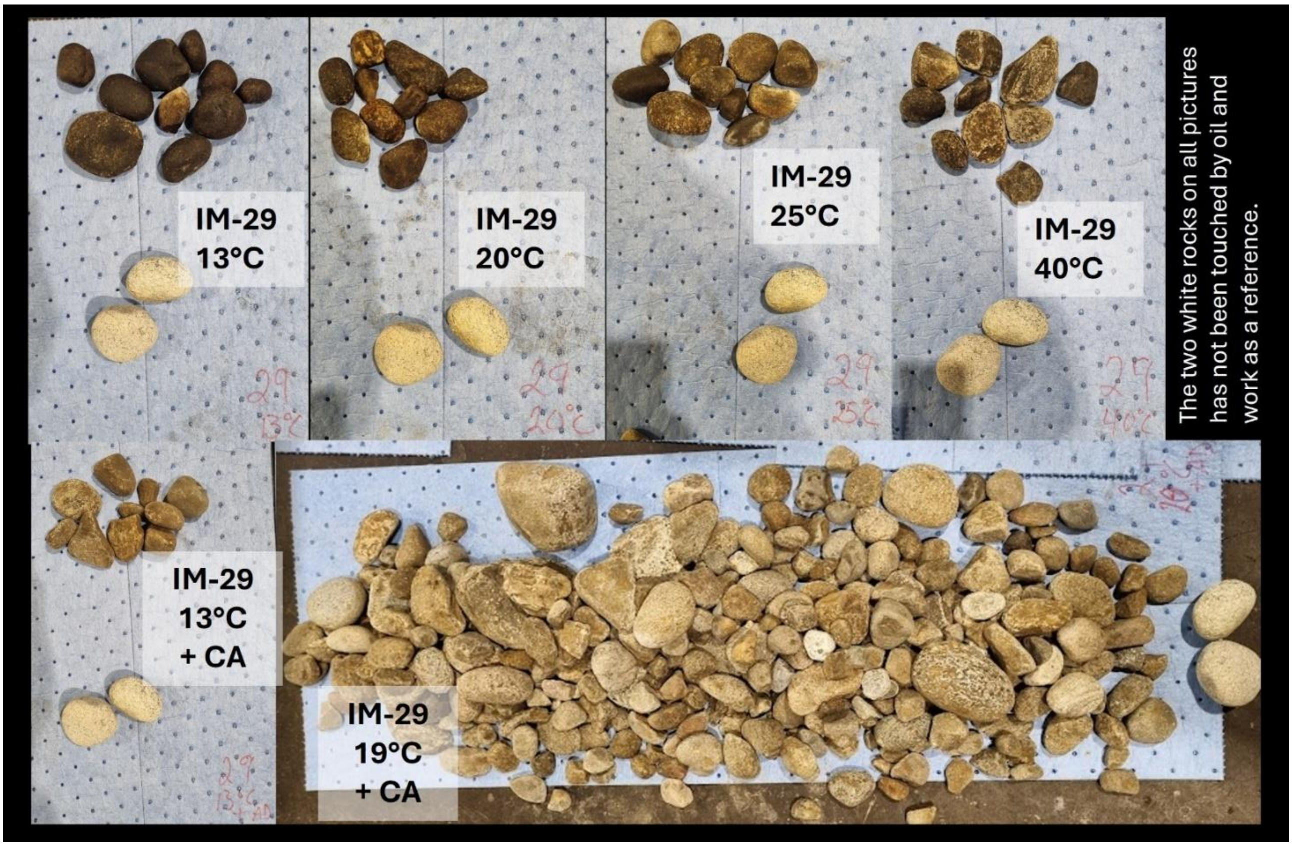


Figure 91: Rocks with weathered IM-29 after treatment.

None of the tested water temperatures, with or without the use of shoreline cleaning agents, resulted in a 100% clean outcome. Compared to the initial condition, the stones became significantly cleaner after just two minutes of tumbling, even at a water temperature of 13°C. However, all stones still showed oil some smearing upon contact. As the pictures shows, the rock became noticeably cleaner as we increased the temperature, but the use of shoreline cleaning agent made a big improvement still.

Depending on the intended use of the area, the stones might be considered sufficiently clean even at only 13°C. Nevertheless, regardless of the achieved level of cleanliness, it is recommended to place the stones in the surf zone afterward to allow for continued natural surf washing. In fact, surf washing alone might have been sufficient without prior tumbling, provided there are no time constraints. In time-sensitive situations, tumbling with the aid of a shoreline cleaning agent followed by placement in the surf zone is recommended.

It was also evident that the stones were visibly discoloured, and even the areas not originally contaminated with oil became stained during tumbling. It is assumed that this discoloration will gradually diminish through natural surf washing, although it remains uncertain whether it will disappear completely.

IFO380 observations

Figure 92 shows that the weathering affects the oil layer om the rocks on the top side. The oil had penetrated the sand approximately 5 cm but some of this would have happened already when the oil was poured onto the beach.

Figure 92: Weathering of IFO-380

We followed the planned cleaning procedures and left everything to dry over night for picture taking. The visual aspect after the different cleaning temperatures is shown in Figure 92.

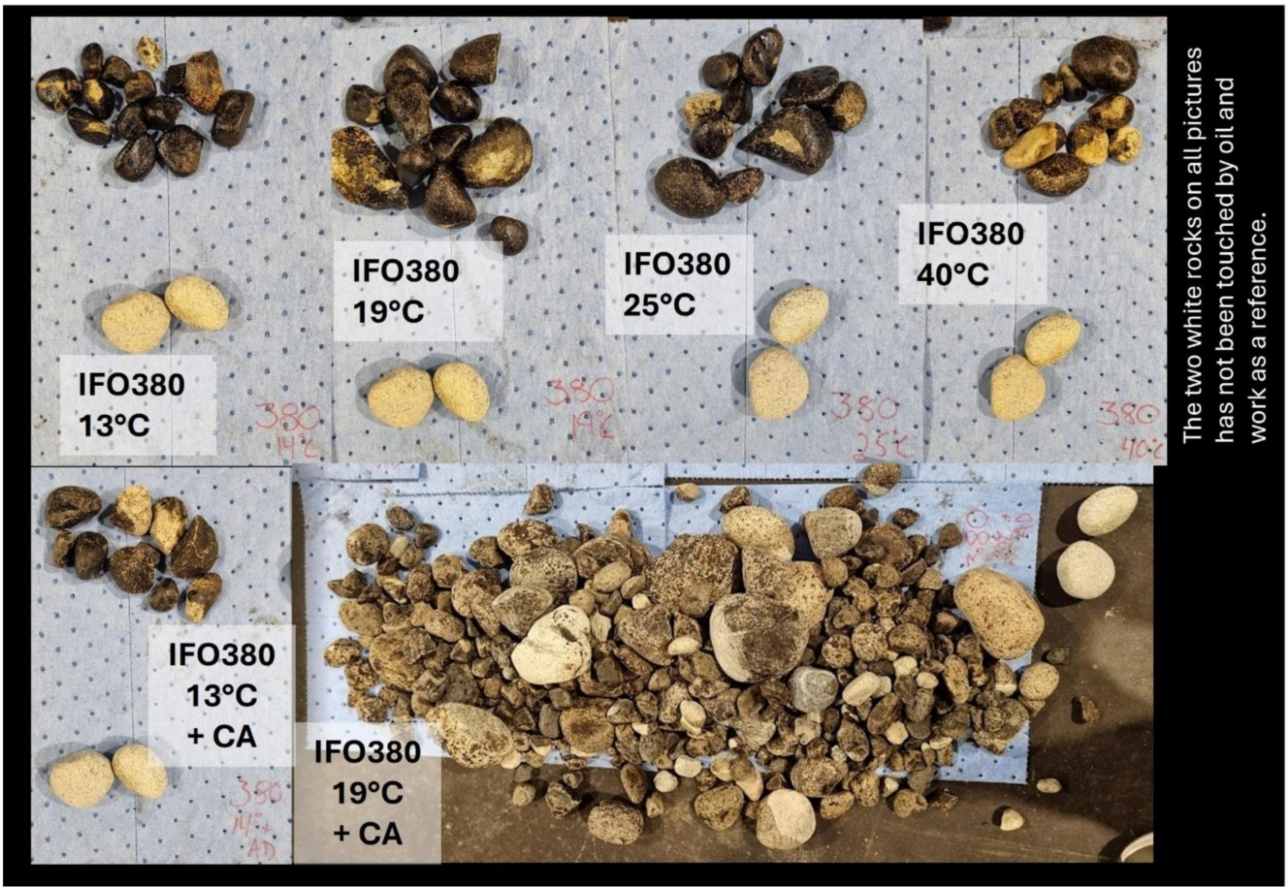


Figure 93: Rocks with weathered IFO 380 after treatment.

As illustrated in the images, the rock surface became progressively cleaner with increasing temperature. Despite this improvement, the overall results remained suboptimal (Figure 93).

Similar to the observations made with IM-27, the necessity of pre-treatment (e.g., tumbling) depends on the intended use of the area. In cases where time is not a limiting factor, surf washing alone may be sufficient. However, it is important to note that tumbling provides the rocks with a significantly cleaner baseline, which can enhance the effectiveness of subsequent treatments.

Regardless of the level of cleanliness achieved through tumbling or surf washing, it is recommended that the rocks be placed in the surf zone afterward to allow for continued natural cleaning by wave action.

The use of shoreline cleaning agent at 19°C during tumbling yielded a noticeable improvement and is recommended – provided the agent is approved – prior to final surf washing. Nevertheless, across all treatments and temperatures, residual oil smearing was observed upon contact.

Some discoloration was noted, although to a lesser extent than with the VLSFOs. Additionally, the clean portions of the rocks tended to remain clean throughout the tumbling process to a greater degree than observed with the VLSFOs.

Oil comparison

The image displays rock samples treated with shoreline cleaning agent and subsequently tumbled at approximately 19°C, allowing for a comparative assessment across all four oil types (Figure 94). Among the samples, IM-28 was clearly the most challenging oil to remove. IFO380 and IM-27 exhibited similar cleaning characteristics, while IM-29 was by far the easiest to clean.

Despite treatment, all samples continued to exhibit smearing upon contact, and discoloration was observed across the board. Notably, IM-29 showed a more uniform residual coloration compared to the other oils.

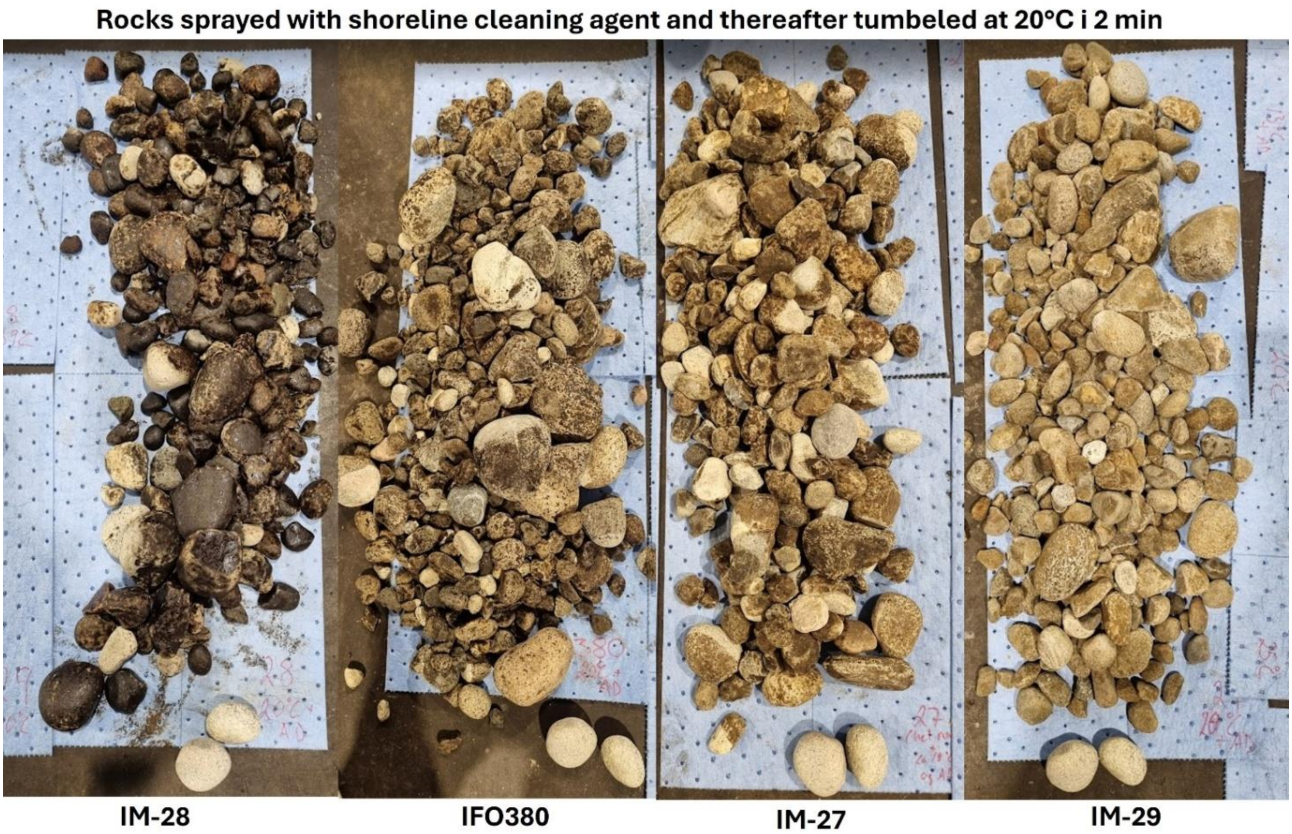


Figure 94: Rocks treated with shoreline cleaning agent and tumbled at 20°C.

To assess the amount of residual oil on the rocks, we selected one rock from each pile, weighed them, and then immersed them in diesel to remove any remaining oil. After rinsing, the rocks were left to dry for 72 hours before a final weighing.

As the pictures indicate, the oil appears to have been almost completely removed after the diesel baths (Figure 95). While the weighing does not reveal the exact amount of oil retained by each rock following the initial tumbling and washing, it does demonstrate that only minimal residues remain, each sample contained less than one gram of oil.

A final small-scale test was conducted on weathered rocks that had not been cleaned after four months of exposure. The rocks were manually polished in a bucket containing sorbent bark for approximately 30 seconds. As shown in Figure 95, this process did not completely remove all oil; however, the remaining oil did not smear when touched afterward. This represents a better outcome than the tumbling test using beach cleaning agents and 19°C water, even though the rocks visually appear less clean.

This suggests that the method should not be dismissed, despite its labour-intensive nature. It requires only sorbent bark, buckets, and personnel, making it significantly easier to implement in areas with difficult access. The sorbent material can be reused until it becomes saturated with oil, after which it can be easily collected in bags and sent for incineration or other waste treatment.

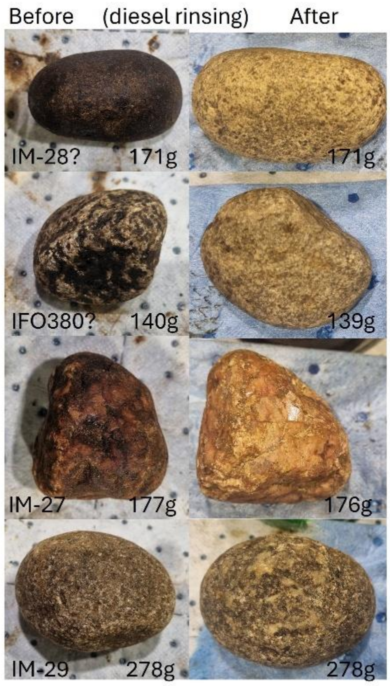


Figure 95: Rocks after final cleaning.

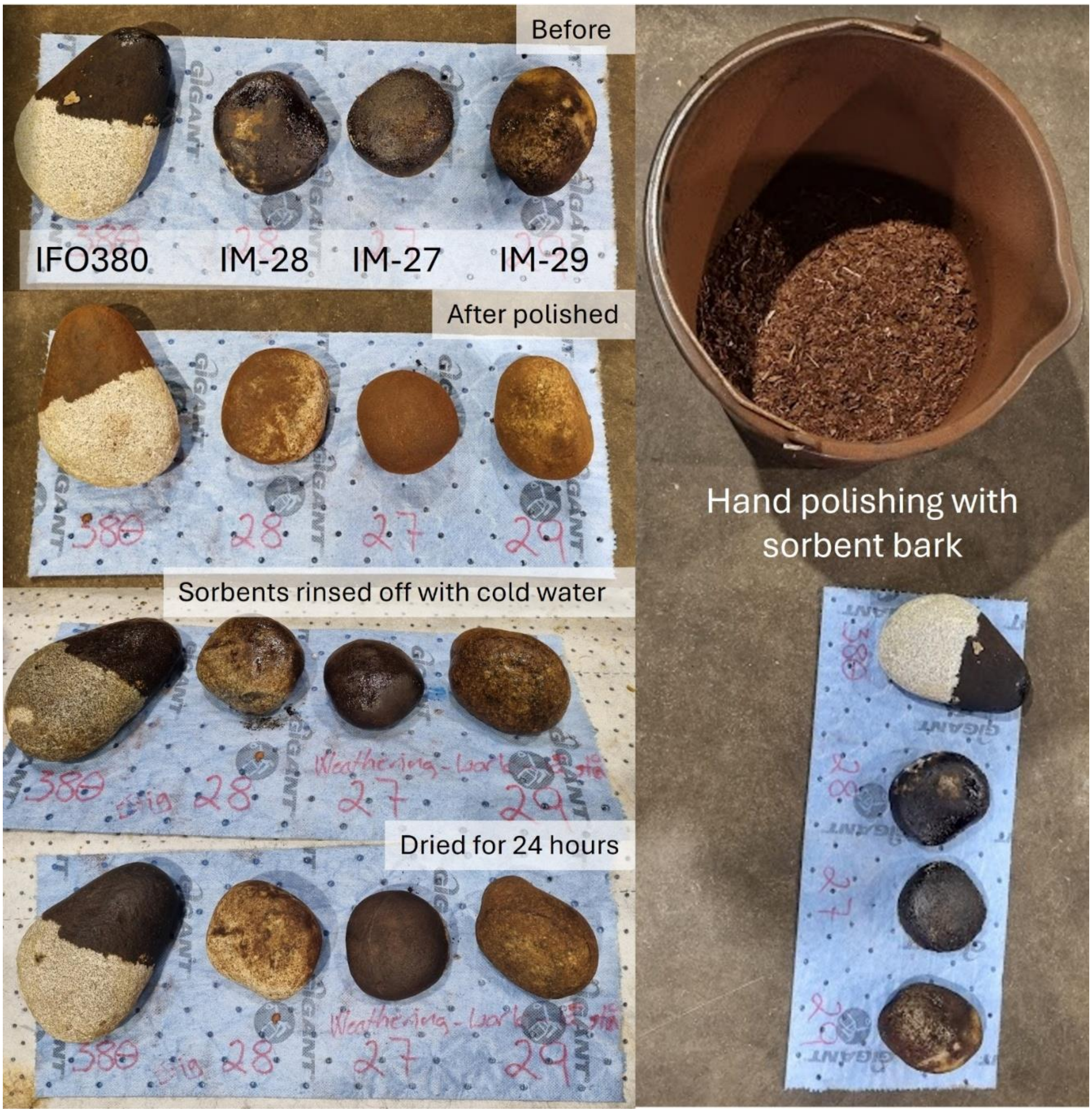


Figure 96: Small-scale test 3 - release of oil at different water temperatures.

4 CONCLUSION

The main observations and findings from the tests conducted on rocky substrates are as follows:

- Oil penetration was observed in all rock types tested, though the extent varied depending on both the nature of the LSFO and the rock type.
- The efficiency of high-pressure washing is dependent on the type of oil and substrate.
- For thick layers of fluid oils, washing efficiency is high, even without the use of shoreline cleaning agents.
- For oils with high pour points or those that are viscous/semi-solid, washing efficiency is significantly reduced (<10%). While shoreline cleaning agents can improve efficiency, results remain unsatisfactory (<20%).
- Increasing the water temperature enhances washing efficiency (30–60%).
- Washing operations effectively remove thick oil layers, but rocks often remain stained. No significant difference in efficiency was observed between the tested LSFOs and the comparative heavy fuel oil.
- Natural cleaning processes—such as wave energy and solar radiation—contribute to completing the cleaning process, particularly in temperate and warm climates. In cold climates, although some oil removal is visible, tiles remain heavily stained even after eight months of exposure to natural conditions. The comparative heavy fuel oil demonstrated intermediate behavior in terms of natural recovery and recolonization.
- Toxicity tests on algae and copepods did not indicate higher toxicity for the tested LSFOs compared to traditional heavy fuel oil.

The tests conducted on sand, gravel, and pebbles yielded the following key findings:
The behaviour of LSFO is highly temperature dependent, and few degrees difference may be important. To increase beach cleaning efficiency, the following techniques can be listed:

- Flushing (with increased water temperature);
- Shoreline cleaning agents ;
- Tumbling (concrete mixer or excavator based screening machine, with water and/or shoreline cleaning agents and/or sorbents as bark or peat, with increased water temperature);
- Manual use of sorbents for polishing;
- "Tactical" use of surf washing (Moving oiled pebbles to the surf zone) can also be efficient, alone or together with other cleaning techniques and recovery methods.

The use of those techniques can be challenged by stickiness of the LSFOs, leading to re-contamination of pebbles due to re-attachment of LSFOs. This challenge could be mitigated with a closed cleaning station equipped with a receiving pool of high water volume.

If oily effluents are released in the sea, attention must be drawn to the skimmers efficiency (see operational guidelines for sea operations) Responders must also be prepared to potentially implement manual recovery methods (e.g. with hooves).

Main findings from this WP are summarized in the Operational Guidelines dedicated to the shoreline response (Deliverable D1.6).

APPENDIX

APPENDIX 1

Task 5.1

Rock cleaning

Table 1 *Washing efficiency (in %) for the 3 LSFO tested) and the comparative oil (heavy fuel oil), for the 4 experimental conditions tested.*

NB: When the mass of oil extracted after washing was higher than the mass of oil extracted from the control tile, the washing efficiency was set at zero.

	washing conditions	replicate	mass of oil extracted from the control	mass of oil extracted after washing (g)	mass of oil removed thanks to washing (g)	Washing efficiency (%)	Average (%)	Standard deviation (%)
HFO	Control	1						
		2	2,53 ± 0,11					
		3						
	15°C - 50 bars	1	-	2,70	0	0	0,0	0,0
		2	-	2,77	0	0		
		3	-	2,73	0	0		
	15°C - 100 bars	1	-	2,43	0	0	0,0	0,0
		2	-	2,68	0	0		
		3	-	2,54	0	0		
	50°C - 50 bars	1	-	2,26	0,27	11	16,9	7,5
		2	-	2,15	0,38	15		
		3	-	1,89	0,63	25		
	50°C - 100 bars	1	-	2,30	0,22	9	7,1	1,7
		2	-	2,35	0,18	7		
		3	-	2,39	0,14	5		
IM-27	Control absorbed	1						
		2	2,17 ± 0,18					
		3						
	15°C - 50 bars	1	-	2,20	0	0	9,1	8,0
		2	-	1,91	0,26	12		
		3	-	1,84	0,33	15		
	15°C - 100 bars	1	-	1,53	0,64	29	28,0	1,4
		2	-	1,59	0,58	27		
		3	-	1,57	0,60	28		
	50°C - 50 bars	1	-	1,69	0,48	22	27,1	12,1
		2	-	1,77	0,40	18		
		3	-	1,28	0,89	41		
	50°C - 100 bars	1	-	1,36	0,81	37	36,8	2,6
		2	-	1,32	0,85	39		
		3	-	1,43	0,74	34		
IM-28	Control absorbed	1						
		2	1,00 ± 0,06					
		3						
	15°C - 50 bars	1	-	0,92	0,08	8	4,7	4,3
		2	-	0,94	0,06	6		
		3	-	1,16	0	0		
	15°C - 100 bars	1	-	0,86	0,14	14	11,0	4,8
		2	-	0,87	0,14	14		
		3	-	0,95	0,05	5		
	50°C - 50 bars	1	-	0,80	0,20	20	12,8	7,5
		2	-	0,87	0,13	13		
		3	-	0,95	0,05	5		
	50°C - 100 bars	1	-	1,02	0	0	0,0	0,0
		2	-	1,06	0	0		
		3	-	1,03	0	0		
IM-29	Control	1						
		2	0,63 ± 0,13					
		3						
	15°C - 50 bars	1	-	0,51	0,12	19	6,8	10,6
		2	-	0,71	0	0		
		3	-	0,63	0,01	1		
	15°C - 100 bars	1	-	0,63	0,00	0	0,0	0,0
		2	-	0,67	0	0		
		3	-	0,70	0	0		
	50°C - 50 bars	1	-	0,54	0,10	15	15,6	1,7
		2	-	0,55	0,09	14		
		3	-	0,52	0,11	17		
	50°C - 100 bars	1	-	0,73	0	0	8,8	15,2
		2	-	0,47	0,17	26		
		3	-	0,73	0	0		

APPENDIX 2

Task 5.2

Efficiency of cleaning agents

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IMAROS-2: Efficiency of cleaning agents (WP 5.2)

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For your attention	Comments are invited	For your information	As agreed

DISTRIBUTION
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Introduction

The Flushing Robot was established at SINTEF SeaLab in 2006 and has since then been used to study the effectiveness of different shoreline cleaning agents on oil contaminated bedrock, using flushing as a countermeasure. The effectiveness of flushing was studied with and without using shoreline cleaning agents (SCA)

Oils and shoreline cleaning agents

Three fresh low sulphur fuel oils (Table 1) were used and effectiveness of the two shoreline cleaning agents Aqua Delta (SCA 1) and Cytoclean (SCA 2) were tested.

Table 1 The oils physical properties. Viscosity measurements are from the temperature sweeps. Additional measurements of the pour point were performed, minimum and maximum temperatures are given.

SINTEF ID	IM no.	Viscosity, temp sweep (cP)		Density (g/mL)		Pour point (ASTM-D97)	Pour point (Min and max)
		15 °C	50 °C	50 °C (measured)	(°C)	(°C)	(°C)
2024-5377	IM-27	11676	282	0.931	0.954	21	9 - 24
2024-5378	IM-28	18170	110	0.909	0.932	30	21 - 30
2024-5379	IM-29	289	9.6	0.866	0.890	21	15 - 21

The flushing robot

To study the effectiveness of high pressure washing for fuel oil removal, the flushing robot was used. All tests were performed at a room temperature of 15 °C with a water flushing pressure of 50 bar.

Oil contaminated bedrock tiles (slate) were placed in a steel rack and exposed for fresh water flushing of 50 bars using a high-pressure washer. A nozzle with number 25065, giving a spray angle of 25° and an opening of 1.5 mm was used (Figure 1).

Figure 1 *Pictures showing the Flushing Robot, the steel rack holding the tiles and the nozzle***.**

The edges of the tiles were masked with tape to avoid quantification of oil covering the edges and tempered to the study temperature of 15 °C before use. As a standard, 10 g +/-0,25 g of oil is applied to the bedrock tiles measuring 10 x 10 cm, representing an oil film thickness of 1 mm. The oils were heated in order to apply the oil. The tiles were then stored horizontally in a temperature-controlled room at test temperature of 15 °C for 1 day to let the oil settle and cover the tile evenly.

The shoreline cleaning agents (SCA) were applied using a pipette, at an Agent to Oil (AoR) ratio of 1:5. The agent was then allowed to soak for 20 min before the tiles were mounted on the steel rack for flushing treatment. A flushing pressure of 50 bar, serving approximately 10 litres per minute at a water temperature of 9 ° C (cold tap water), was applied.

After exposure, the tiles were placed horizontally at test temperature for 1 day to dry off the last remains of water, before quantifying the remaining oil on the tiles gravimetrically. The tape on the edges were removed before quantification. The tiles were photo documented before and after exposure.

In addition, higher water flushing temperature (25 °C) was applied in extra tests using Aqua Delta on IM-27 and IM-28. The tiles were conditioned at 15 °C for 1 day prior to water flushing and the tests were performed at a room temperature of 15 °C.

Results and discussion

Three parallels of each combination of oils and SCA were performed. The effectiveness is given in percentage, and represents the oil removed during flushing, compared with the initial oil applied on the tile surface. The percentage effectiveness of SCA and water flushing are detailed in Table 2.

The results are summarized in Figure 2. For IM-27 and IM-28 using cold tap water (9 °C), there was an effect of the SCAs compared with only water flushing, and the effectiveness of Aqua Delta was slightly higher than for Cytoclean. However, the effectiveness of both SCAs were between 10 and 17%. Pictures taken before and after flushing are shown in Figure 4 for IM-27 and in Figure 5 for IM-28.

On the IM-29 oil, the water flushing using cold tap water was very effective (close to 100%), but using water without SCA was as effective as applying SCAs. This is also illustrated in pictures in Figure 5.

Using a water flushing temperature of 25 °C resulted in an increase in the effectiveness of Aqua Delta on IM-27 from 17% to 60% (without SCA from 5 to 39%). On IM-28 the effectiveness increased from 16% to 26 % (from 2 to 13% without SCA). The higher water temperature was not tested on IM-29.

No absorption of oil into the tiles (slate) was observed.

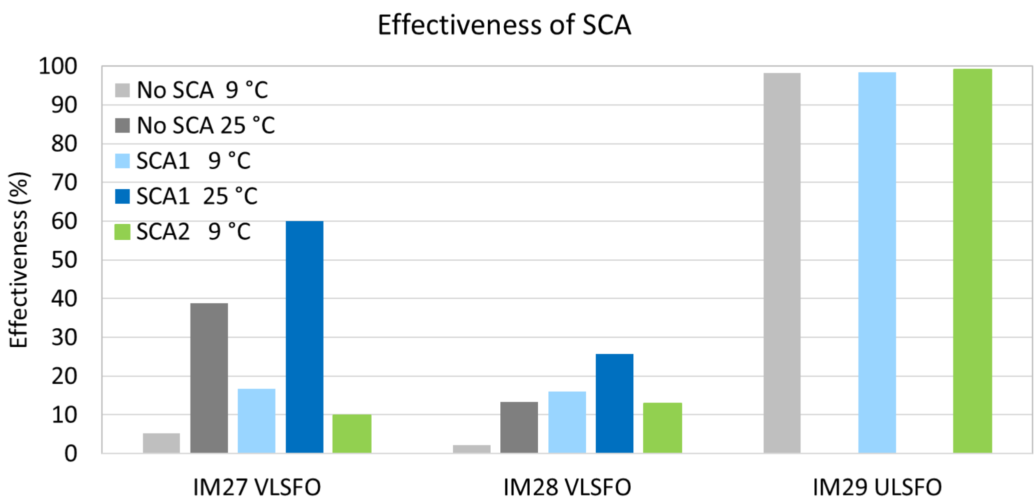


Figure 2 *Effectiveness of water flushing (50 bar) and use of SCA with water temperatures of 9 °C and 25 °C. SCA1 is Aqua Delta and SCA2 is Cytoclean. Cytoclean was not tested with water flushing temperature of 25 °C. All tests were performed at a room temperature of 15 °C.*

Table 2 Effectiveness of water flushing using shoreline cleaning agents. Three parallels of each test, including the effectiveness of flushing without SCA.

Tile no.	Oil	SCA	Water temp (°C)	Parallell	Effectiveness (%)		Average effectiveness (%)
1	IM27 VLSFO	Aqua Delta	9	A	16,2		16,6
2	IM27 VLSFO	Aqua Delta	9	B	17,2		
3	IM27 VLSFO	Aqua Delta	9	C	16,6		
4	IM27 VLSFO	Cytoclean	9	A	8,9		9,8
5	IM27 VLSFO	Cytoclean	9	B	10,0		
6	IM27 VLSFO	Cytoclean	9	C	10,6		
7	IM27 VLSFO	None	9	A	4,9		5,2
8	IM27 VLSFO	None	9	B	5,6		
9	IM27 VLSFO	None	9	C	15,9	Outlier	
10	IM28 VLSFO	Aqua Delta	9	A	14,8		16,0
11	IM28 VLSFO	Aqua Delta	9	B	15,9		
12	IM28 VLSFO	Aqua Delta	9	C	17,3		
13	IM28 VLSFO	Cytoclean	9	A	13,2		12,9
14	IM28 VLSFO	Cytoclean	9	B	11,9		
15	IM28 VLSFO	Cytoclean	9	C	13,7		
16	IM28 VLSFO	None	9	A	2,6		2,1
17	IM28 VLSFO	None	9	B	2,5		
18	IM28 VLSFO	None	9	C	1,3		
19	IM29 ULSFO	Aqua Delta	9	A	98,4		98,4
20	IM29 ULSFO	Aqua Delta	9	B	98,5		
21	IM29 ULSFO	Aqua Delta	9	C	98,3		
22	IM29 ULSFO	Cytoclean	9	A	99,4		99,1
23	IM29 ULSFO	Cytoclean	9	B	99,2		
24	IM29 ULSFO	Cytoclean	9	C	98,8		
25	IM29 ULSFO	None	9	A	97,8		98,3
26	IM29 ULSFO	None	9	B	98,1		
27	IM29 ULSFO	None	9	C	99,0		
28	IM27 VLSFO	Aqua Delta	25	A	59,8		60,0
29	IM27 VLSFO	Aqua Delta	25	B	58,8		
30	IM27 VLSFO	Aqua Delta	25	C	61,4		
31	IM27 VLSFO	None	25	A	37,8		38,8
32	IM27 VLSFO	None	25	B	39,8		
33	IM27 VLSFO	None	25	C	74,8	Outlier	
34	IM28 VLSFO	Aqua Delta	25	A	27,1		25,6
35	IM28 VLSFO	Aqua Delta	25	B	24,8		
36	IM28 VLSFO	Aqua Delta	25	C	25,0		
37	IM28 VLSFO	None	25	A	22,5		13,3
38	IM28 VLSFO	None	25	B	4,8		
39	IM28 VLSFO	None	25	C	12,6		

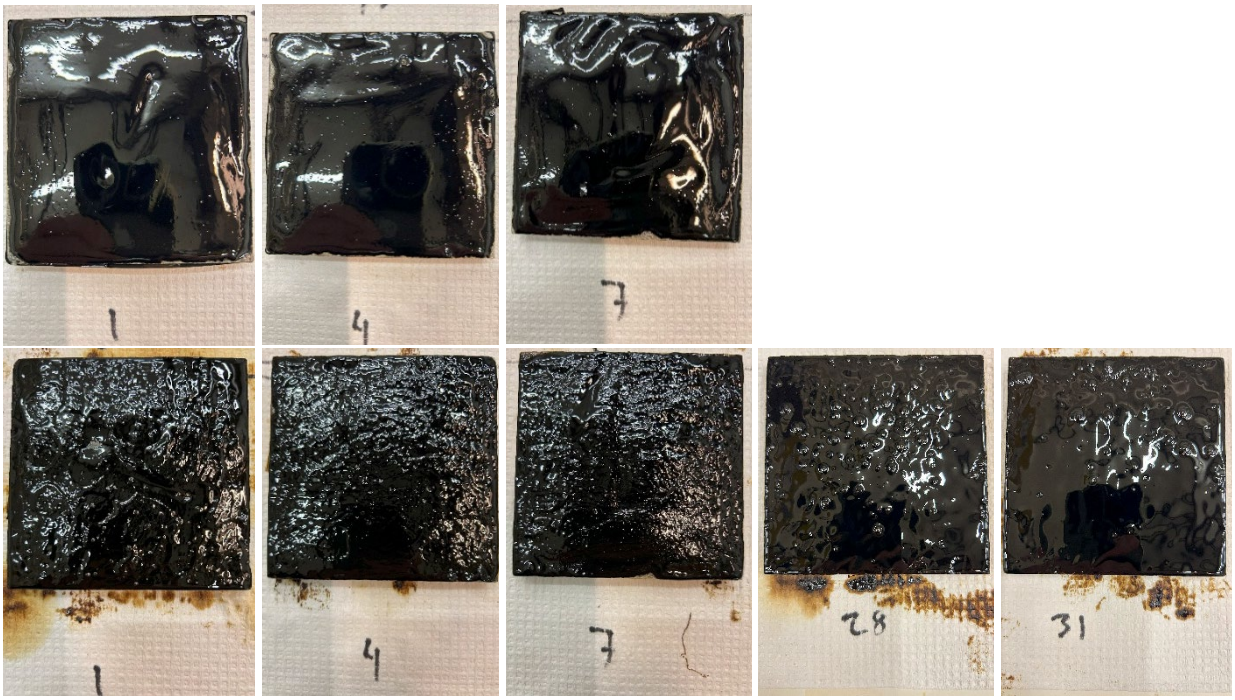


Figure 3 *Tiles with IM-27: Upper row is prior to washing, and lower row after washing. From left to right: Aqua Delta (1), Cytoclean (4), and no SCA (7), flushed with water temperature of 9 °C, and Aqua Delta (28) and no SCA (31) with water flush temperature of 25 °C.*

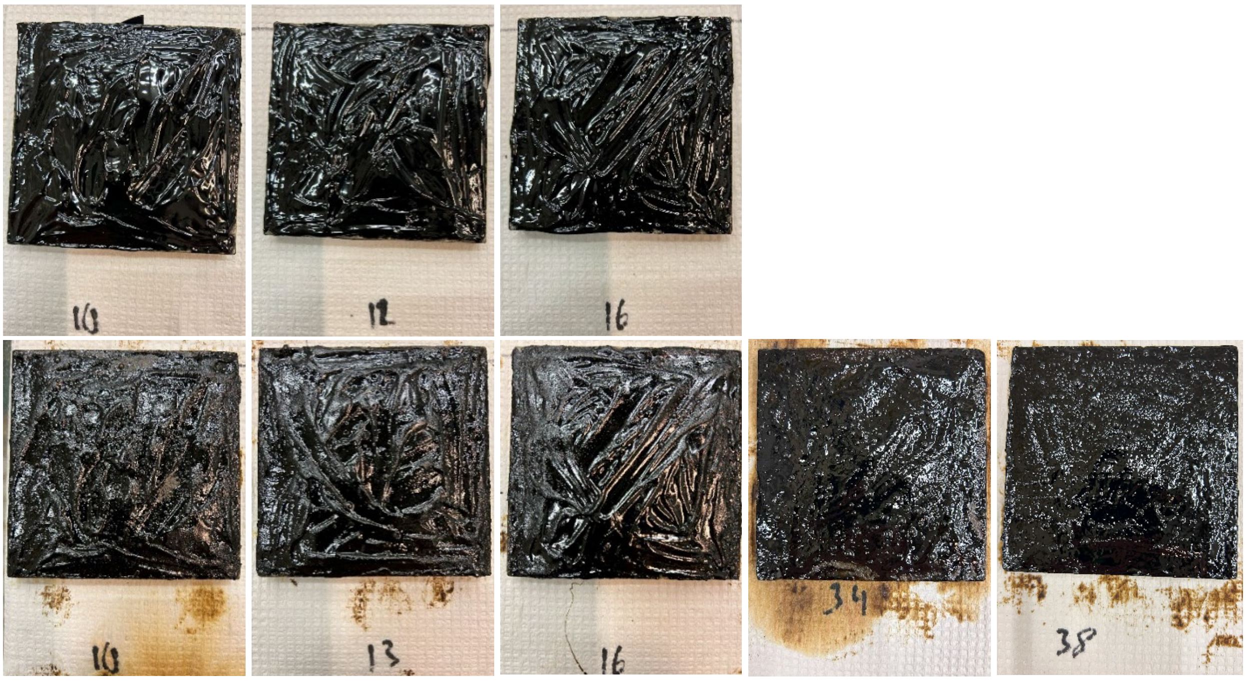


Figure 4 *Tiles with IM-28: Upper row is prior to washing, and lower row after washing. From left to right: Aqua Delta (10), Cytoclean (12), and no SCA (16), flushed with water temperature of 9 °C, and Aqua Delta (34) and no SCA (38) with water flush temperature of 25 °C.*

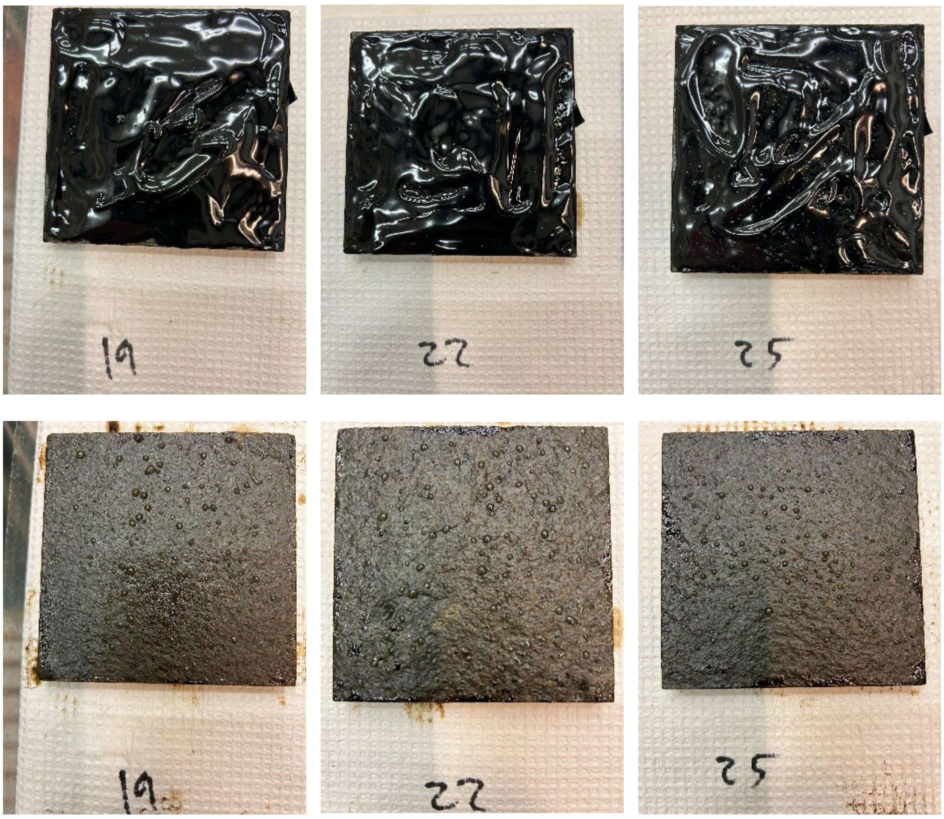


Figure 5 *Tiles with IM-29: Upper row is prior to washing, and lower row after washing. From left to right: Aqua Delta, Cytoclean, and no SCA.*

Summary

Using cold tap water and flushing with a pressure of 50 bar was very effective on the ULSFO (IM-29), which also was the oil with the lowest viscosity and density. However, the effectiveness was close to 100% both without and with SCA.

The effectiveness on the two VLSFOs IM-27 and IM-28 was relatively low (< 20%) when using water at 9 °C, even when applying SCA. The results indicated that Aqua Delta was slightly more effective than Cytoclean on these two oils. Applying a water temperature to 25 °C increased the water flushing effectiveness of Aqua Delta on IM-27 from 17% to 60% (without SCA from 5 to 39%), and on IM-28 it increased from 16% to 26 % (from 2 to 15% without SCA).

APPENDIX 3

Task 5.3

Release and toxicity of oil absorbed in rocks

(Algae)

Co-funded by the European Union

Table 1 *Mean PAH concentrations in the culture media used for algal test*

Concentration moyenne (ng/L) (n=3)										
Composés	**Contrôle Eau de mer**	**Contrôle plaque**	**HFO nettoyée**	**IM 27 nettoyée**	**IM 28 nettoyée**	**IM 29 nettoyée**	**HFO non nettoyée**	**IM 27 non nettoyée**	**IM 28 non nettoyée**	**IM 29 non nettoyée**
BT	0	0	0	0	0	0	0	0	0	0
BT 1	0	0	0	0	0	0	0	0	0	0
BT 2	0	0	0	0	0	0	0	0	0	0
BT3	0	0	0	0	0	0	0	0	0	0
N	0	15	198	24	67	74	38	54	103	336
N1	1	44	341	59	245	306	204	140	594	415
N2	0	141	898	192	804	931	1056	377	2 015	889
N3	0	121	1034	216	1232	1252	1049	277	1772	781
Biphenyl	1	9	73	12	27	69	40	40	70	126
Acenaphthylene	1	1	0	1	2	18	0	4	5	14
Acenaphthene	2	27	140	35	97	115	188	62	304	251
Fluorene	2	80	517	117	493	560	549	145	949	734
F1	0	115	1021	177	1017	1148	964	179	1182	1130
F2	1	76	1060	201	703	1049	855	204	638	747
F3	0	38	689	119	173	416	466	115	227	239
Dibenzothiophene	2	59	543	50	430	82	488	43	530	104
DBT 1	1	64	815	49	311	96	654	42	423	102
DBT 2	1	26	529	27	209	52	374	22	176	46
DBT 3	1	8	233	17	65	21	139	13	56	17
Phenanthrene	2	396	1756	370	1421	1097	1554	324	1618	1358
Anthracene	2	28	467	43	212	198	282	44	230	218
P1	1	363	5 214	320	2 230	1318	3 880	286	2 338	1302
P2	1	128	4 144	146	1 166	617	2 877	131	1 129	496
P3	1	23	1475	64	353	212	946	55	380	149
Fluoranthene	2	11	125	31	54	58	104	28	55	58
Pyrene	1	25	497	60	355	116	406	54	360	114
FL1	1	13	647	47	227	103	457	39	227	79
FL2	1	4	337	29	77	46	179	22	82	35
FL3	1	1	107	11	17	15	49	8	16	12
Benzo[a]anthracene	2	2	72	13	17	12	51	9	19	9
Chrysene	2	4	193	29	43	36	141	19	47	27
C1	2	3	158	19	31	26	100	12	34	15
C2	2	2	66	9	13	12	36	6	13	6
C3	2	2	9	2	3	3	4	2	3	3
Benzo[b]fluoranthene	1	1	17	4	3	5	7	3	3	3
Benzo[k]fluoranthene	1	1	4	2	2	2	3	2	2	2
Benzo[e]pyrene	1	1	39	9	6	9	18	5	6	4
Benzo[a]pyrene	1	1	22	5	4	4	10	3	4	2
Perylene	1	1	7	3	2	2	4	2	2	2
Indeno[1,2,3-cd]fluoranthene	2	2	3	2	2	2	2	2	2	2
Dibenzo(a,h)anthracene	2	2	4	2	2	2	3	2	2	2
Benzo(g,h,i)perylene	2	2	5	3	4	3	3	3	3	2
[HAPs] ng/L	**50**	**1 841**	**23 461**	**2 520**	**12 121**	**10 088**	**18 181**	**2 778**	**15 621**	**9 829**
[HAPs] µg/L		**2**	**23**	**2**	**12**	**61**	**18**	**3**	**16**	**10**

Table 2 *Growth rate (d^{-1}) obtained with the positive substance $K_2Cr_2O_7$*

K2Cr2O7 - Specific growth rate µ (d-1)					
T = 24h					
Concentration (mg/L)	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
3,2	0,39	0,33	0,59	0,44	31,66
5,6	0,13	0,14	0,61	0,29	94,57
10,0	0,00	0,00	0,00	0,00	-
18,0	0,00	0,00	0,01	0,00	173,21
32,0	0,00	0,00	0,00	0,00	-
T = 48h					
Concentration (mg/L)	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
3,2	1,32	1,29	1,34	1,32	1,70
5,6	1,16	1,15	1,19	1,17	1,72
10,0	0,99	0,96	1,07	1,01	5,77
18,0	0,74	0,67	0,69	0,70	5,42
32,0	0,29	0,37	0,30	0,32	13,70
T = 72h					
Concentration (mg/L)	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
3,2	1,30	1,30	1,32	1,30	0,85
5,6	1,22	1,21	1,22	1,21	0,67
10,0	1,06	1,07	1,07	1,07	0,37
18,0	0,81	0,77	0,82	0,80	2,82
32,0	0,54	0,50	0,52	0,52	3,91

Table 3 *Growth rate (d^{-1}) obtained with the control and the control tile*

T = 24h						
Condition	**[HAP]diss. (ng/L)**	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
Control	**50**	0,10	0,02	0,70	0,27	135,9
Control Tile	**2254**	0,00	0,00	0,00	0,00	-
T = 48h						
Condition	**[HAP]diss. (ng/L)**	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
Control	**50**	1,34	1,32	1,39	1,35	2,8
Control Tile	**2254**	1,09	1,03	1,05	1,06	3,2
T = 72h						
Condition	**[HAP]diss. (ng/L)**	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
Control	**50**	1,37	1,37	1,38	1,37	0,2
Control Tile	**2254**	1,18	1,13	1,16	1,15	1,9

Table 4 *Growth rate (d^{-1}) obtained with the four oils tested*

		HFO - Specific growth rate (d^{-1})				
		T = 24h				
Condition	**[HAP]diss. (ng/L)**	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
Tile: Polluted + cleaned	**23461,0**	0,00	0,60	0,00	0,20	173,21
Tile: Polluted	**18181,0**	0,00	0,35	0,00	0,12	173,21
		T = 48h				
Condition	**[HAP]diss. (ng/L)**	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
Tile: Polluted + cleaned	**23 461**	0,76	0,76	0,70	0,74	4,82
Tile: Polluted	**18 181**	1,13	0,96	0,92	1,00	11,12
		T = 72h				
Condition	**[HAP]diss. (ng/L)**	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
Tile: Polluted + cleaned	**23 461**	0,96	0,91	0,93	0,94	2,53
Tile: Polluted	**18 181**	1,24	1,15	1,15	1,18	4,36

		IM-27 - Specific growth rate (d^{-1})				
		T = 24h				
Condition	**[HAP]diss. (ng/L)**	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
Tile: Polluted + cleaned	**2520**	0,00	0,00	0,00	0,00	
Tile: Polluted	**2778**	0,00	0,00	0,00	0,00	
		T = 48h				
Condition	**[HAP]diss. (ng/L)**	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
Tile: Polluted + cleaned	**2520**	1,06	1,00	0,94	1,00	6,27
Tile: Polluted	**2778**	0,95	0,93	0,95	0,94	1,34
		T = 72h				
Condition	**[HAP]diss. (ng/L)**	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
Tile: Polluted + cleaned	**2520**	1,16	1,09	1,17	1,14	3,34
Tile: Polluted	**2778**	1,14	1,16	1,16	1,15	0,91

		IM-28 - Specific growth rate (d^{-1})				
		T = 24h				
Condition	**[HAP]diss. (ng/L)**	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
Tile: Polluted + cleaned	**12121**	0,00	0,00	0,00	0,00	
Tile: Polluted	**15621**	0,00	0,00	0,00	0,00	
		T = 48h				
Condition	**[HAP]diss. (ng/L)**	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
Tile: Polluted + cleaned	**12121**	1,08	1,06	0,97	1,04	5,80
Tile: Polluted	**15621**	1,22	0,97	0,95	1,05	14,40
		T = 72h				
Condition	**[HAP]diss. (ng/L)**	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
Tile: Polluted + cleaned	**12121**	1,21	1,20	1,19	1,20	0,91
Tile: Polluted	**15621**	1,23	1,14	1,13	1,17	4,66

		IM-29 - Specific growth rate (d^{-1})				
		T = 24h				
Condition	**[HAP]diss. (ng/L)**	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
Tile: Polluted + cleaned	**10088**	0,92	0,00	0,00	0,31	173,21
Tile: Polluted	**9829**	0,00	0,00	0,00	0,00	
		T = 48h				
Condition	**[HAP]diss. (ng/L)**	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
Tile: Polluted + cleaned	**10088**	1,40	0,73	0,92	1,02	33,62
Tile: Polluted	**9829**	1,05	1,12	1,02	1,07	4,92
		T = 72h				
Condition	**[HAP]diss. (ng/L)**	Replicate 1	Replicate 2	Replicate 3	Mean	CV %
Tile: Polluted + cleaned	**10088**	1,35	1,11	1,11	1,19	11,96
Tile: Polluted	**9829**	1,20	1,20	1,20	1,20	0,24

APPENDIX 4

Task 5.3

Release and toxicity of oil absorbed in rocks

(Copepods)

Table 1 *Mean PAH concentrations in the culture media used for algal test*

Concentration moyenne (ng/L) (n=3)										
Composés	Contrôle Eau de mer	Contrôle plaque	HFO nettoyée	IM 27 nettoyée	IM 28 nettoyée	IM 29 nettoyée	HFO non nettoyée	IM 27 non	IM 28 non	IM 29 non
BT	0	0	0	0	0	0	0	0	0	0
BT 1	0	0	0	0	0	0	0	0	0	0
BT 2	0	0	0	0	0	0	0	0	0	0
BT3	0	0	0	0	0	0	0	0	0	0
N	0	51	67	68	73	71	107	204	186	192
N1	1	255	396	249	517	175	529	342	1377	1558
N2	0	344	1547	479	2 064	388	1661	562	3 334	3 319
N3	0	212	1457	457	2 429	662	1463	347	2 762	1853
Biphenyl	1	47	102	63	101	64	116	59	161	880
Acenaphthylene	1	4	8	5	3	8	3	6	0	184
Acenaphthene	2	69	321	76	376	130	364	115	628	1548
Fluorene	2	127	742	234	1090	578	811	235	1502	2 134
F1	0	186	1205	261	1595	1222	1286	259	1803	2 228
F2	1	107	1140	288	996	969	1139	270	952	1167
F3	0	65	634	157	410	387	493	142	293	345
Dibenzothiophene	2	37	522	50	534	73	548	63	680	108
DBT 1	1	41	695	48	488	96	693	55	534	95
DBT 2	1	21	378	21	218	55	338	23	198	46
DBT 3	1	10	174	11	95	23	120	9	51	14
Phenanthrene	2	236	1551	345	1481	1280	1618	465	1754	1698
Anthracene	2	21	331	54	268	219	310	66	314	383
P1	1	205	3 936	297	2 445	1245	3 707	374	2 726	1507
P2	1	77	2 804	140	1340	583	2 206	167	1260	615
P3	1	17	1080	67	483	217	721	63	389	205
Fluoranthene	2	20	117	40	68	61	104	36	61	64
Pyrene	1	54	455	79	459	119	409	71	407	122
FL1	1	15	553	66	353	104	388	49	237	90
FL2	1	4	281	39	154	53	148	24	66	38
FL3	1	2	112	16	44	14	38	9	15	10
Benzo[a]anthracene	2	2	70	17	31	14	42	11	19	12
Chrysene	2	4	209	38	78	43	121	25	48	33
C1	2	2	165	26	71	29	77	14	29	22
C2	2	2	70	11	33	14	31	7	10	10
C3	2	2	10	3	5	3	5	2	2	2
Benzo[b]fluoranthene	1	1	25	13	8	10	9	4	3	5
Benzo[k]fluoranthene	1	1	7	6	3	3	3	2	2	2
Benzo[e]pyrene	1	1	57	30	18	19	23	6	7	7
Benzo[a]pyrene	1	2	29	16	13	8	13	4	4	3
Perylene	1	1	9	7	5	4	4	2	2	2
Indeno[1,2,3-cd]fluoranthene	2	2	4	6	3	2	2	3	2	2
Dibenzo(a,h)anthracene	2	2	6	4	3	3	3	2	2	2
Benzo(g,h,i)perylene	2	2	8	8	11	4	4	3	3	3
[HAPs] ng/L	**50**	**2 254**	**21279**	**3 796**	**18 365**	**8 953**	**19 659**	**4 099**	**21823**	**20 512**
[HAPs] µg/L		**2**	**21**	**4**	**18**	**9**	**19**	**4**	**22**	**20**

Table 2 *Mortality rate obtained with the toxic of reference*

Toxique de reference	Result 24h					
1 mg/L	4	3	0	0	100	23
		6	2	33	67	
		5	1	20	80	
		5	2	40	60	
Toxique de reference	Result 48h					
Concentration	Replicats	Copepods / tank	Nb of death copepods	Mortality (%)	Survival (%)	Mean mortality (%)
1 mg/L	4	3	1	33	67	65
		6	4	67	33	
		5	3	60	40	
		5	5	100	0	

Table 3 *Mortality rate obtained for the controls*

Control	Result 24h					
Concentration	Replicates	Copepods / tank	Nb of death copepods	Mortality (%)	Survival (%)	Mean mortality (%)
0	6	5	0	0	100	0
		5	0	0	100	
		5	0	0	100	
		8	0	0	100	
		7	0	0	100	
		6	0	0	100	
Controle - tile	Result 24h					
0	6	7	0	0	100	0
		5	0	0	100	
		4	0	0	100	
		5	0	0	100	
		7	0	0	100	
		2	0	0	100	
Control	Result 48h					
Concentration	Replicates	Copepods / tank	Nb of death copepods	Mortality (%)	Survival (%)	Mean mortality (%)
0	6	5	0	0	100	7
		5	0	0	100	
		5	0	0	100	
		8	2	25	75	
		7	0	0	100	
		6	1	17	83	
Control tile	Result 48h					
0	6	7	1	14	86	9
		5	0	0	100	
		4	1	25	75	
		5	0	0	100	
		7	1	14	86	
		2	0	0	100	

Table 4 *Mortality rate obtained for the four oils tested*

Oil	Result 24h					
Concentration (mg.L^{-1})	Replicates	Copepods / tank	Nb of death copepods	Mortality (%)	Survival (%)	Mean mortality (%)
IM27		9	0	0	100	
Tile: Polluted + Cleaned	4	4	0	0	100	6
		4	0	0	100	
		4	1	25	75	
IM27		5	2	40	60	
Tile: Polluted	4	4	1	25	75	25
		6	1	17	83	
		5	1	20	80	
IM28		7	2	29	71	
Tile: Polluted + Cleaned	4	5	1	20	80	20
		12	4	33	67	
		5	0	0	100	
IM28		6	2	33	67	
Tile: Polluted	4	5	3	60	40	38
		5	1	20	80	
		5	2	40	60	
IM29		5	1	20	80	
Tile: Polluted + Cleaned	4	6	1	17	83	18
		6	1	17	83	
		6	1	17	83	
IM29		5	1	20	80	
Tile: Polluted	4	5	1	20	80	30
		7	2	29	71	
		8	4	50	50	
HFO		3	0	0	100	
Tile: Polluted + Cleaned	4	4	1	25	75	11
		4	0	0	100	
		5	1	20	80	
HFO		3	1	33	67	
Tile: Polluted	4	3	2	67	33	53
		5	3	60	40	
		4	2	50	50	

Oil	Result 48h					
Concentration (mg.L^{-1})	Replicates	Copepods / tank	Nb of death copepods	Mortality (%)	Survival (%)	Mean mortality (%)
IM27		9	1	11	89	
Tile: Polluted + Cleaned	4	4	0	0	100	28
		4	0	0	100	
		4	4	100	0	
IM27		5	3	60	40	
Tile: Polluted	4	4	2	50	50	68
		6	6	100	0	
		5	3	60	40	
IM28		7	5	71	29	
Tile: Polluted + Cleaned	4	5	5	100	0	80
		12	8	67	33	
		5	4	80	20	
IM28		6	3	50	50	
Tile: Polluted	4	5	5	100	0	63
		5	2	40	60	
		5	3	60	40	
IM29		5	3	60	40	
Tile: Polluted + Cleaned	4	6	2	33	67	40
		6	2	33	67	
		6	2	33	67	
IM29		5	4	80	20	
Tile: Polluted	4	5	3	60	40	82
		7	7	100	0	
		8	7	88	13	
HFO		3	3	100	0	
Tile: Polluted + Cleaned	4	4	3	75	25	84
		4	4	100	0	
		5	3	60	40	
HFO		3	2	67	33	
Tile: Polluted	4	3	3	100	0	92
		5	5	100	0	
		4	4	100	0	

APPENDIX 5

Task 5.4

Rock colonisation by biota / Natural recovery

Visual observations with time and Quantitative degradation

Co-funded by the European Union

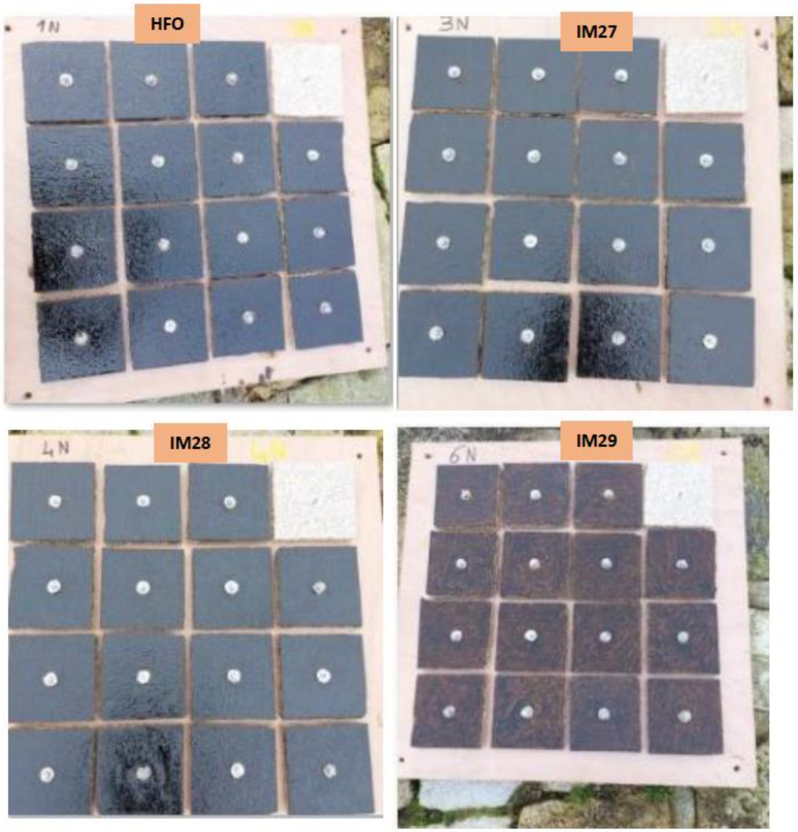
I – Experiment in France

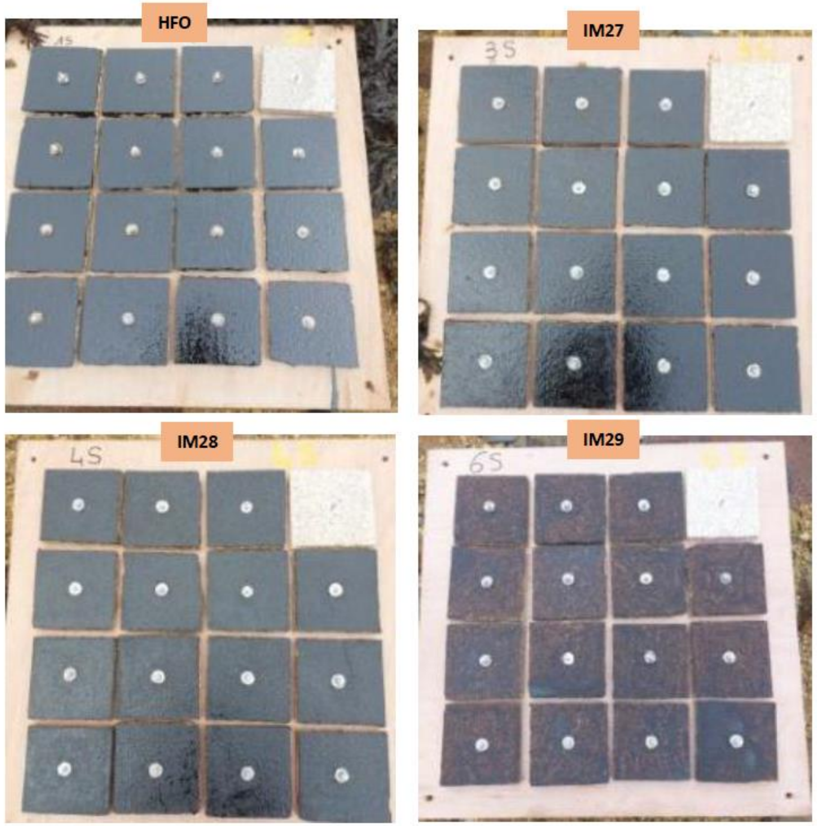
Pictures taken in the field

North Face

T0

South Face

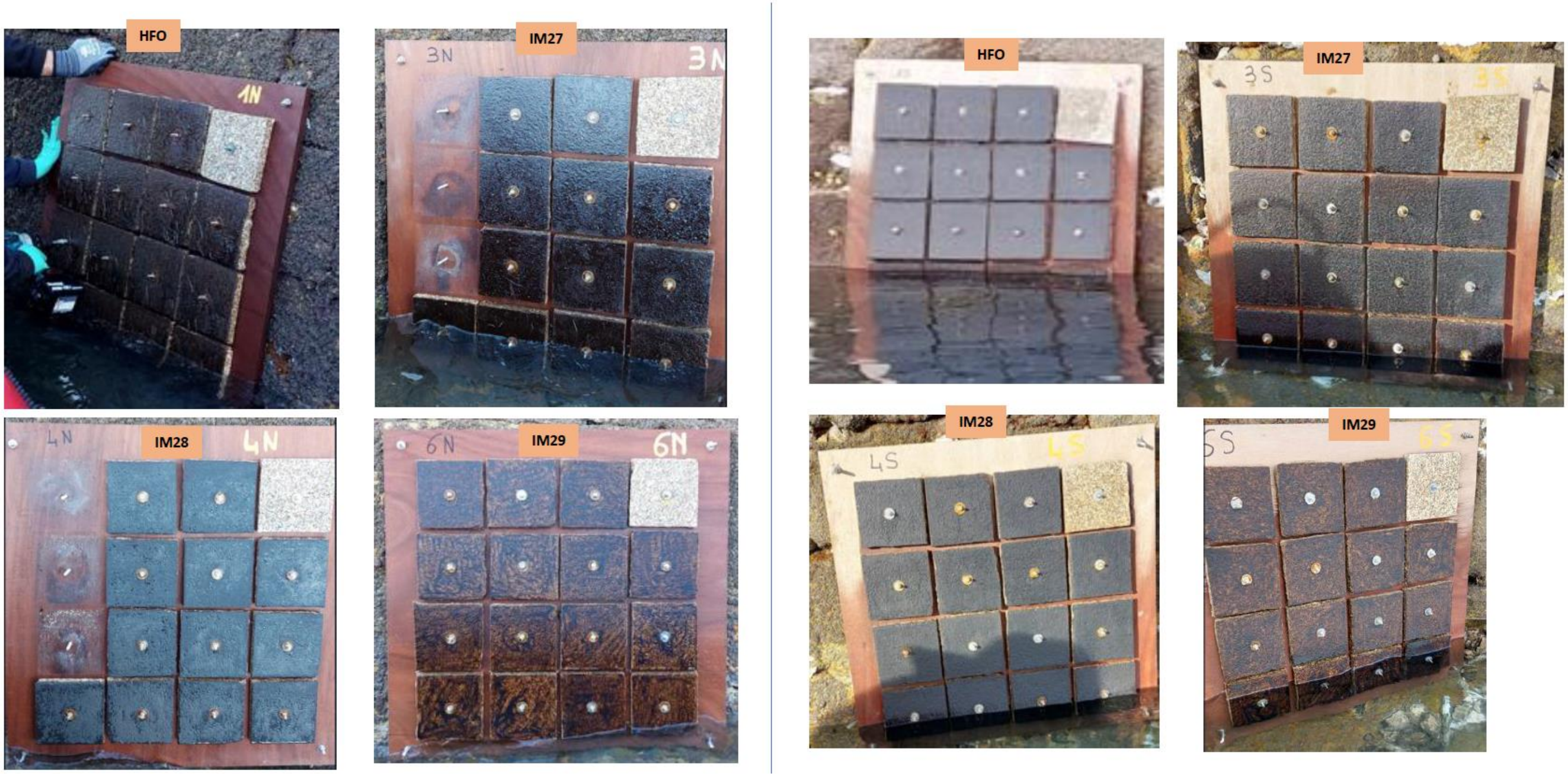




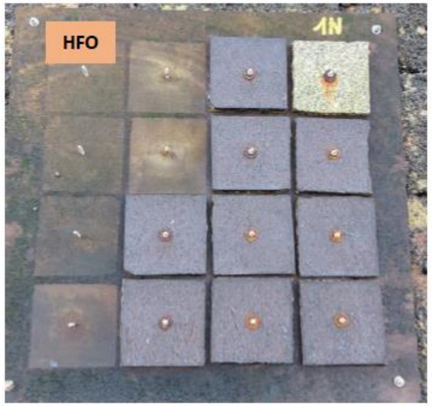
North Face

T1 + 15d

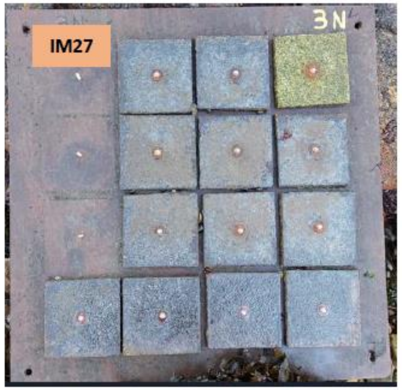
South Face



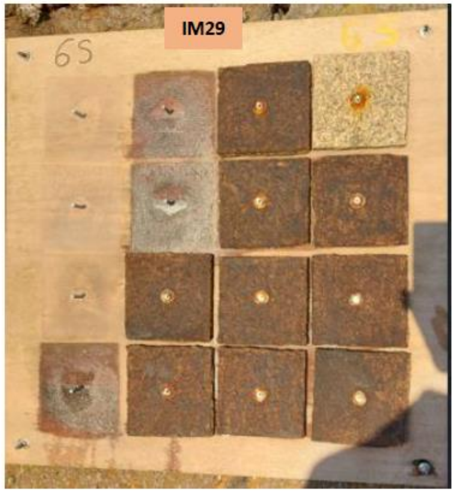
North Face | T2 + 1 month | South Face



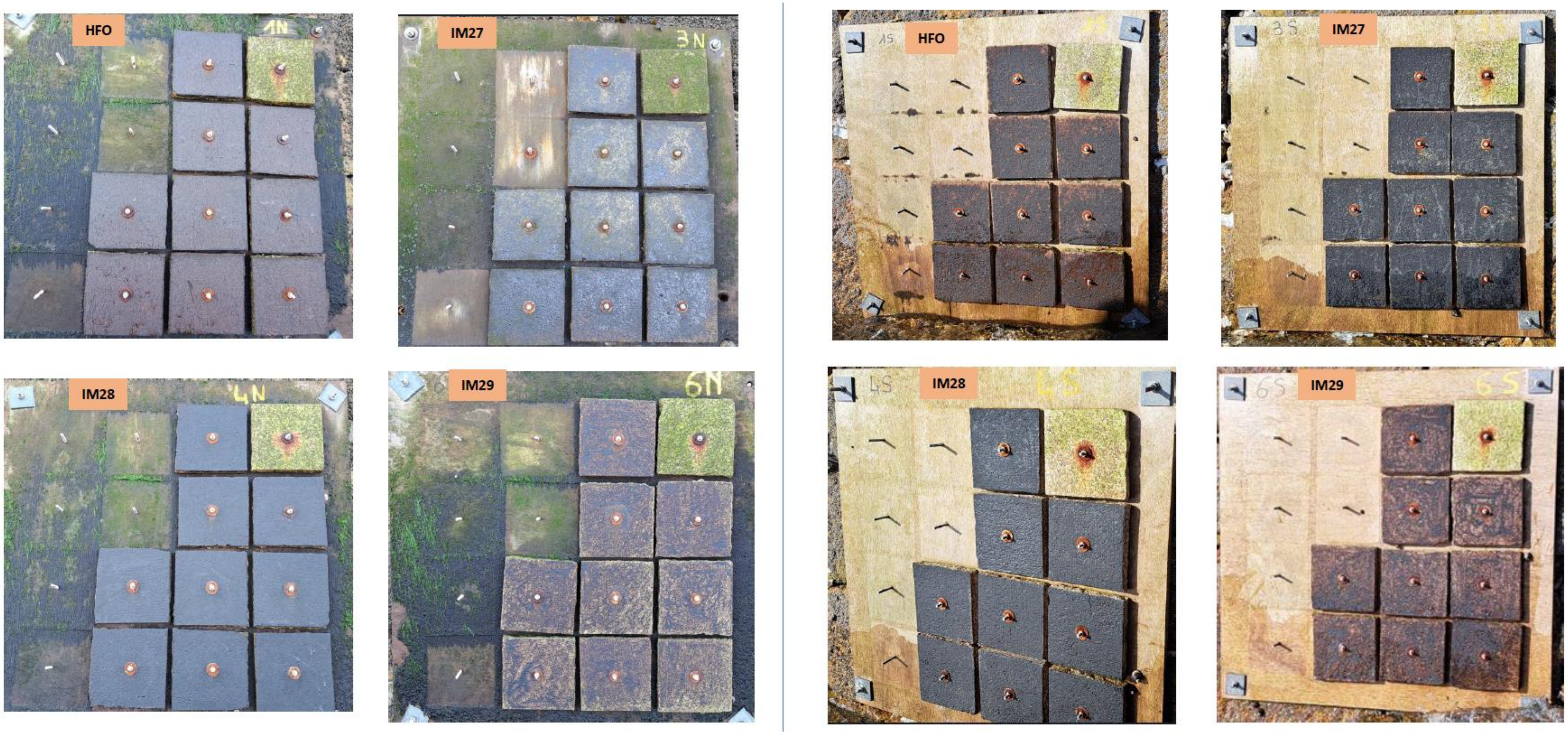
NB: picture taken at T+2m (picture at T+1 month in the field not found)



Frame lost at sea on T+1 month. Found on the foreshore at T+ 2 months (picture taken at T+2m)



North Face | T3 + 3 months | South Face

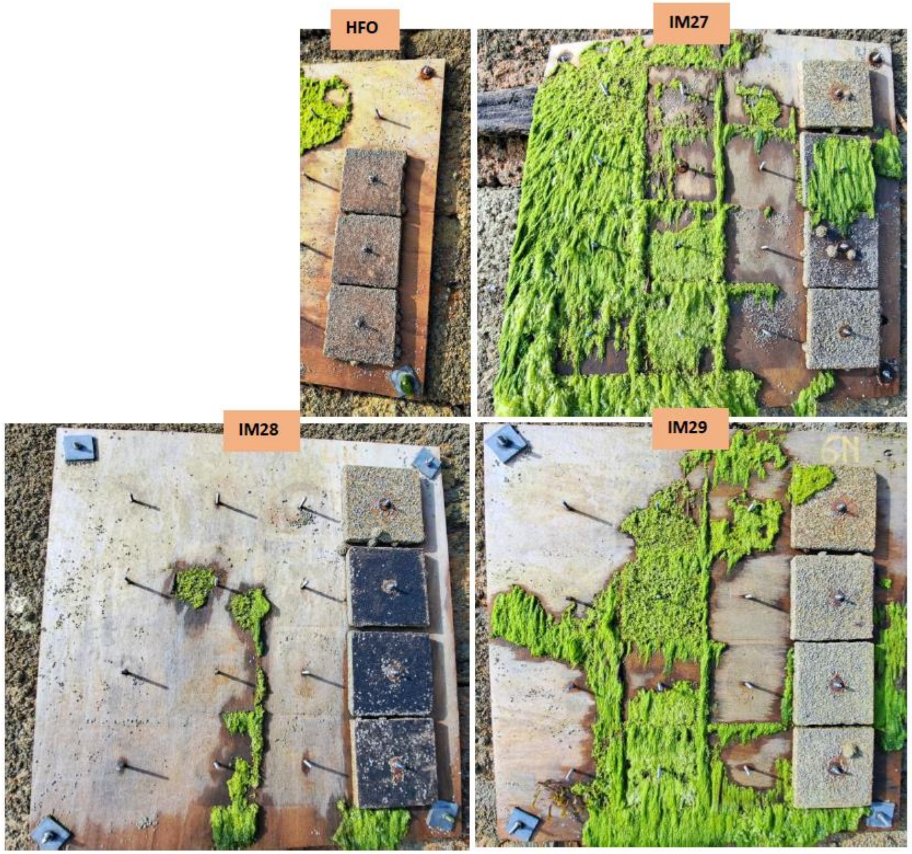


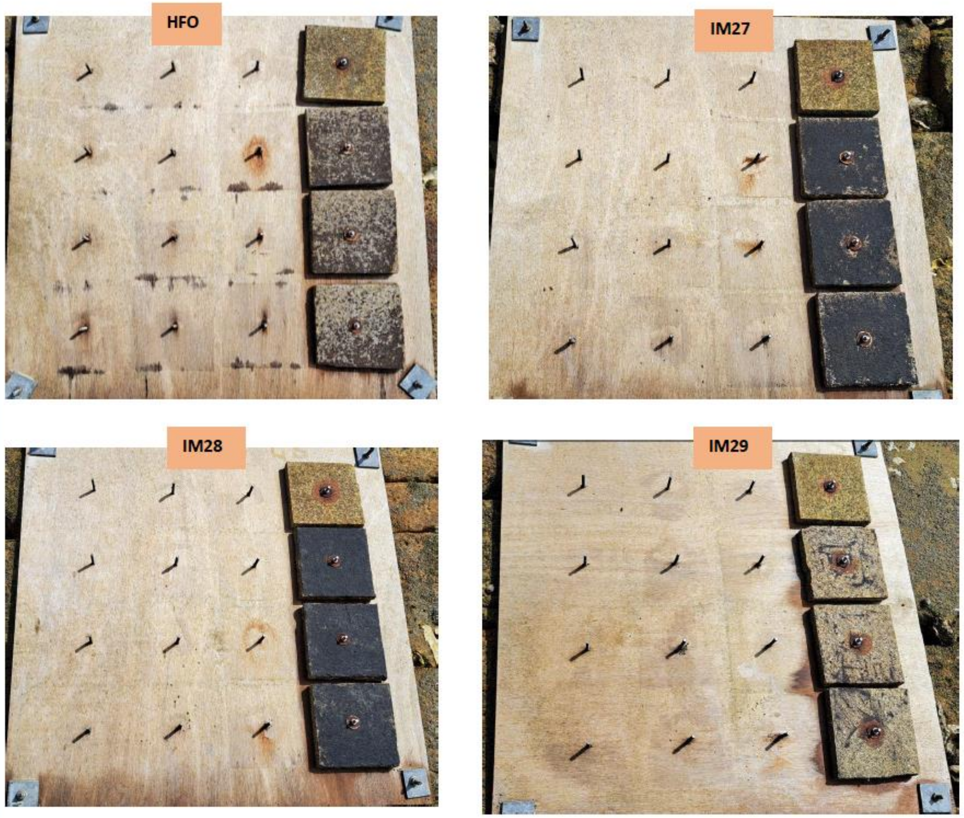
North Face

T4 + 6 months

South Face

North Face | T5 + 9 months | South Face





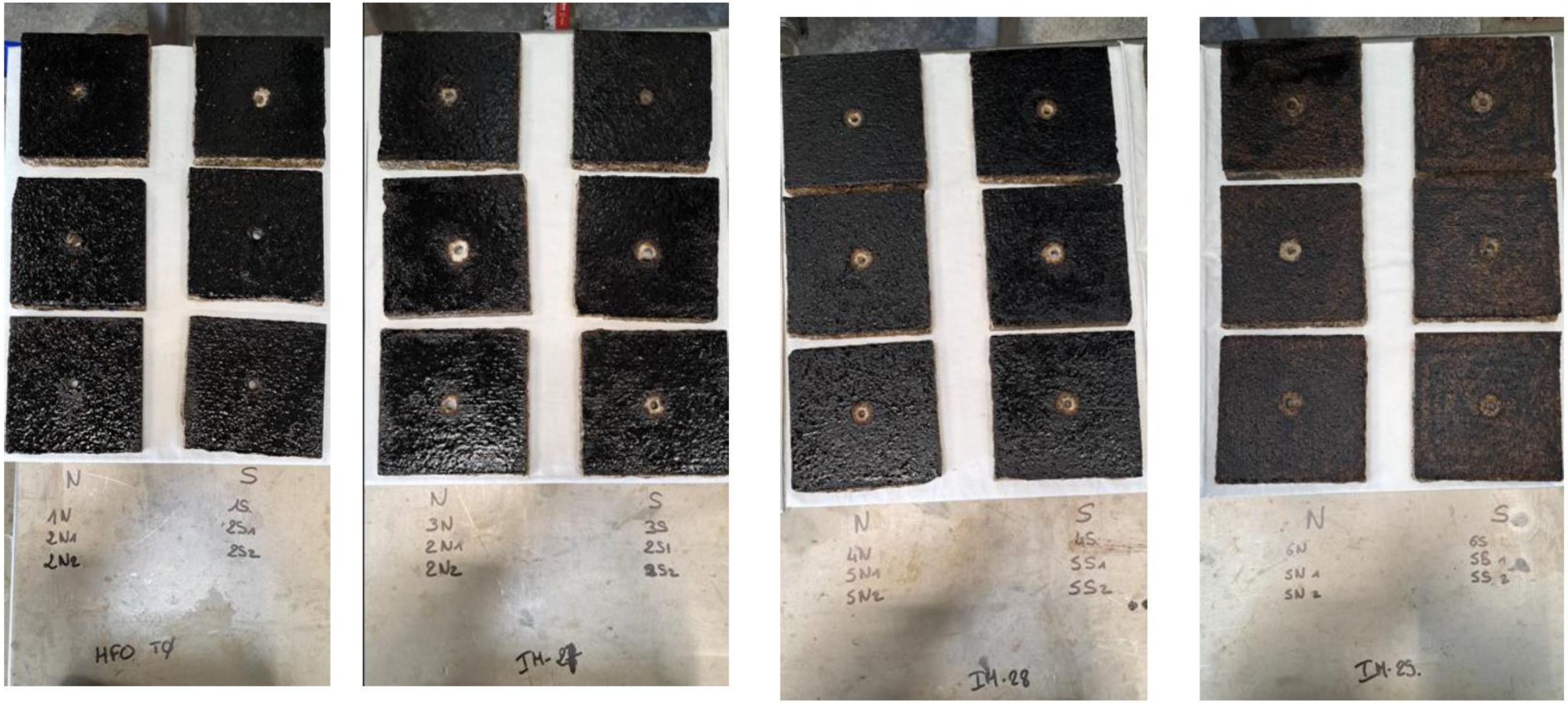
North Face

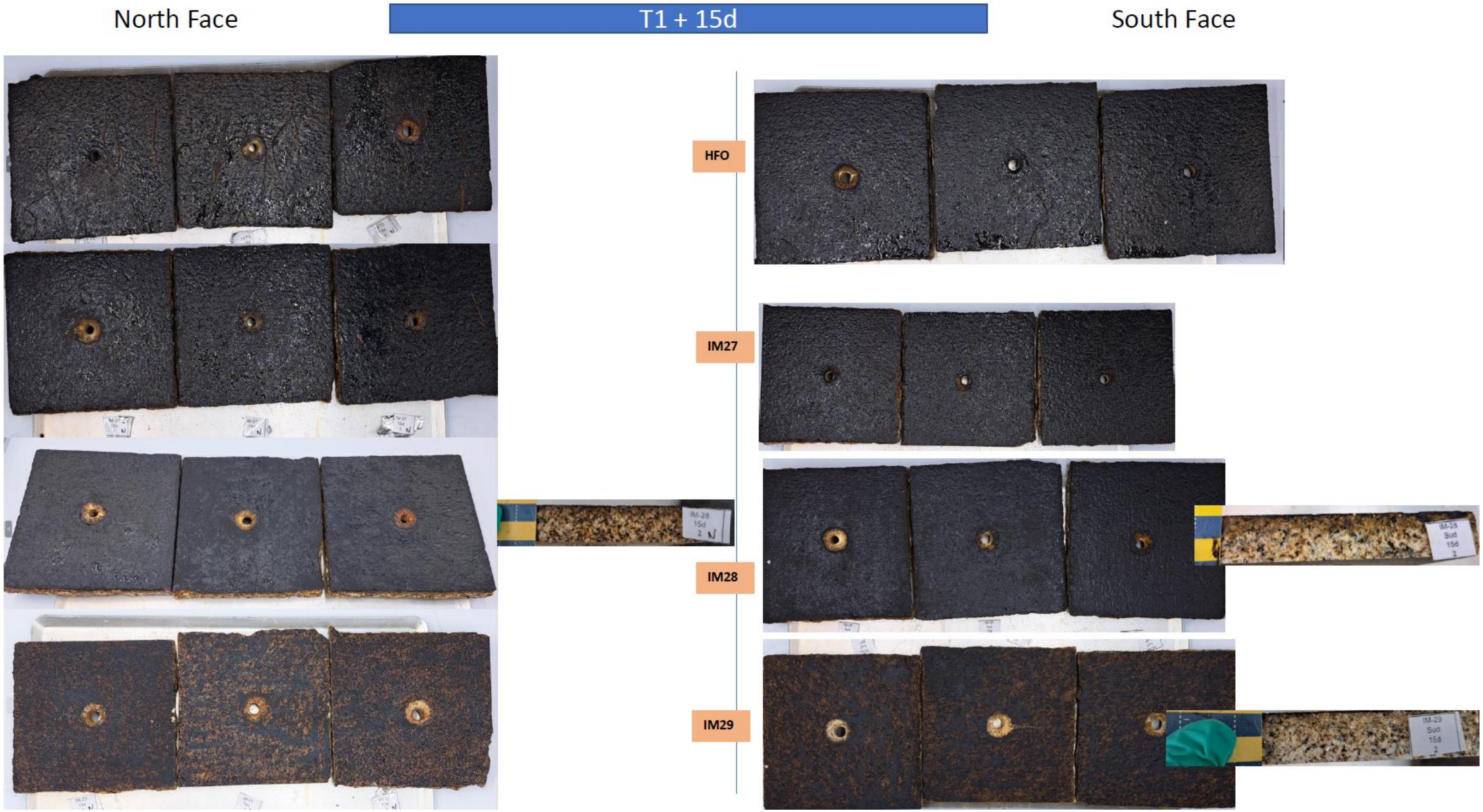
T6 + 11 months

South Face

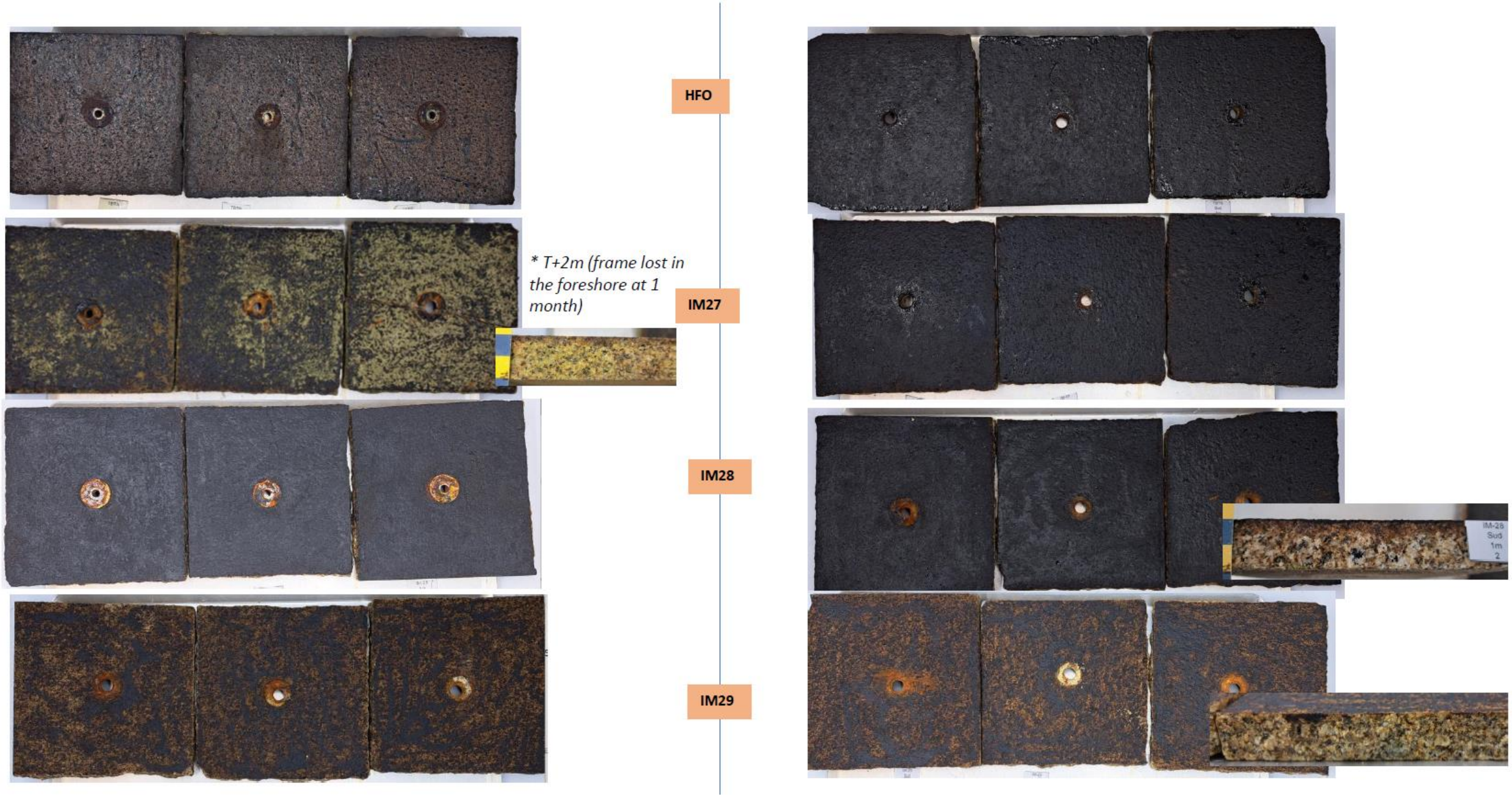
Pictures taken at the laboratory, before oil extraction

T0


N
S
1N
2N1
2N2
1S
2S1
2S2
HFO T0
N
S
3N
2N1
2N2
3S
2S1
2S2
N
S
4N
5N1
5N2
4S
5S1
5S2
N
S
6N
5N1
5N2


North Face
T1 + 15d
South Face
HFO
IM27
IM28
IM29

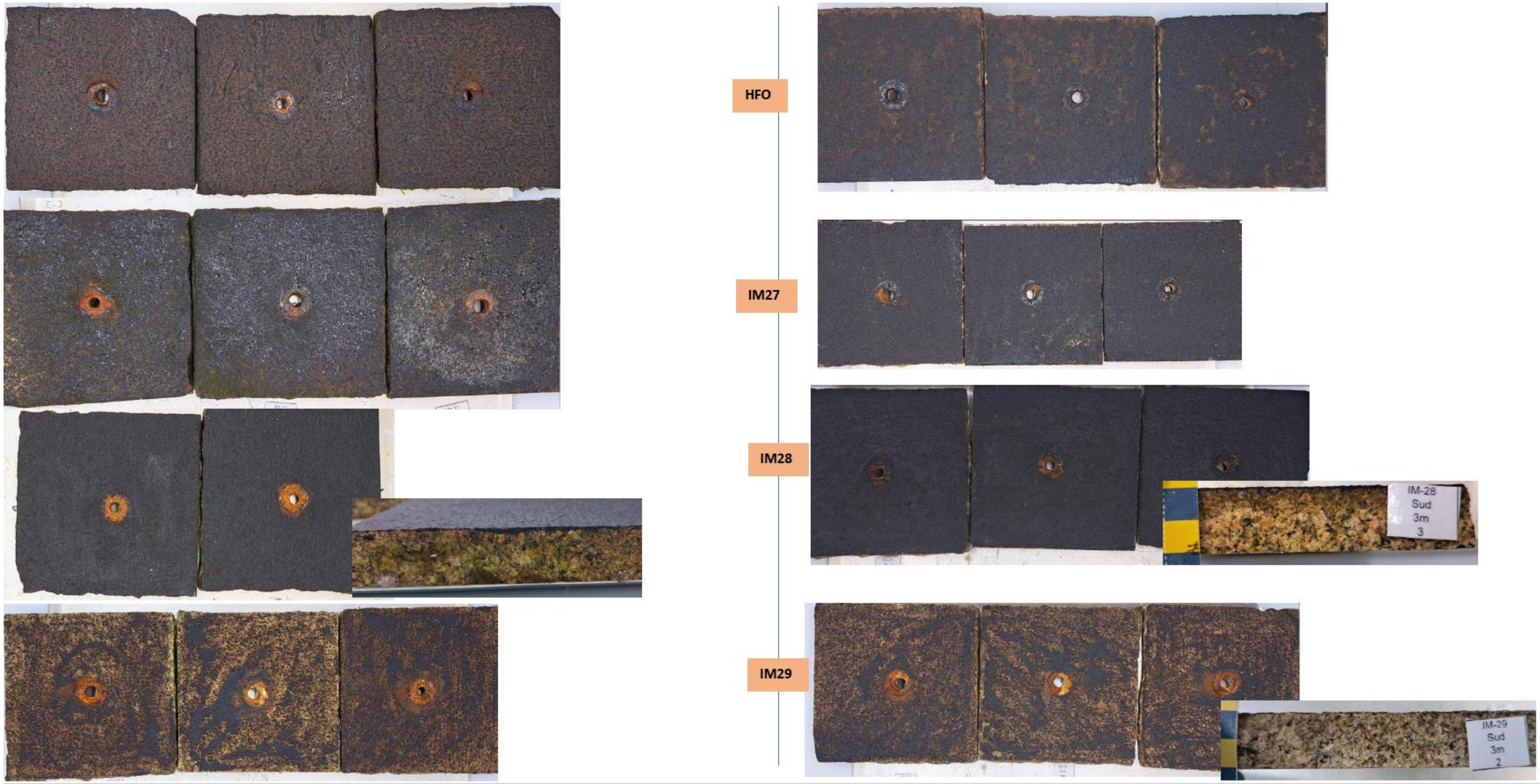
North Face | T2 + 1 month | South Face

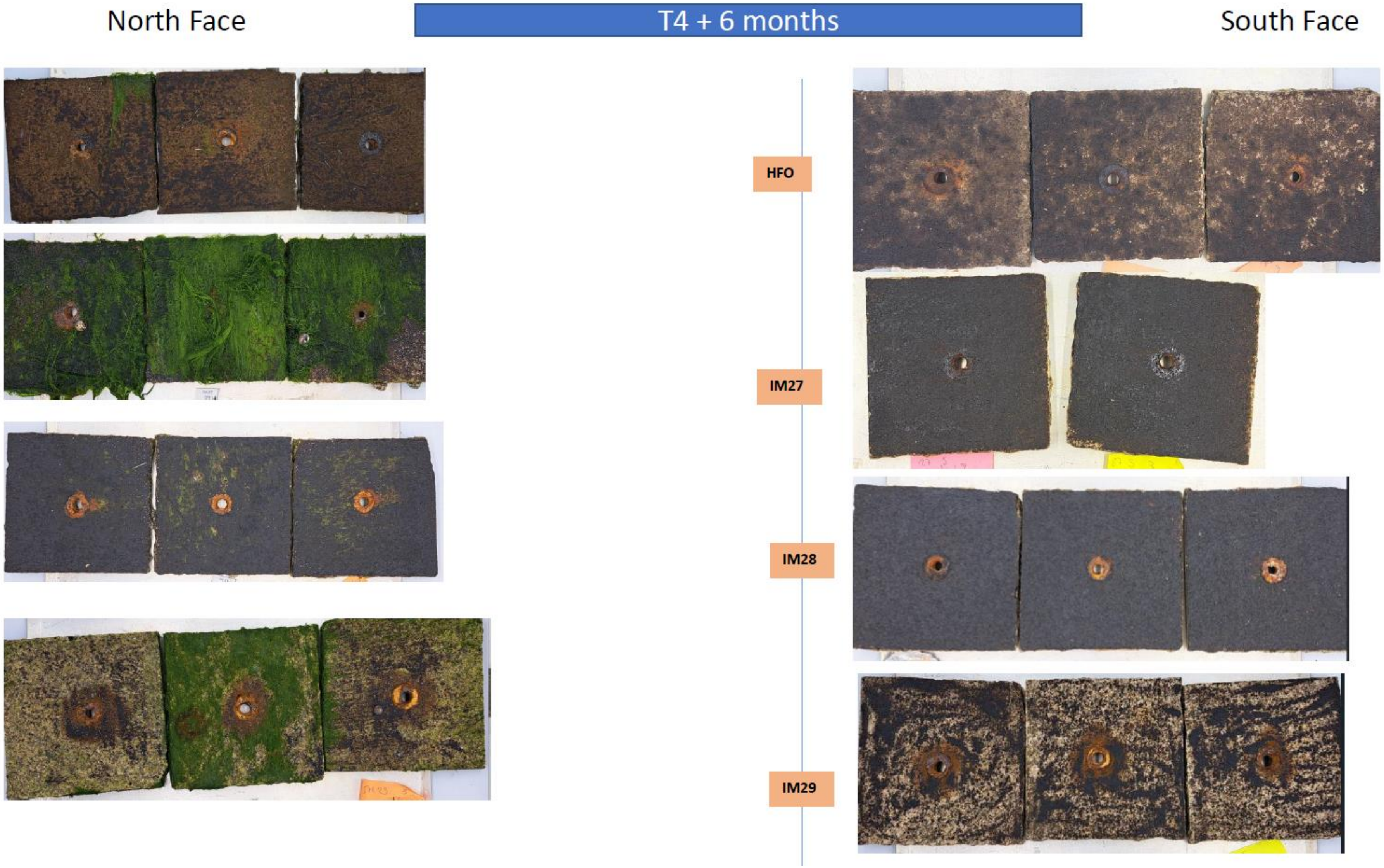


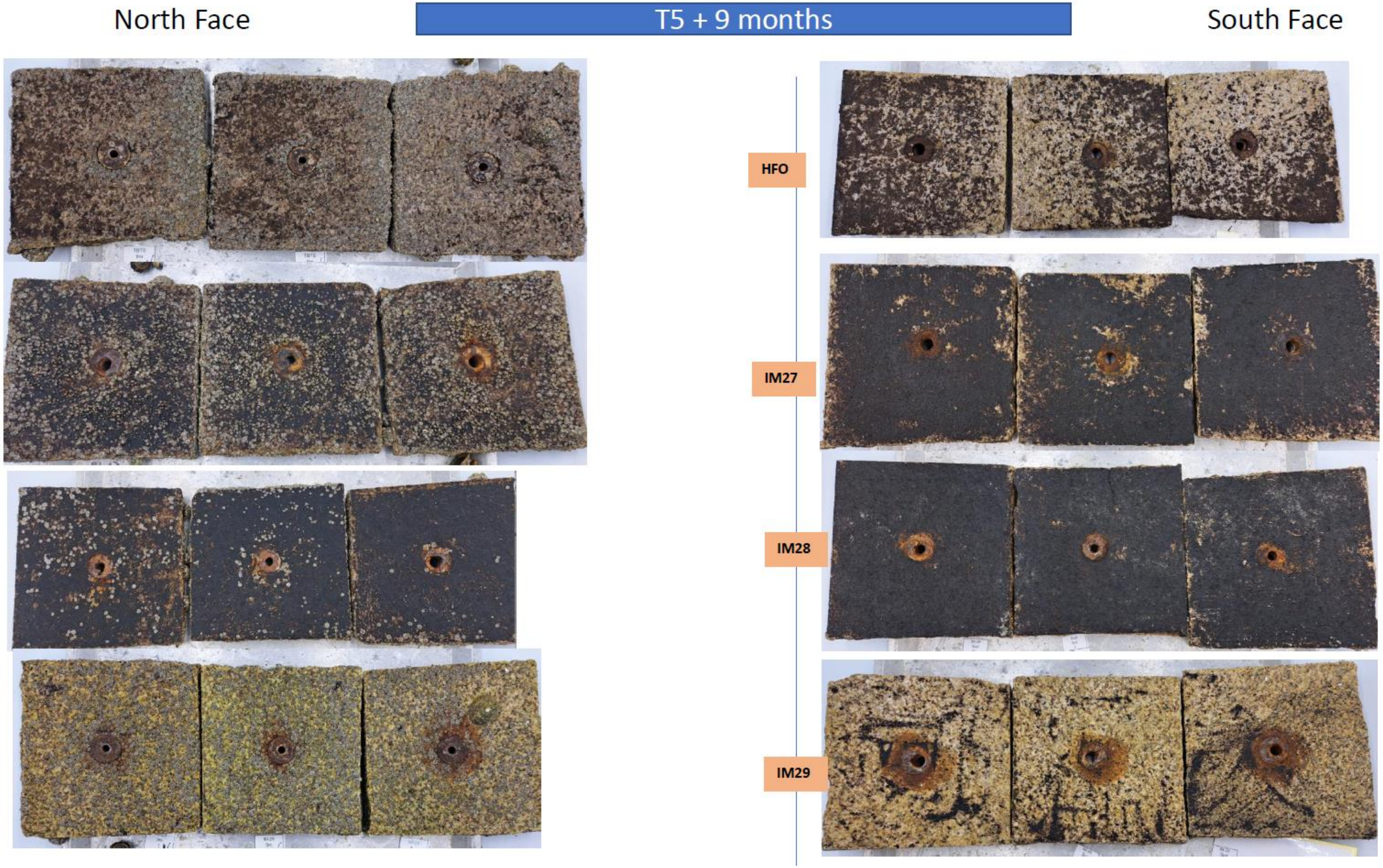
North Face

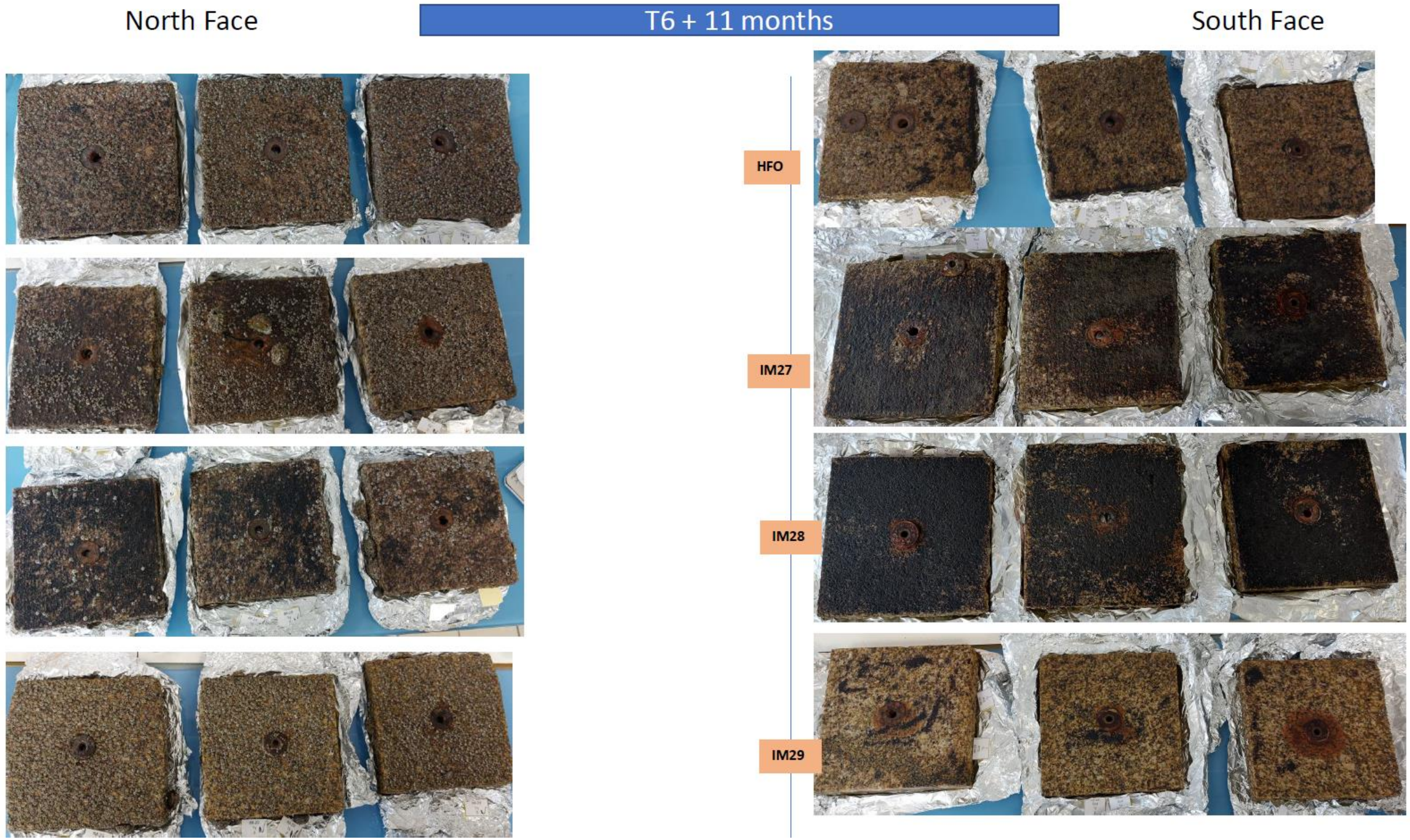
T3 + 3 months

South Face




North Face
T4 + 6 months
South Face
HFO
IM27
IM28
IM29


North Face
T5 + 9 months
South Face
HFO
IM27
IM28
IM29


North Face
T6 + 11 months
South Face
HFO
IM27
IM28
IM29

Control North (T6)

Control South (T6)

Mass recovered from the Tiles

Time exposure (days)		mass of oil (g)	Std. Dev.
0	HFO North T0	2,607	0,118
0	HFO South T0	2,660	0,101
0	IM-27 North T0	2,670	0,170
0	IM-27 South T0	2,592	0,096
0	IM-28 North T0	1,819	0,297
0	IM-28 South T0	1,963	0,269
0	IM-29 North T0	0,931	0,387
0	IM-29 South T0	0,868	0,133

Time exposure (days)		mass of oil (g)	Std. Dev.
17	HFO North T1	2,019	0,149
17	HFO South T1	1,987	0,118
17	IM-27 North T1	2,327	0,126
17	IM-27 South T1	2,189	0,021
17	IM-28 North T1	1,488	0,181
17	IM-28 South T1	1,650	0,136
17	IM-29 North T1	0,653	0,087
17	IM-29 South T1	0,743	0,077

Time exposure (days)		mass of oil (g)	Std. Dev.
37	HFO North T2	1,564	0,029
37	HFO South T2	1,817	0,053
37	IM-27 North T2	1,639	0,224
37	IM-27 South T2	2,115	0,057
37	IM-28 North T2	1,352	0,097
37	IM-28 South T2	1,487	0,148
37	IM-29 North T2	0,424	0,071
37	IM-29 South T2	0,589	0,071

Time exposure (days)		mass of oil (g)	Std. Dev.
98	HFO North T3	1,322	0,089
98	HFO South T3	1,467	0,160
98	IM-27 North T3	1,323	0,286
98	IM-27 South T3	2,154	0,085
98	IM-28 North T3	1,101	0,093
98	IM-28 South T3	1,248	0,102
98	IM-29 North T3	0,330	0,129
98	IM-29 South T3	0,508	0,058

Time exposure (days)		mass of oil (g)	Std. Dev.
176	HFO North T4	0,828	0,102
176	HFO South T4	0,922	0,028
176	IM-27 North T4	1,126	0,270
176	IM-27 South T4	1,835	0,024
176	IM-28 North T4	0,821	0,030
176	IM-28 South T4	1,146	0,107
176	IM-29 North T4	0,187	0,056
176	IM-29 South T4	0,641	0,076

Time exposure (days)		mass of oil (g)	Std. Dev.
262	HFO North T5	0,355	0,031
262	HFO South T5	0,392	0,035
262	IM-27 North T5	0,721	0,721
262	IM-27 South T5	1,189	1,189
262	IM-28 North T5	0,548	0,062
262	IM-28 South T5	0,686	0,062
262	IM-29 North T5	0,216	0,080
262	IM-29 South T5	0,149	0,026

Time exposure (days)		mass of oil (g)	Std. Dev.
328	HFO North T5	0,103	0,007
328	HFO South T5	0,148	0,028
328	IM-27 North T5	0,203	0,076
328	IM-27 South T5	0,575	0,026
328	IM-28 Nord T5	0,236	0,116
328	IM-28 South T5	0,610	0,059
328	IM-29 North T5	0,041	0,006
328	IM-29 South T5	0,073	0,025

WP5 - Persistence of oil on natural rocky shore : Natural cleanup, Oil degradation and Kinetics of recolonization by biota

Setup in Tromsø, Norway

Kjersti Dale
Norwegian costal administration

KYSTVERKET
NORWEGIAN COASTAL ADMINISTRATION

Set up location - quay in Tromsø

- tiles set up randomly on 3 sections

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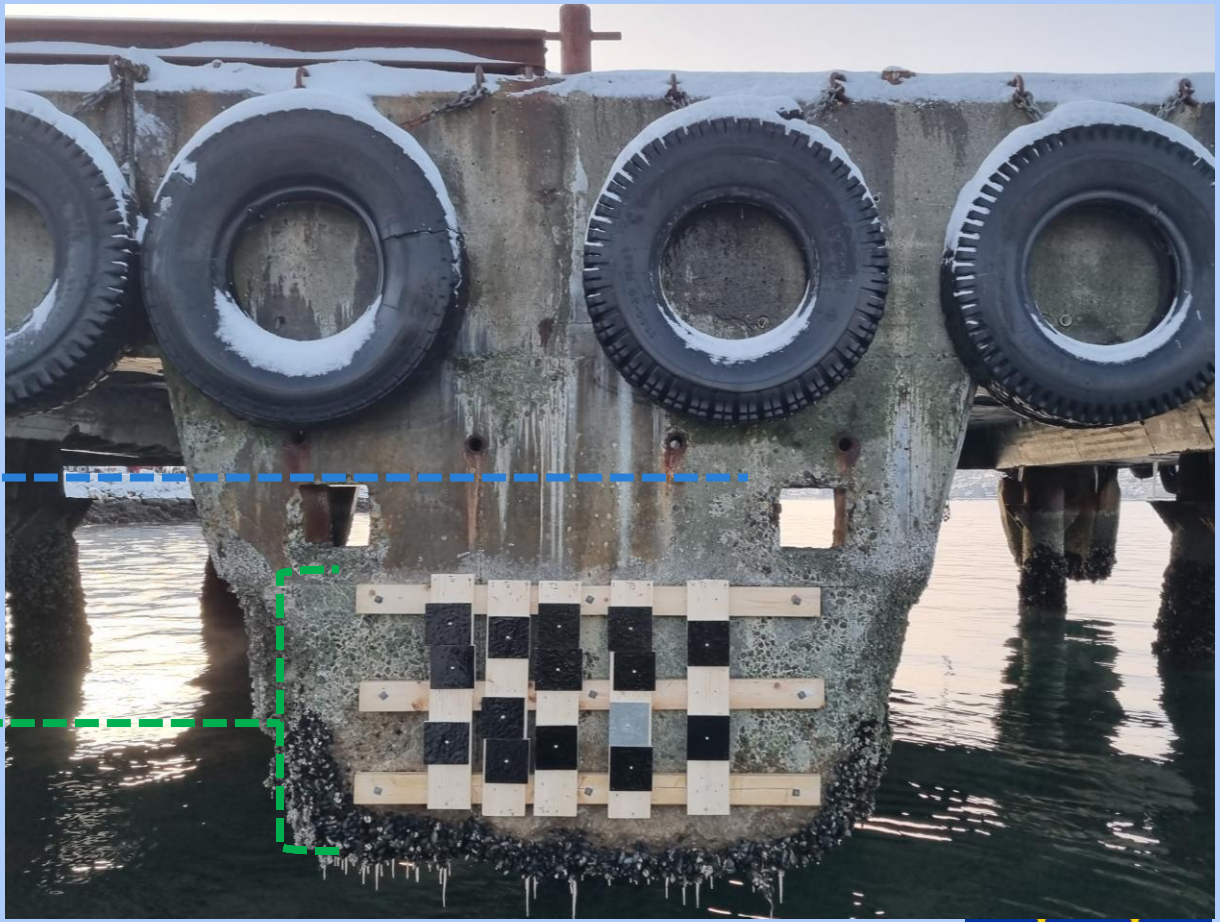
KYSTVERKET
NORWEGIAN COASTAL ADMINISTRATION

Tiles setup

- Tidal difference varies form **1,77 m – 2,32 m**
- Maximum difference in tidal water around equinox **3,60 m**
- Quay not in commercial use due to standard
- Access by boat



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Sampling plan

		T0	T1 (15 days)	T2 (1 mnd)	T3 (3 mnd)	T4 (6 mnd)	T5 (8 mnd/9mnd)	T6 12mnd	total
Sampled			**14.feb**	**28.feb**	**30.may**	**11.july**	**19.sep**	**Not in project**	
Days in field		20.jan	**25**	**39**	**100**	**142**	**212**		
Oil 1	LSFO IM-27	3	3	3	3	3	3	3	21
Oil 2	LSFO IM-28	3	3	3	3	3	3	0	18
Oil 3	LSFO IM-29	3	3	3	3	3	3	0	18
Oil 4	HFO	3	**2**	3	3	3	3	0	17
No oil		0	0	0	3	3	3	0	9
Tiles sampled		**12**	**11**	**12**	**15**	**15**	**15**	**0**	

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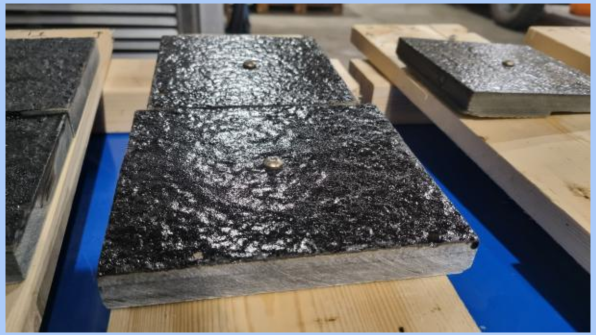
KYSTVERKET
NORWEGIAN COASTAL ADMINISTRATION

Samling T1(15 days)

- 14. February

IM-27 (oil 1)



IM-28 (oil 2)

LSFO IM-29 (oil3)

HFO

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Samling T2 (1 mnd)
- 28. February

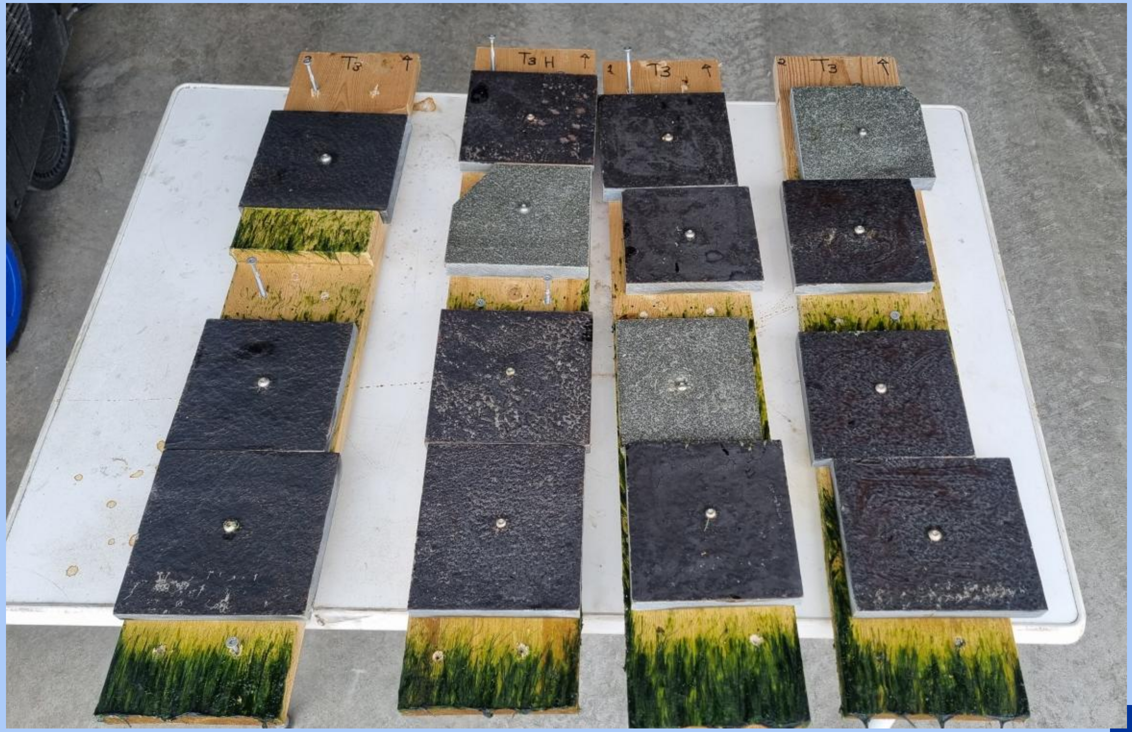
IM-27 (oil 1)

IM-28 (oil 2)

IM-29 (oil3)

HFO

Samling T3 (3 mnd)
- 30. May



No barnacles or biota growth on tiles
Green algae around the setup

Samling T4 (6 mnd)
- 11. July

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Samling T5 (9 mnd)
- 19. September

IM-27 (oil 1)

IM-28 (oil 2)

IM-29 (oil3)

HFO

Red algae dominate the algae growth on the setup.

Some growth of green algae on the referent and IM-29 (oil3) tiles

LSFO IM-27

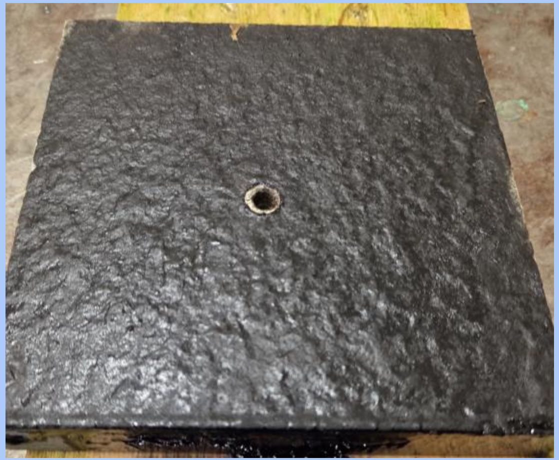
Oil 1

Sampling T1 – 15 days
25 days in field

Sampling T2 – 1 mnd
39 days in field

Sampling T3 – 3 mnd
100 days in field

Sampling T4 – 6 mnd
142 days in field



Sampling T5 – 8 mnd
212 days in field

LSFO IM-28

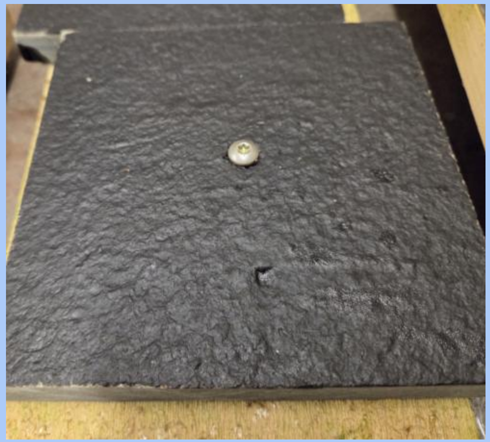
Oil 2

Sampling T1 – 15 days
25 days in field

Sampling T2 – 1 mnd
39 days15 days in field

Sampling T3 – 3 mnd
100 days in field

Sampling T4 – 6 mnd
142 days in field



Sampling T5 – 8 mnd
212 days in field

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KYSTVERKET
NORWEGIAN COASTAL ADMINISTRATION

LSFO IM-29

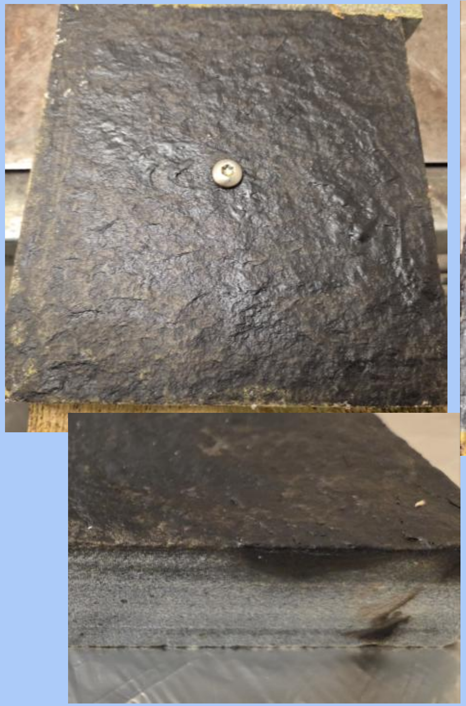
Oil 3

Sampling T1 – 15 days
25 days in field

Sampling T2 – 1 mnd
39 days15 days in field

Sampling T3 – 3 mnd
100 days in field

Sampling T4 – 6 mnd
142 days in field



Sampling T5 – 8 mnd
212 days in field

HFO

Sampling T1 – 15 days
25 days in field

Sampling T2 – 1 mnd
39 days15 days in field

Sampling T3 – 3 mnd
100 days in field

Sampling T4 – 6 mnd
142 days in field

Sampling T5 – 8 mnd
212 days in field

Biota growth

Sampling T3 – 3 mnd 100 days in field – 30 May

Green algae on setup
No barnacles on setup or concrete base

Sampling T4 – 6 mnd 142 days in field – 11 July

Barnacles fond on tiles and on wood is about 7 mm

Some green algae on the setup.
Few barnacles on the referent tiles and on the wood. A lager amount of barnacles is settled on the concrete base

Sampling T5 – 8 mnd 212 days in field – 19 September

Red algae dominate the algae growth on the setup. Some growth of green algae on the referent and IM-29 (oil3) tiles. More dense growth of barnacles on the base and a few on the wood, but not apparent on the tiles. Some mussel's growth on the tiles side.

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Short summary of observations

- **Sampling T1 and T2** (15 days and 1 mnd) showed little difference in degradation and no biota grown
- **Sampling T3** (3 mnd) 30 May – showed obvious transformation of the oil layers on the tiles
  - Biota grown at the setup location of green algae. No observation of barnacles.
  - The new settled green algae grew on the wood and concrete surfaces, but not on oiled or reference tiles.
  - The nauplii larvae of barnacles settles on surfaces in the north in the period May-June

- **Sampling T4** (6 mnd) 11. July – showed the first growth of barnacles on the tiles. The few numbers of barnacles were found on the referent tiles. No growth of alga on the oiled and reference tiles. The oil starts to show more characteristic of degradation.

- **Sampling T5** (9 mnd) 19 September – showed even more degraded oil and no more “fresh oil”. In field on the setup the green algae that was grown on the setup earlier in the springtime was gone and replaced by growth of red alga. Some green algae present on the referent and IM-29 (oil3) tiles. No growth of barnacles on any tiles, only on the side of the wooden board along with a few mussels.

Mass recovered from the Tiles

Time step	T0			T1			T2			T3			T4			T5		
Time (days)	0			25			39			100			142			212		
	triplicate	average	std deviation	triplicate	average	std deviation	triplicate	average	std deviation	triplicate	average	std deviation	triplicate	average	std deviation	triplicate	average	std deviation
	3,0877			3,3339			3,5382			3,5258			1,3555			9,1122		
HFO	4,0524	3,2908	0,6832	2,4107	2,8723	0,6528	3,4214	3,5450	0,1270	3,0123	3,1503	0,3289	2,2497	2,1318	0,7245	9,1450	9,1536	0,0462
	2,7321			XXX			3,6753			2,9129			2,7901			9,2034		
	3,6988			3,3872			3,2303			3,5804			3,0871			9,3636		
IM-27	3,5946	3,3861	0,4543	3,1142	2,9894	0,1931	3,1011	3,3689	0,3577	2,9038	2,9623	0,5909	2,6098	2,6625	0,4009	8,7385	8,9963	0,3266
	2,8650			2,4668			3,7751			2,4029			2,2904			8,8869		
	3,7645			3,4059			2,6588			2,9096			2,1150			2,3922		
IM-28	2,5051	3,0129	0,6641	2,5339	2,9312	0,6166	3,1693	3,1552	0,4895	2,6124	2,5940	0,3252	1,9297	2,0407	0,0980	1,7490	1,7833	0,5925
	2,7691			2,8537			3,6375			2,2599			2,0775			1,2087		
	2,5697			1,8803			1,5045			0,7742			0,8113			0,6441		
IM-29	2,6690	2,5411	0,1444	2,0691	1,8823	0,1335	1,4993	1,4185	0,1444	0,9849	0,8969	0,1095	0,8077	0,8047	0,0085	0,6873	0,6348	0,0577
	2,3845			1,6974			1,2518			0,9315			0,7952			0,5731		

APPENDIX 6

Task 5.4

Rock colonisation by biota / Natural recovery

Tiles recolonisation

Co-funded by the European Union

I – Experiment in France

		T4		T5		T6	
		average	st. dev.	average	st. dev.	average	st. dev.
North	Control	33	11	40	29	57	35
	HFO	28	5	118	38	104	23
	IM-27	64	84	183	35	84	40
	IM-28	6	5	23	16	19	10
	IM-29	135	33	164	46	133	17

Co-funded by the European Union

APPENDIX 7

Task 5.4

Rock colonisation by biota / Natural recovery

Chemical composition of the oils

Co-funded by the European Union

I – Experiment in France

PAH abundances (Hopane Unit)

IM 27

Weathering time (days)	[PAH] North	std dev. North	[PAH] South	std dev. South
Fresh oil (lab)	66		66	
0	53	8	50	3
17	44	3	43	4
37	42	13	33	8
98	34	2	25	1
176	26	3	9	0
262	15	5	7	3
328	9	1	3	0

IM 28

Weathering time (days)	[PAH] North	std dev. North	[PAH] South	std dev. South
Fresh oil (lab)	604		604	
0	422	26	434	25
17	301	18	296	5
37	299	37	295	54
98	154	15	161	40
176	88	2	65	20
262	70	13	56	21
328	21	5	13	1

IM 29

Weathering time (days)	[PAH] North	std dev. North	[PAH] South	std dev. South
Fresh oil (lab)	401		401	
0	125	20	129	12
17	68	14	83	12
37	56	9	72	22
98	38	21	76	21
176	54	3	90	15
262	104	16	43	10
328	22	6	16	6

HFO

Weathering time (days)	[PAH] North	std dev. North	[PAH] South	std dev. South
Fresh oil (lab)	52 757		52 757	
0	29 030	1 002	28 342	7 213
17	21 545	792	21 505	1 169
37	28 478	6 262	24 068	7 215
98	16 100	1 077	15 457	1 196
176	11 064	249	7 917	688
262	19 340	6 039	11 203	1 262
328	7 106	2 716	7 283	793

n-alkanes abundances (Hopane Unit)

IM 27

Weathering time (days)	[n-alkanes] North	std dev. North	[n-alkanes] South	std dev. South
Fresh oil (lab)	114		114	
0	113	17	106	3
17	114	11	115	11
37	34	4	83	17
98	27	1	85	10
176	25	5	81	2
262	25	5	58	25
328	13	3	69	6

IM 28

Weathering time (days)	[n-alkanes] North	std dev. North	[n-alkanes] South	std dev. South
Fresh oil (lab)	424		424	
0	511	56	481	56
17	480	172	548	64
37	431	46	629	151
98	281	41	612	220
176	222	127	445	45
262	166	30	353	110
328	97	22	406	54

IM 29

Weathering time (days)	[n-alkanes] North	std dev. North	[n-alkanes] South	std dev. South
Fresh oil (lab)	592		592	
0	628	94	631	109
17	551	61	520	40
37	383	33	385	88
98	235	95	400	11
176	273	16	272	13
262	353	43	315	32
328	100	13	198	58

HFO

Weathering time (days)	[n-alkanes] North	std dev. North	[n-alkanes] South	std dev. South
Fresh oil (lab)	3 853		3 853	
0	2 152	147	2 129	689
17	1 845	70	1 922	61
37	1 718	233	2 126	776
98	390	79	1 436	332
176	388	57	1 159	266
262	907	375	637	47
328	387	103	423	98

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II – Experiment in Norway

PAH abundances (Hopane Unit)

IM 27		
Weathering time (month)	[PAH]	std dev.
0	75	30
25	46	5
39	58	3
100	40	8
142	16	3
212	6	1

IM 28		
Weathering time (month)	[PAH]	std dev.
0	583	268
25	430	68
39	388	64
100	261	31
142	86	13
212	39	18

IM 29		
Weathering time (month)	[PAH]	std dev.
0	263	78
25	143	55
39	113	13
100	38	6
142	14	7
212	6	1

HFO		
Weathering time (month)	[PAH]	std dev.
0	37 849	4 736
25	57 331	
39	30 757	5 174
100	26 156	3 563
142	16 262	2 067
212	17 138	8 011

n-alkanes abundances (Hopane Unit)

IM 27		
Weathering time (month)	[n-alkanes]	std dev.
0	141	55
25	114	23
39	175	26
100	184	9
142	205	44
212	129	14

IM 28		
Weathering time (month)	[n-alkanes]	std dev.
0	472	183
25	568	94
39	586	84
100	732	54
142	1 875	917
212	707	103

IM 29		
Weathering time (month)	[n-alkanes]	std dev.
0	725	169
25	835	275
39	1 055	141
100	1 190	88
142	979	122
212	868	82

HFO		
Weathering time (month)	[n-alkanes]	std dev.
0	2 849	424
25	5 257	
39	3 232	584
100	3 226	467
142	5 644	2 104
212	2 769	1 502

III – Experiment in Malta

Colonne1	Weathering time	[PAH] (HU)	Loss PAH (%) /T0	[n-alkanes (HU)	Loss n-alkanes (%)
HFO	T0	27084		1604	
	Tf	689	97	9	99
IM-27	T0	57		104	
	Tf (LCL)	7	88	2	98
	Tf (GL)	10	83	3	97
IM-28	T0	552		396	
	Tf (LCL)	104	81	78	80
	Tf (GL)	99	82	20	95
	Tf (GL) -2	116	79	10	97
IM-29	T0	438		604	
	Tf (LCL)	7	98	5	99
	Tf (LCL) -2	50	89	194	68

Lower coralline Limestone (LCL)
Globigerina Limestone (GL)

APPENDIX 8

Task 5.5

Interaction with sediments

Behaviour of IM-27

Addition on DRY sediments		
Sand	**Gravel**	**Pebbles**
		
Penetration of few millimetres and thick layer on the top of the sediment	Full filtering down the sediment	Full filtering down the sediment
Slow addition of water (without agitation)		
		
No oil remobilisation. The oil stays trapped on/in the sediment		
Agitation		

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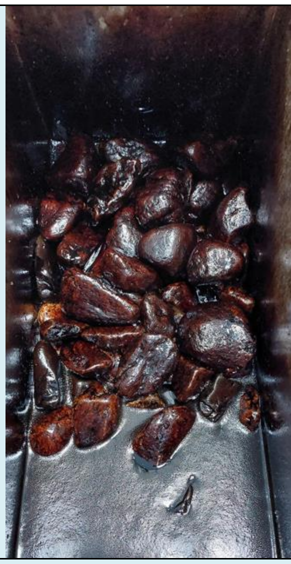
Slow remobilisation of the oil layer covering the sediment. The oil trapped in the sediment does not resurface. Manual agitation of the sediment allows an easy remobilisation of the trapped oil, leaving cleaned sediments.

Addition on WET sediment		
Sand	**Gravel**	**Pebbles**
		
Penetration of few millimetres and thick layer on the top of the sediment (same as addition on DRY sediment)	Full filtering down the sediment (same as addition on DRY sediment)	Full filtering down the sediment (same as addition on DRY sediment)
Alternating low and high tides and agitation (oscillating table) over 5 days		

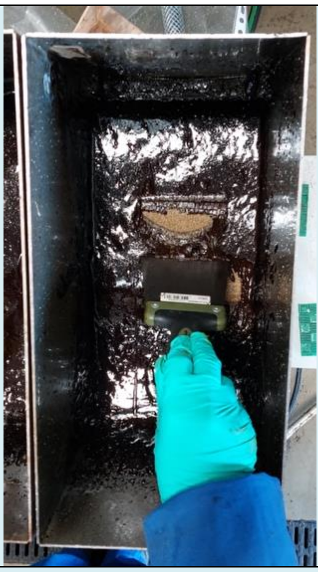
<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>Penetration in the sediment (~ over 2 cm)</td><td>Full filtering down the sediment</td><td>Full filtering down the sediment</td></tr>
<tr><td colspan="3">Addition of water</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Remobilisation of the oil layer present on the top of the sediment leaving the surface sediment almost cleaned. Trapped oil needs manual agitation to resurface.</td></tr>
</table>

Behaviour of IM-28

Addition on DRY sediments		
Sand	**Gravel**	**Pebbles**
		
No penetration. Oil slick nearly frozen	Full filtering down the sediment	Shiny frozen slick on the top of the sediment (slight filtering down)
Slow addition of water (without agitation)		
		
No oil remobilisation. The oil stays trapped on/in the sediment		
Agitation		


Slow remobilisation of the oil layer covering the sediment, leaving the surface of the sediment almost clean. Oil trapped in the sediment does not resurface. Manual agitation of the sediment allows an easy remobilisation of the trapped oil, leaving cleaned sediments.

Addition on WET sediment		
Sand	**Gravel**	**Pebbles**
		
No penetration. Oil frozen on the top of the sediment (same as during addition on DRY sediment)	Full filtering down the sediment (same obs. as addition on DRY sediment)	Shiny frozen slick on the top of the sediment (slight filtering down) (same obs. as addition on DRY sediment)
Alternating low and high tides and agitation (oscillating table) over 5 days		

<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>Emulsion laid on the sediment. Can be easily removed by rolling the slick, with very limited sand aggregation</td><td>Full filtering down the sediment</td><td>Shiny and varnished aspect of the slick laid on the pebbles surface, with filtering through</td></tr>
<tr><td colspan="3">Addition of water</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Very slow remobilisation of the slick with agitation. Clean sediment below.</td><td colspan="2">Easy remobilisation of the oil layer present on the top of the sediment leaving the surface sediment almost cleaned. Trapped oil needs manual agitation of the sediment to resurface.</td></tr>
</table>

Behaviour of IM-29

Addition on DRY sediments		
Sand	**Gravel**	**Pebbles**
		
Full filtering down the sediment	Full filtering down the sediment	Full filtering down the sediment
Slow addition of water (without agitation)		
		
No oil remobilisation	Remobilisation of oil at the water surface	
Agitation		

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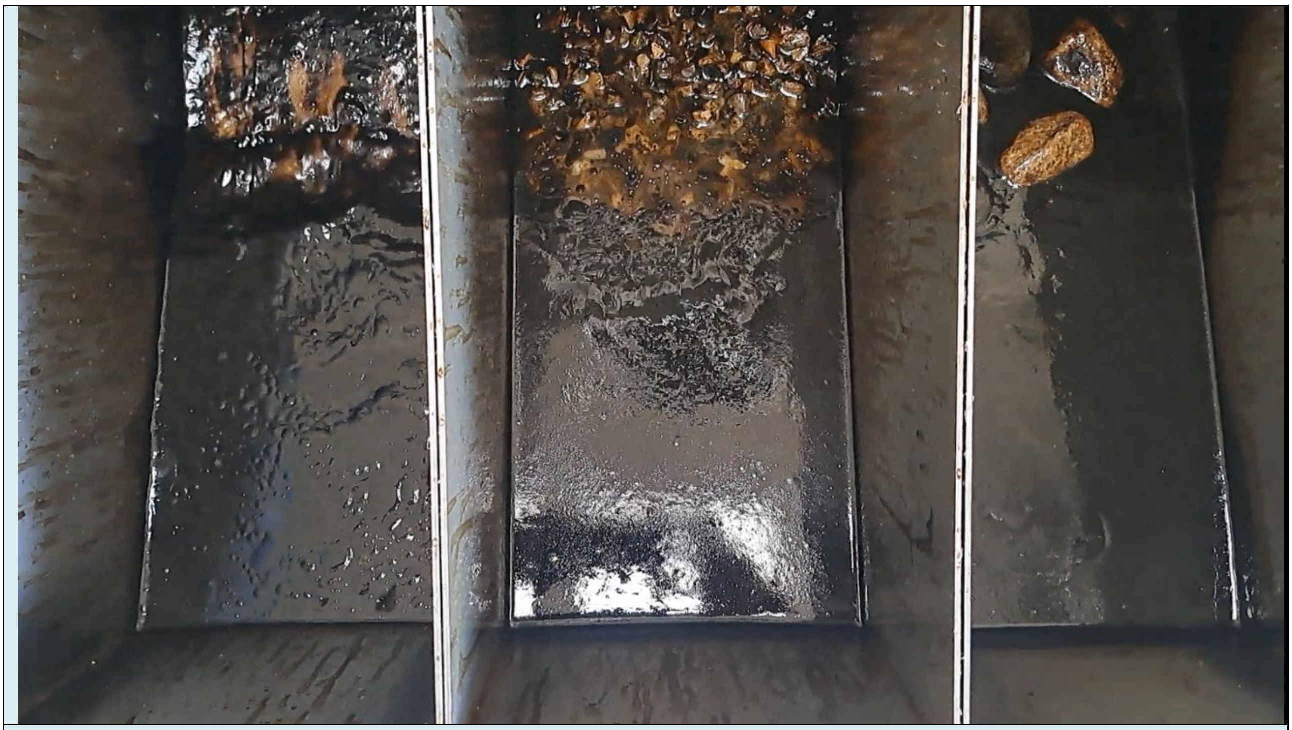

Easy remobilisation of the oil layer present on the top of the sediment leaving the surface sediment almost cleaned. Trapped oil needs manual agitation of the sediment to resurface.

Addition on WET sediment		
Sand	**Gravel**	**Pebbles**
		
The thin layer of water on the top of the sediment avoids the oil penetration in the sand	Full filtering down the sediment (same obs. as addition on DRY sediment)	Shiny and varnished aspect of the slick laid on the pebbles surface, with filtering through (same obs. as addition on DRY sediment)
Alternating low and high tides and agitation over 5 days		

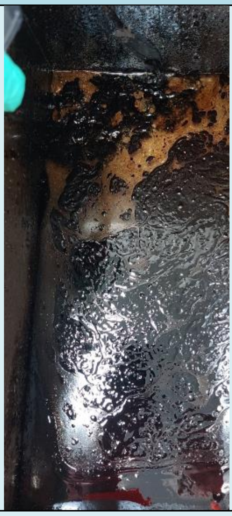
<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>Penetration in the sediment (~ over 1 cm)</td><td>Full filtering down the sediment</td><td>Full filtering down the sediment</td></tr>
<tr><td colspan="3">Addition of water</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Remobilisation of the oil layer present on the top of the sediment leaving the surface sediment almost cleaned. Trapped oil needs manual agitation of the sediment to resurface.</td></tr>
</table>

Behaviour of the comparative oil HFO

<table>
<tr><th colspan="3">Addition on DRY sediments</th></tr>
<tr><th>Sand</th><th>Gravel</th><th>Pebbles</th></tr>
<tr><td colspan="3"></td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td>Penetration of few millimetres and thick layer on the top of the sediment that solidifies with time and can be removed from the sediment by rolling it without incorporation sand</td><td>Full filtering down the sediment</td><td>Full filtering down the sediment</td></tr>
<tr><td colspan="3">Slow addition of water (without agitation)</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">No oil remobilisation. The oil stays trapped on/in the sediment</td></tr>
<tr><td colspan="3">Agitation</td></tr>
</table>


Little remobilisation of the oil that mainly stick to the walls. Oil trapped in the sediment does not easily resurface and stays stuck on the manual tools when mixing the sediment.

Addition on WET sediment		
Sand	**Gravel**	**Pebbles**
		
No obvious penetration. Oil layer laid on the sediment	Full filtering down the sediment	Full filtering down the sediment (same obs. as addition on DRY sediment)
Alternating low and high tides and agitation over 5 days		

<table>
<tr><td></td><td></td><td></td></tr>
<tr><td>Oil laid on the sediment. Can be rolled with very limited amount of sand</td><td>Full filtering down the sediment</td><td>Full filtering down the sediment</td></tr>
<tr><td colspan="3">Addition of water</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>Remobilisation of the oil layer. Some oil droplets remain stuck on the sediment or on the walls.</td><td colspan="2">Easy remobilisation of the oil layer present on the top of the sediment leaving the surface sediment almost cleaned. Trapped oil remains below the sediment surface and sticks to the manual tools when mixing the sediment</td></tr>
</table>

APPENDIX 9

Task 5.6

Observations on practical cleaning techniques

Funded by the European Union

IMAROS 2

WP 5 - Task 5.6 Observations on practical cleaning techniques

Appendix – Results tables

Funded by
the European Union

imaros2

3.6.1.1. Small scale test 1 and 2 – frozen surroundings

Small scale test 1	Freezing	Dry rocks (pebbles/cobbles)	Water content in oil emulsion	33,3%	04.02.2025	The test objective is to study adhesion to wet and dry rocks in sub-zero conditions and the applicability of cleaning techniques.
Oil	IM-27 (VLSFO)					
Fase 1 (rock 1)	"Pull" off the oil by hand if possible, alternative scrape it off with a wooden spatula.					
Fase 2 (rock 2)	Rub/polish with oil bark by hand.					
Fase 3 (rock 3)	Lower the rock in 25 °C water bath. Observe for 5 mins.					
Fase 4 (rock 3)	Wash the rock in the 25°C water bath (if needed)					
Fase 5 (rock 3)	Scrub the rock in the 25°C water bath with a toothbrush (if needed)					

Fase/rock no	Date	Initial weight (g)	Weight after test (g)	Weight after diesel ++ (27.02.2025) (g)	Initial oil (g)	Oil removed with test method (g)	Percent oil removed by test method
Fase 1 (rock 1)	06.02.2025	48	44	44	4	4	100,00 %
Fase 2 (rock 2)	06.02.2025	79	65	65	14	14	100,00 %
Fase 3 (rock 3)	06.02.2025	83	77	72	11	6	54,55 %
Fase 4 (rock 3)	06.02.2025	83	72	72	11	11	100,00 %
Fase 5 (rock 3)	06.02.2025	83	72	72	11	11	100,00 %

Observations:

*** The stone during test 2 required more force than expected. The rock hade a more rough surface than we generally experienced, so we assumed that this was why the oil stuck better.**
*** Test 2 and test 4 seemed to make the stones completely clean.**
*** According to tests 1 and 3, we see that the oil infects the latex gloves much and "prefers" this as a substrate versus the stones surface. We also saw that the oil adheres well to the plastic fibers on the toothbrush used for test 5. Might this effect the choice of surface materials in skimmers. Will the oil stick better to a surface made of latex/rubber/plastic/paint than pure metal? (It might be possible to conduct a simple test on this later). Maybe this might affect skimmer "surface design" in the future?**
*** No difference in weight between tests 4 and 5 was observed, although we saw that there were some mini oil droplets left that we removed with the toothbrush at the end.**
*** We observed some cross-contamination from the glove to the stone during test 4. Perhaps only brushing (test 5) would have been better. The contamination only affected parts of the stone, so the details in rock surface probably have a lot to do with it.**

Small scale test 2	Freezing	Wet rocks (pebbles/cobbles)	Water content in oil emulsion	33,3%	04.02.2025	The test objective is to study adhesion to wet and dry rocks in sub-zero conditions and the applicability of cleaning techniques.

Oljetype	IM-27 (VLSFO)
Fase 1 (rock 1)	"Pull" off the oil by hand if possible, alternative scrape it off with a wooden spatula.
Fase 2 (rock 2)	Rub/polish with oil bark by hand.
Fase 3 (rock 3)	Lower the rock in 25 °C water bath. Observe for 5 mins.
Fase 4 (rock 3)	Wash the rock in the 25°C water bath (if needed)
Fase 5 (rock 3)	Scrub the rock i the 25°C water bath with a toothbrush (if needed)

Fase/rock no	Date	Initial weight (g)	Weight after test (g)	Weight after diesel ++ (27.02.2025) (g)	Initial oil (g)	Oil removed with test method (g)	Percent oil removed by test method
Fase 1 (rock 1)	06.02.2025	107	96	95	12	11	91,67 %
Fase 2 (rock 2)	06.02.2025	39	35	35	4	4	100,00 %
Fase 3 (rock 3)	06.02.2025	77	71	70	7	6	85,71 %
Fase 4 (rock 3)	06.02.2025	77	70	70	7	7	100,00 %
Fase 5 (rock 3)	06.02.2025	77	70	70	7	7	100,00 %

Comments:

*** No noticeable difference between wet and dry stones - see comments dry IM-27**

*** There was a slight difference when applying the oil (it probably stuck a little worse with a layer of ice on it).**

*** The main difference between dry (Test 1) and wet oil (Test 2) was that polishing with oil bark went faster. We suspect that the difference has more to do with the rock surface, rather than whether it was dry or wet when frozen (smoother surface).**

Small scale test 2	Freezing	Dry rocks (pebbles/cobbles)		Water content in oil emulsion	51,6%	04.02.2025	The test objective is to study adhesion to wet and dry rocks in sub-zero conditions and the applicability of cleaning techniques.	
Oljetype	**IM-28 (VLSFO)**							
Fase 1 (rock 1)	"Pull" off the oil by hand if possible, alternative scrape it off with a wooden spatula.							
Fase 2 (rock 2)	Rub/polish with oil bark by hand.							
Fase 3 (rock 3)	Lower the rock in 25 °C water bath. Observe for 5 mins.							
Fase 4 (rock 3)	Wash the rock in the 25°C water bath (if needed)							
Fase 5 (rock 3)	Scrub the rock in the 25°C water bath with a toothbrush (if needed)							
Fase/rock no	**Date**	**Initial weight (g)**	**Weight after test (g)**	**Weight after diesel ++ (27.02.2025) (g)**		**Initial oil (g)**	**Oil removed with test method (g)**	**Percent oil removed by test method**
Fase 1 (rock 1)	06.02.2025	68	58	57		11	**10**	**90,91 %**
Fase 2 (rock 2)	06.02.2025	59	49	48		11	**10**	**90,91 %**
Fase 3 (rock 3)	06.02.2025	68	68	68		10	**0**	**0,00 %**
Fase 4 (rock 3)	06.02.2025	68	60	60		10	**8**	**80,00 %**
Fase 5 (rock 3)	06.02.2025	68	58	58		10	**10**	**100,00 %**

Comments:
*** The calculations/numbers does not show it, but the practical observation showed that polishing with sorbents (bark) gave the best result.**

Small scale test 2	Freezing	Wet rocks (pebbles/cobbles)		Water content in oil emulsion	51,6%	04.02.2025	The test objective is to study adhesion to wet and dry rocks in sub-zero conditions and the applicability of cleaning techniques.	
Oljetype	**IM-28 (VLSFO)**							
Fase 1 (rock 1)	"Pull" off the oil by hand if possible, alternative scrape it off with a wooden spatula.							
Fase 2 (rock 2)	Rub/polish with oil bark by hand.							
Fase 3 (rock 3)	Lower the rock in 25 °C water bath. Observe for 5 mins.							
Fase 4 (rock 3)	Wash the rock in the 25°C water bath (if needed)							
Fase 5 (rock 3)	Scrub the rock in the 25°C water bath with a toothbrush (if needed)							
Fase/rock no	**Date**	**Initial weight (g)**	**Weight after test (g)**	**Weight after diesel ++ (27.02.2025) (g)**		**Initial oil (g)**	**Oil removed with test method (g)**	**Percent oil removed by test method**
Fase 1 (rock 1)	06.02.2025	75	68	67		8	**7**	**87,50 %**
Fase 2 (rock 2)	06.02.2025	86	82	81		5	**4**	**80,00 %**
Fase 3 (rock 3)	06.02.2025	58	53	52		6	**5**	**83,33 %**
Fase 4 (rock 3)	06.02.2025	58	52	52		6	**6**	**100,00 %**
Fase 5 (rock 3)	06.02.2025	58	52	52		6	**6**	**100,00 %**

Comments:
*** Test 2: Our practical observations showed that the polishing with bark cleaned almost 100% after a very short time, even though the weighing shows this method as the least effective. The fact that it was the rock with the least amount of oil, compared to the others and the weight of the rock, has probably something to do with it, since we did not weigh in decimals of grams.**
*** Test 4: The oil sticks to the latex glove and then spreads back onto the stone in a noticeable extent.**
*** There were visible oil residues on the rock after test 5, but this did not affect the weight.**

Small scale test 1	Freezing	Dry rocks (pebbles/cobbles)		Water content in oil emulsion	51,3%	04.02.2025	The test objective is to study adhesion to wet and dry rocks in sub-zero conditions and the applicability of cleaning techniques.
Oljetype	IM-29 (ULSFO)						
Fase 1 (rock 1)	"Pull" off the oil by hand if possible, alternative scrape it off with a wooden spatula.						
Fase 2 (rock 2)	Rub/polish with oil bark by hand.						
Fase 3 (rock 3)	Lower the rock in 25 °C water bath. Observe for 5 mins.						
Fase 4 (rock 3)	Wash the rock in the 25°C water bath (if needed)						
Fase 5 (rock 3)	Scrub the rock i the 25°C water bath with a toothbrush (if needed)						
Fase/rock no	Date	Initial weight (g)	Weight after test (g)	Weight after diesel ++ (27.02.2025) (g)	Initial oil (g)	Oil removed with test method (g)	Percent oil removed by test method
Fase 1 (rock 1)	06.02.2025	78	64	64	14	14	100,00 %
Fase 2 (rock 2)	06.02.2025	76	64	64	12	12	100,00 %
Fase 3 (rock 3)	06.02.2025	51	45	45	8	6	75,00 %
Fase 4 (rock 3)	06.02.2025	51	43	43	8	8	100,00 %
Fase 5 (rock 3)	06.02.2025	51	43	43	8	n.a	n.a.

Comments:

*** No need to conduct test 5 already clean after test 4.**

*** See comments IM-27 > IM-29 behaves/reacts quite similarly.**

Small scale test 2	Freezing	Wet rocks (pebbles/cobbles)		Water content in oil emulsion	51,3%	04.02.2025	The test objective is to study adhesion to wet and dry rocks in sub-zero conditions and the applicability of cleaning techniques.	
Oljetype	IM-29 (ULSFO)							
Fase 1 (rock 1)	"Pull" off the oil by hand if possible, alternative scrape it off with a wooden spatula.							
Fase 2 (rock 2)	Rub/polish with oil bark by hand.							
Fase 3 (rock 3)	Lower the rock in 25 °C water bath. Observe for 5 mins.							
Fase 4 (rock 3)	Wash the rock in the 25°C water bath (if needed)							
Fase 5 (rock 3)	Scrub the rock i the 25°C water bath with a toothbrush (if needed)							
Fase/rock no	Date	Initial weight (g)	Weight after test (g)	Weight after diesel ++ (27.02.2025) (g)		Initial oil (g)	Oil removed with test method (g)	Percent oil removed by test method
Fase 1 (rock 1)	06.02.2025	73	63	63		10	10	100,00 %
Fase 2 (rock 2)	06.02.2025	61	54	54		7	7	100,00 %
Fase 3 (rock 3)	06.02.2025	56	48	48		8	8	100,00 %
Fase 4 (rock 3)	06.02.2025	56	48	48		8	n.a	n.a
Fase 5 (rock 3)	06.02.2025	56	48	48		8	n.a	n.a

Comments:

*** The rocks look completely clean after tests 1 and 2.**

*** There was some oil left after test 3, but that was probably because it was partially stuck under the rock. Expect that it would be released quickly if moved and this would have made the rock completely clean without the need for tests 4 and 5.**

Small scale test 1	Freezing	Dry rocks (pebbles/cobbles)		Water content in oil emulsion	1%	04.02.2025	The test objective is to study adhesion to wet and dry rocks in sub-zero conditions and the applicability of cleaning techniques.	
Oljetype	IFO 380							
Fase 1 (rock 1)	"Pull" off the oil by hand if possible, alternative scrape it off with a wooden spatula.							
Fase 2 (rock 2)	Rub/polish with oil bark by hand.							
Fase 3 (rock 3)	Lower the rock in 25 °C water bath. Observe for 5 mins.							
Fase 4 (rock 3)	Wash the rock in the 25°C water bath (if needed)							
Fase 5 (rock 3)	Scrub the rock i the 25°C water bath with a toothbrush (if needed)							
Fase/rock no	Date	Initial weight (g)	Weight after test (g)	Weight after diesel ++ (27.02.2025) (g)		Initial oil (g)	Oil removed with test method (g)	Percent oil removed by test method
Fase 1 (rock 1)	06.02.2025	59	50	47		12	9	75,00 %
Fase 2 (rock 2)	06.02.2025	122	107	104		18	15	83,33 %
Fase 3 (rock 3)	06.02.2025	65	60	60		9	5	55,56 %
Fase 4 (rock 3)	06.02.2025	65	57	57		9	8	88,89 %
Fase 5 (rock 3)	06.02.2025	65	56	56		9	9	100,00 %

Comments:

*** The oil is sticking so hard to the rock and the plastic can that it is difficult to remove the rocks for cleaning tests**

*** Fase 1: The oil sticks very much to the latex gloves, difficult/hard to work this way.**

*** Fase 2: We had to saturate the oil with bark first, then pull it off. Gets cleaner, but it requires a lot of energy/force. You "feel" when the oil is saturated and ready to be pulled off. It has probably also to do with that you have to thaw the oil before it can be removed.**

Small scale test 2	Freezing	Wet rocks (pebbles/cobbles)		Water content in oil emulsion	1%	04.02.2025	The test objective is to study adhesion to wet and dry rocks in sub-zero conditions and the applicability of cleaning techniques.	
Oljetype	IFO 380							
Oljetype	"Pull" off the oil by hand if possible, alternative scrape it off with a wooden spatula.							
Fase 1 (rock 1)	Rub/polish with oil bark by hand.							
Fase 2 (rock 2)	Lower the rock in 25°C water bath. Observe for 5 mins.							
Fase 3 (rock 3)	Wash the rock in the 25°C water bath (if needed)							
Fase 4 (rock 3)	Scrub the rock i the 25°C water bath with a toothbrush (if needed)							
Fase 5 (rock 3)	Date	Initial weight (g)	Weight after test (g)	Weight after diesel ++ (27.02.2025) (g)		Initial oil (g)	Oil removed with test method (g)	Percent oil removed by test method
Fase/rock no	06.02.2025	95	84	79		16	11	68,75 %
Fase 1 (rock 1)	06.02.2025	77	66	64		13	11	84,62 %
Fase 2 (rock 2)	06.02.2025	83	77	73		10	6	60,00 %
Fase 3 (rock 3)	06.02.2025	83	73	73		10	10	100,00 %
Fase 4 (rock 3)	06.02.2025	83	73	73		10	10	100,00 %

Comments:

*** Test 1: Actually a "useless" method, as it ends up being very dirty where the oil sticks to the gloves and therefore generates a lot of extra unnecessary waste. Scraping with a trowel on larger stones will of course work, but these stones were so small that we had to hold them in our hand.**

*** Test 2: Same experience as with test 2 on dry stones.**

*** Test 4 and 5: Imperceptible difference from the result of test 3 when 4 and 5 are added. Creates extra waste due to a lot of unnecessary soiling. There was oil residues left on the rock, even if not represented by the weight. Still, too polluted to be at an acceptable level. However, we have an expectation that tumbling in water at 25°C might leave an acceptable result.**

3.6.1.2 Small-scale test 3 – Water baths

Small scale test 3: Water bath	IM-27 (VLSFO)	Water content in oil emulsion	33,3%	04.02.2025
Water temperature (°C)	5°C (in refrigerator)	15°C (room temperature)	25°C (heating cabinet)	50°C (heating cabinet)
Date start	04.02.2025	04.02.2025	04.02.2025	05.02.2025
Air temp (°C)	14,6°C	14,6°C	14,6°C	15°C
Water temp start (°C)	10°C	10°C	10°C	10°C
Weight box (g)	107g	107g	107g	107g
Weight box incl rocks	850g	819g	843g	835g
Weight box incl rocks and oil	1050g	1019g	1046g	1033g
Netto weight oil (g)	200g	200g	203g	198g
Added water	1500g	1500g	1500g	1500g
Initial observations	No immediate sheen when water was added. A small amount of oil floated to the surface when water was added.	A very small amount of sheen was observed when water was added but it disappeared almost instantly. A small amount of oil floated to the surface when water was added.	Not relevant since we had to wait for the oil to be heated in the cabinet first.	Not relevant since we had to wait for the oil to be heated in the cabinet first.
Date of measurement	06.02.2025	06.02.2025	06.02.2025	06.02.2025
Air temp (°C)	15°C	15°C	15°C	15°C
Total weight	2539g	2539g	2550g	2530g
Weight floating oil + water	1026g	1026g	885g	856g
Netto weight floating/removed oil	24g	24g	161g	177g
	12,00%	12,00%	79,31%	89,39%
Comments	We assume the effect inside the refrigerator at 5°C has been minimal/none. The floating oil was (mainly) released when adding water initially (ergo a slight water pressure effect on some of the oil that was not "sticky" enough). The oil temperature was about 15°C and the water temperature about 10°C during filling and was then chilled to 5°C in the refrigerator afterwards. No oil film on the surface.	The effect at 15°C has been minimal. The temperature during the 2 days has not been accurate, since the box was standing in the test hall, so the temperatures inside has been between 13 and 16°C. The floating oil was (mainly) released when adding water initially (ergo a slight water pressure effect on some of the oil that was not "sticky" enough). The oil temperature was about 15°C and the water temperature about 10°C during filling.	We considered it more appropriate to pick out the stones with residual oil, than to pour off water + oil as in the 5 og 15 °C tests. This was due to oil behavior and distribution in the box. A lot of it had just moved to the edges of the box and did not float on the surface. We probably overestimated "success rate" on this test, but still the test shows that this oil is probably easier to remove (flushing or other ways of adding energy) compared to IFO bunker oils in 25°C water temperatures.	We observed that most of the oil had been released from the rocks and had floated to the surface. Control temperature was measured to 41.4 °C (ergo not 50 °C) as the cabinet was set to. Maybe we should have had the boxes inside the cabinet for 2 days for an even higher success rate. Anyhow this temperature had a very good effect on the oil.

Small scale test 3: Water bath	IM-28 (VLSFO)	Water content in oil emulsion	51,6%	04.02.2025
Water temperature (°C)	5°C (in refrigerator)	15°C (In the test hall)	25°C (heating cabinet)	50°C (heating cabinet)
Date start	04.02.2025	04.02.2025	04.02.2025	05.02.2025
Air temp (°C)	14,6°C	14,6°C	14,6°C	15°C
Water temp (°C)	10°C	10°C	10°C	10°C
Weight box (g)	107g	107g	107g	107g
Weight box incl rocks	814g	857g	866g	915g
Weight box incl rocks and oil	1018g	1058g	1066g	1018g
Netto weight oil (g)	204g	201g	200g	203g
Added water	1500g	1500g	1500g	1500g
Initial observations	Observed a hint of sheen when adding water.			
Date check	06.02.2025	06.02.2025	06.02.2025	06.02.2025
Air temp (°C)	15°C	15°C	15°C	15°C
Total weight	2514g		2565g	2550g
Weight floating oil + water	1002g	1058g	1069g	939g
Netto weight floating/removed oil	16g	0g	-3g	179g
	7,84%	0,00%	-1,50%	88,18%
Comments	The box could be held upside down without any of the rocks or oil falling out after the water was removed. No oil accompanied the removed water. We assess that the oil loss probably must be explained due to inaccurate measurement. For all practical measures 5°C water temperature has no effect.	The box could be held upside down without any of the rocks or oil falling out after the water was removed. No oil accompanied the removed water. For all practical measures 15°C water temperature has no effect.	Weighing more than before. We assess this can be explained due to inaccurate measurement. In any case, no noticeable oil has floated up and been removed. A minimal amount of oil was present when we poured off the water > small drops but weight-wise almost equal to zero.	Most of the oil had been released from the rocks and had floated to the surface. Control temperature was measured to 43.4 °C (ergo not 50 °C) as the cabinet was set to. Maybe we should have had the boxes inside the cabinet for 2 days for an even higher success rate. Anyhow this temperature had a very good effect on the oil.

Small scale test 3: Water bath	IM-29 (VLSFO)	Water content in oil emulsion	51,3%	04.02.2025
Water temperature (°C)	5°C (in refrigerator)	15°C (In the test hall)	25°C (heating cabinet)	50°C (heating cabinet)
Date start	04.02.2025	04.02.2025	04.02.2025	05.02.2025
Air temp (°C)	14,6°C	14,6°C	14,6°C	15°C
Water temp (°C)	10°C	10°C	10°C	10°C
Weight box (g)	107g	107g	107g	107g
Weight box incl rocks	831g	907g	908g	862g
Weight box incl rocks and oil	1031g	1109g	1107g	1062g
Netto weight oil (g)	200g	202g	199g	200g
Added water	1500g	1500g	1500g	1500g
Initial observations	No visible sheen when filling with water. The oil released some small droplets when filling (didn't stick well enough to the stones?).	No visible sheen when filling with water. The oil released some small droplets when filling (didn't stick well enough to the stones?).	No visible sheen when filling with water. The oil released some small droplets when filling (didn't stick well enough to the stones?).	No visible sheen when filling with water. The oil released some small droplets when filling (didn't stick well enough to the stones?).
Date check	06.02.2025	06.02.2025	06.02.2025	06.02.2025
Air temp (°C)	15°C	15°C	15°C	15°C
Total weight	2524g	2612g	2406g	2550g
Weight floating oil + water	1033g	1115g	1065g	904g
Netto weight floating/removed oil	-2g	-6g	42g	158g
	-1,00%	2,97%	21,11%	79,00%
Comments	The box could be held upside down without any of the rocks or oil falling out after the water was removed. No oil accompanied the removed water. We assess that the added weight can be inaccurate measurement. unless the oil has taken up even more water. For all practical measures: 5°C is assed to have no effect.	The box could be held upside down without any of the rocks or oil falling out after the water was removed. No oil accompanied the removed water. We assess that the added weight can be inaccurate measurement etc, unless the oil has taken up even more water, more than at 5°C. For all practical measures: 15°C is assed to have no effect.	This temperature has some effect, as numbers indicate. However, this box was placed closer to the fan inside the heating cabinet and had lost 201g of water overnight. This might indicate that the temperature has been higher (More than 25°C) than for the other oil types in this test and could suggest that the effect is overestimated.	We observed that most of the oil had been released from the rocks and had floated to the surface. Control temperature was measured to 44.1 °C (ergo not 50 °C) as the cabinet was set to. Maybe we should have had the boxes inside the cabinet for 2 days for an even higher success rate. Anyhow this temperature had a very good effect on the oil.

Small scale test 3: Water bath	IFO 380	Water content in oil emulsion	1,0%	04.02.2025
Water temperature (°C)	5°C (in refrigerator)	15°C (In the test hall)	25°C (heating cabinet)	50°C (heating cabinet)
Date start	04.02.2025	04.02.2025	04.02.2025	05.02.2025
Air temp (°C)	14,6°C	14,6°C	14,6°C	15°C
Water temp (°C)	10°C	10°C	10°C	10°C
Weight box (g)	107g	107g	107g	107g
Weight box incl rocks	868g	879g	866g	890g
Weight box incl rocks and oil	1070g	1180g	1066g	1093g
Netto weight oil (g)	202g	201g	200g	203g
Added water	1500g	1500g	1500g	1500g
Initial observations	Little sheen immediately after filling water, but after a few minutes the amount increased slightly. However, the water held approximately 10°C and the oiled rock held 15°C during filling so this is not an appropriate observation for a 5°C environment.	Little sheen immediately after filling water, but after a few minutes the amount increased slightly	Little sheen immediately after filling water, but after a few minutes the amount increased slightly	Little sheen immediately after filling water, but after a few minutes the amount increased slightly
Date check	06.02.2025	06.02.2025	06.02.2025	06.02.2025
Air temp (°C)	15°C	15°C	15°C	15°C
Total weight	2570g		2574g	2589g
Weight floating oil + water	1078g	999g	992g	914g
Netto weight floating/removed oil	-8g	81g	74g	179g
	-3,96%	40,30%	37,00%	88,18%
Comments	The box could be held upside down without any of the rocks or oil falling out after the water was removed. No oil accompanied the removed water. We assess that the added weight can be explained by the oil has taken up more water (only 1% emulsion) or inaccurate measurements. For all practical measures: 5°C is assed to have no effect.	We could clearly see the effect visually when opening the lid. A lot of oil has floated up at this temperature. Some oil has probably already floated up when adding water due to some added kinetical energy during the filling.	Compared with 15°C test we should have seen a better result. (or 15°C should have shown a poorer result)	We observed that most of the oil had been released from the rocks and had floated to the surface. Control temperature was measured to 44.2 °C (ergo not 50 °C) as the cabinet was set to. This temperature had a very good effect on the oil.

3.6.1.3 Small-scale test 4 – Concrete mixer

Small scale test 4: Concrete mixer	IM-27	Water content in oil emulsion	33,3%	04.02.2025
Water temperature (°C)	12,5°C (sea temperature)	15°C (In the test hall)	25°C (heating cabinet)	50°C (heating cabinet)
Date start	26.02.2025	n.a. due to 12,5°C result		
Air temp (°C)	14,6°C			
Water temp (°C)	12,5°C			
Weight bucket + rocks	21,0 kg			
Weight bucket	0,733 kg			
Weight rocks	20,267kg			
Netto weight oil	2,124kg			
Control weighing				
Comments to the different temperatures	See comments			

Comments:
The stones are actually starting to release a noticeable amount of water from the oil emulsion quite quickly (because it is so evident we suspect much of the water is released from water pockets and not from breaking up the emulsion). This means that the "internal" water start helping to clean the pebbles after a very short time of tumbling, even without adding any water. We observed that the oil is gradually released from the pebbles and then starting to stick to the inside of the drum instead.

The added water caused the oil to be transferred from the pebbles to the water as well as onto the inside of the tumbler. The pebbles were visually assessed to be cleaned almost to a 100% level after the tumbling period.
There was some oil left on some pebbles, and this is mainly due to them re-attaching from the water in the bucket when we poured the content out of the mixer. This would probably not have happened if we had poured the content into a larger water mass, for example, released them into the wave zone (sea) on a beach within a boom barrier, or if necessary, keeping everything inside a closed of system into a small pool with more water than the bucket was able to receive (for easier skimming – ref WP 4 - or in vulnerable areas).

This method **seems** to be an effective way to clean pebble/cobble beaches when the seawater temperature available is 12°C and above. Off course we will then face the same issues with oil skimming from the sea as shown under WP 4. A closed cleaning station might solve this if the oil is hard to skim from the sea surface.

Small scale test 4: Concrete mixer	**IM-28**	**Water content in oil emulsion**	**51,6%**	**04.02.2025**
Water temperature (°C)	11,0°C	18,5°C	22,2-20,0°C	28,8>25,1°C
Date start	26.02.2025	26.02.2025	26.02.2025	26.02.2025
Air temp (°C)	14,6°C	14,6°C	14,6°C	14,6°C
Water temp (°C)	11,0°C	18,5°C	22,2-20,0°C	22,2-20,0°C
Weight bucket + rocks	20,7 kg	20,7 kg	20,7 kg	20,7 kg
Weight bucket	0,733 kg	0,733 kg	0,733 kg	0,733 kg
Weight rocks	19,967kg	19,967kg	19,967kg	19,967kg
Netto weight oil	3,020kg	3,020kg	3,020kg	3,020kg
Comments to the different temperatures	No "help" from the water temperature, and far from clean enough.	Little "help" from the water temperature, and far from clean enough.	The oil is starting to loosen, however, not clean enough. (22,2° water temp when added in the mixer – fell to prox 20,0° during tumbling)	Very good instant effect. Some remains, but clean enough. (28,8° water temp when added in the mixer – fell to prox 25,1° during tumbling)
With Aqua Delta	10,5°C > 0,5l agent	10,5°C > 0,1l agent		
Date start	06.03.2025	06.03.2025		
Air temp (°C)	14,6°C	14,6°C		
Water temp (°C)	10,5°C	10,5°C		
Weight bucket + rocks	20,9 kg	20,3 kg	Higher temp not necessary	Higher temp not necessary
Weight bucket	0,733 kg	0,733 kg		
Weight rocks	20,167kg	19,567kg		
Netto weight oil	2,917kg	2,949kg		

Comments:

We used the same "batch of pebbles" throughout the test (exempt with the shoreline cleaning agent) until we experienced an acceptable cleaning level.

At lower temperatures the rocks became glued to the inside of the drum. This eliminates the off course the potential mechanical energy that should have been happening inside the mixer, rocks rubbing towards the inside of the mixer and the rubbing of rocks on each other.

- 11°C water temperature - No effect observed.
- 18,5°C water temperature – No effect observed.
- 22°C water temperature (The temp dropped to 20°C after being added) - some effect observed, oil was being released during tumbling.
- 29°C water temperature (The temp dropped to 25°C after being added) - This caused the oil to be transferred from the pebbles and the tumbler to the water and cleaned almost the pebble almost 100%.

There was some oil left on some pebbles**,** and this is mainly due to them re-attaching from the water in the bucket when we poured the content out of the mixer. This would probably not have happened if we had poured the content into a larger water mass, for example, released them into the wave zone (sea) on a beach within a boom barrier, or if necessary, keeping everything inside a closed of system into a small pool with more water than the bucket was able to receive (for easier skimming – ref WP 4 - or in vulnerable areas).

We then did the same test with beach cleaning agent (AquaDelta) at approximately 10°C. First, we added 0,5l and the tumbling quickly released the oil from the rock avd mixer. We repeated the test at the same water temperature but no with only 0,1l beach cleaning agent. This time the cleaning proses was slower, but the pebbles became clean also with this amount of agent.

Small scale test 4: Concrete mixer	IM-29	Water content in oil emulsion	51,3%	04.02.2025
Water temperature (°C)	12,5°C (sea temperature)	15°C (In the test hall)	25°C (heating cabinet)	50°C (heating cabinet)
Date start	26.02.2025			
Air temp (°C)	14,6°C			
Water temp (°C)	12,5°C			
Weight bucket + rocks	20,9 kg	n.a. due to 12,5°C result		
Weight bucket	0,733 kg			
Weight rocks	20,167kg			
Netto weight oil	2,061kg			
Control weighing				
Comments to the different temperatures	See comments			

The stones are actually starting to release a noticeable amount of water from the oil emulsion quite quickly (because it is so evident we suspect much of the water is released from water pockets and not from breaking up the emulsion). This means that the "internal" water start helping to clean the pebbles after a very short time of tumbling, even without adding any water. We observed that the oil is gradually released from the pebbles and then starting to stick to the inside of the drum instead.

The added water caused the oil to be transferred from the pebbles to the water. The pebbles were visually assessed to be cleaned almost to a 100% level after the tumbling period.
There was some oil left on some pebbles and this is mainly due to them re-attaching from the water in the bucket when we poured the content out of the mixer. This would probably not have happened if we had poured the content into a larger water mass, for example, released them into the wave zone (sea) on a beach within a boom barrier, or if necessary, keeping everything inside a closed of system into a small pool with more water than the bucket was able to receive (for easier skimming – ref WP 4 - or in vulnerable areas).

This method **seems** to be an effective way to clean pebble/cobble beaches when the seawater temperature available is 12°C and above. Off course we will then face the same issues with oil skimming from the sea as shown under WP 4. A closed cleaning station might solve this if the oil is hard to skim from the sea surface.

3.2.6 Container test

Beach container test	Water content in oil emulsion	33,3%	04.02.2025
Oil type		Date	Water temperature
IM-27		25.03.2025	15°C
Comments			

Flooding

Some of the "loose" oil is released but at a low effect. (Areas where the droplets from the flooding system is hitting (thin water beams) gives some effect - extra kinetic energy added).

No real cleaning effect, but it is recommended to use this method parallel with flushing to maintain a continuous water flow through the beach and its sediments.

Flushing

Flushing at this water temperature provides a cleaning effect, but not good enough to be considered "clean enough".

The effect is best on the flagstones. In the pebble/cobble part of the beach, the oil is released from the surface but then pushed down in the sediment and seems to be reattached underneath and between the rocks. We do not manage to keep the oil "floating" on top of the water all the way down to the water line.

We consider that the method may be used at this water temperature, but the sediments must be pushed close to the water so that the oil is able to start floating before it "looses speed" and gets re-attached to other rocks. We are a somewhat sceptical to only using surf washing as a method, because the oil seems to be sticking to the rocks when submerged at this temperature. The 2 methods combined, close to the water line, is considered as a practical good method.

A secondary observation was that the oil appeared to become stickier after it had been flushed than before. We cannot explain this, however it is an observation.

Sorbents

Not tested

Shoreline cleaning agent:

We sprayed a part of the flagstones (which were not clean enough after the flushing) with the shoreline cleaning agent and let it sit for 5mins. When flushing the area afterwards it got completely clean at this temperature. The oil seems to be flowing with the water to a higher degree and therefor is more likely to reach the water line at the beach. However, we still have the same problems of some oil getting re-attached on the underside of the pebbles and cobbles, but it is expected to happen to a smaller degree than without shoreline cleaning agent.

Recommendations at 15°C:

- Pressure washing should only be used close to the water line at a maximum distance of 1-2m so that the oil is not re-attached to the underside of the rocks before reaching the waterline.
- The use of shoreline cleaning agents will help the remaining thin oil layer both to be released and also to flow down to the water line. Keep in mind that there is no point in using it on a thick oil layer.

Beach container test	Water content in oil emulsion	33,3%	04.02.2025
Oil type		**Date**	**Water temperature**
IM-27		**25.03.2025**	**18,5-19°C**

Comments

Flooding:
Some of the "loose" oil is released but at a low effect. (Areas where the droplets from the flooding system is hitting (thin water beams) gives some effect - extra kinetic energy added).
No real cleaning effect, even though the effect is slightly better than with the 15° test. Still it is recommended to use this method parallel with flushing to maintain a continuous water flow through the beach and its sediments.
(High pressure) flushing (fire hose):
The flushing gives a good direct effect on all the 3 beach types, but parts of the oil is re-attaching at the pebble/cobbles underside. This demands the need to turn them after a while for a "re-flushing" and is off course delaying the process. Parallel flooding will reduce this to some extent but will not eliminate the problem.
The oil is loosened quite quickly at this temperature, but not a 100% cleaning effect. Consider this method a coarse cleaning method. Moving the sediments down to the waterline for further surf washing is is assessed to provide good enough cleaning. We experience the same challenges with oil re-attaching as with the 15°C test, so moving the sediments closer to the waterline before flushing or cleaning them in a closed of "tumbler-pool-system" is recommended.
Sorbents not tested
Shoreline cleaning agent:
It was not tested since we concluded that the water temperature of 18-19°C is effective enough.
Recommendations at 18-19°C:

- Pressure washing should only be used close to the water line at a maximum distance of 2m so that the oil is not re-attached to the underside of the rocks before reaching the waterline.
- The use of beach cleaning agents is not considered to be necessary.
- Cleaning the sediments in a closed of "tumbler-pool-system" is recommended for further easier containment of the oil.

Beach container test	Water content in oil emulsion	33,3%	04.02.2025
Oil type		**Date**	**Water temperature**
IM-27		**26.03.2025**	**24,5°C**

Comments

1. **Flooding 30 mins:**

Experiencing quite good effect at 25°C water temperature. For some reason it seems like the effect is lower on the flagstones, but that might just be a coincidence.

2. **(High pressure) flushing (fire hose):**

The flushing gives a good direct effect on all the 3 beach types, but parts of the oil is moved to the rock`s underside in the pebble/cobble areas. This gives the need to turn them after a while for a "re-flushing". One person working parallel to the flushing with iron rake. Parallel flooding will reduce the oils re-attachment to some extent but will not eliminate the problem.

The oil is loosened quite quickly at this temperature, and the result must be considered as clean enough. Moving the sediments afterwards down to the waterline for further surf washing is recommended anyhow. Moving the sediments closer to the waterline before flushing or cleaning them in a closed of "tumbler-pool-system" is also recommended, even at water temperatures above 25°C.

3. **Sorbents:**

It was not tested since we concluded that the water temperature of 25°C is effective enough.

4. **Shoreline cleaning agent:**

It was not tested since we concluded that the water temperature of 25°C is effective enough.

Recommendations at 25°C:

- Pressure washing is still recommende**d** to be used close to the water line at a maximum distance of 2m so that the oil is not re-attached to the underside of the rocks before reaching the waterline.
- The use of sorbents is not considered to be necessary.
- The use of beach cleaning agents is not considered to be necessary.
- Cleaning the sediments in a closed of "tumbler-pool-system" is recommended for further easier containment of the oil.

Beach container test	Water content in oil emulsion	0%	Not tested
Oil type		**Date**	**Water temperature**
IM- 27 fresh oil		27.03.2025	15°C

Comments

1. **Flooding 30 mins:**

Some of the “loose” oil is released but at a low effect. (Areas where the droplets from the flooding system is hitting (thin water beams) gives some effect - extra kinetic energy added).
No real cleaning effect, but it is recommended to use this method parallel with flushing to maintain a continuous water flow through the beach and its sediments.

2. **(High pressure) flushing (fire hose):**

Flushing at this water temperature provides a cleaning effect, but not good enough to be considered “clean enough”.
The effect is best on the flagstones. In the pebble/cobble part of the beach, the oil is released from the surface but then pushed down in the sediment and seems to be reattached underneath and between the rocks. We do not manage to keep the oil “floating” on top of the water all the way down to the water line.
We consider that the method may be used at this water temperature, but the sediments must be pushed close to the water so that the oil is able to start floating before it “loses speed” and gets re-attached to other rocks. We are a somewhat sceptical to only using surf washing as a method, because the oil seems to be sticking to the rocks when submerged at this temperature. The 2 methods combined, close to the water line, is considered as a practical good method.

3. **Sorbents:**

Tested sorbents (bark) which was massaged into the rocks/oil with the motorized FoxMix brushes. This gives a clean enough result after flushing. Done correct this leaves the rocks almost 100% clean. Nevertheless**,** it is still recommended to work very close to waterline to avoid getting the oiled sorbents stuck between the rocks.

4. **Shoreline cleaning agent:**

Not tested

Beach container test	Water content in oil emulsion	51,6%	04.02.2025
Oil type		**Date**	**Water temperature**
IM28		28.03.2025	15°C
Comments			

1. **Flooding 30 mins:**

Some of the "loose" oil is released but at a very low effect. Areas where the droplets from the flooding system is hitting (thin water beams) gives more effect (extra kinetic energy added).
Even though no/low effect it is recommended to use this method parallel with pressure washing in order to maintain a continuous water flow through the beach and its sediments.

2. **(High pressure) flushing (fire hose):**

The flushing gives immediately a good effect, especially at the flagstones, but the oil re-attaches very quickly (loosing flow-speed). The water is not able to "capsule in" the oil so that it will flow down to the water line with the water.
The oil is "thrown" off the rocks as small lumps (kind of a coagulation) and is then only moved to the next rock for re-attachment.
We consider that the method may be used at this water temperature, but the sediments must be pushed close to the water so that the oil is able to start floating before it "looses speed" and gets re-attached to other rocks. We are a somewhat sceptical to only using surf washing as a method, because the oil seems to be sticking to the rocks when submerged at this temperature. The 2 methods combined, close to the water line, is considered as a practical good method.
This oil is without doubt a troublesome oil to work with in loose sediments as pebble/cobbles.

3. **Sorbents:**

this has a good effect, but it requires a lot of sorbents. Working as we did with mechanised brushes is probably not a god idea. If sorbents are to be used, hand polishing should be the preferred method because it uses less sorbents because you can re-use the for a while before it gets to soaked with oil. For thin (remaining) layers of oil it is assessed to be an effective polishing finish.

4. **Shoreline cleaning agent:**

We sprayed with shoreline cleaning agents and let it sit for 5mins. When flushing the area afterwards it showed a very good result on the top of the rocks. The oil seems to be flowing with the water to a higher degree than without and therefor is more likely to reach the water line at the beach. However, you will still have the same problems of oil getting re-attached to the underside of the pebbles/cobbles, but it is expected to happen to a smaller degree than without beach cleaning agent.

Recommendations at 15°C:

- Move the rocks down to the surf wash sone, pressure wash them in that area or even better tumble them in this area before letting the natural surf washing finish the job. We recommend using a higher water temperature than 15°C to get wanted end result.
- Even better, make a closed of "tumbler-pool-system" and clean the people/cobbles before putting them back on the beach. Then you may also use much higher water temperatures (high pressure washer with a build in heater). We recommend using a higher water temperature than 15°C to get wanted end result.
- Beach cleaning agents is effective at these temperatures.
- Looking back, the "hand polish test" with natural sorbents is still a recommendation. It is time consuming, but you have a high degree of control. And "all" oil can be collected for further burning or composting.

Beach container test	Water content in oil emulsion	51,6%	04.02.2025
Oil type		**Date**	**Water temperature**
IM28 emulsion		**28.03.2025**	**19°C**

Comments

1. **Flooding 30 mins:**

Low/no effect. Even though low effect it is recommended to use this method parallel with pressure washing to maintain a continuous water flow through the beach and its sediments.

2. **(High pressure) flushing (fire hose):**

The flushing gives immediately a good effect as at the 15°C test, especially at the flagstones. The oil still re-attaches (loosing flow-speed), but to a lower degree than during the 15°C test.

The sediments get cleaned, but due to the re-attaching this method will be very time consuming to “push” everything “through” the beach and down to the waterline. Varying pressure so that you use high pressure to loosen the oil end then directly lower the pressure to get the oil to flow with the water seems to be more effective than only high pressure, but it requires some “experience” (trying and adapting). The oil builds up in the lower parts of the beach.

We are also somewhat sceptical to only using surf washing as a method at this temperature, because the oil seems to be sticking to the pebble/cobble when submerged at this temperature. The 2 methods combined, close to the water line, is considered as a practical good method.

This oil is without doubt a troublesome oil to work with in loose sediments as pebble/cobbles.

There is a need for an assistant turning the rocks parallel to the flushing. If not**,** you will only push the oil further down the sediments. The oil resembles a “good old” IFO380 but seems to flow poorer (re-attaches quickly).

3. **Sorbents**:

This has a good effect, but it requires a lot of sorbents. The oiled sorbents flow easier down towards the water line, however we experienced some build-up of sorbents between the rocks and in the metal grids between the beach areas. Working as we did with mechanised brushes is probably not a god idea. If sorbents are to be used, hand polishing should be the preferred method because it uses less sorbents due to the fact that you can re-use the for a while before it gets to soaked with oil and you don`t flush the remains trough the beach afterwards.

4. **Shoreline cleaning agent:**

The shoreline cleaning agent makes the oil less “re-attaching” And makes the released oil flow better with the water stream.

Recommendations at 19°C:

- Move the rocks down to the surf wash sone, pressure wash them in that area or even better tumble them in this area before letting the natural surf washing finish the job.
- Even better, make a closed of “tumbler-pool-system” and clean the people/cobbles before putting them back on the beach. Then you may also use much higher water temperatures (high pressure washer with a build in heater).
- The beach cleaning agent makes the oil less “re-attaching”.
- Looking back, the “hand polish test” with natural sorbents is still a recommendation. It is time consuming, but you have a high degree of control. And “all” oil can be collected for further burning or composting.

Beach container test		Water content in oil emulsion	51,6%	04.02.2025
Oil type			Date	Water temperature
IM28 emulsion			28.03.2025	25°C

Comments

1. **Flooding 30 mins:**

Low/no effect. Even though low effect it is recommended to use this method parallel with pressure washing to maintain a continuous water flow through the beach and its sediments.

2. **(High pressure) flushing (fire hose):**

The flushing gives immediately a good effect as at the 15/19°C test, especially at the flagstones. The oil still re-attaches (loosing flow-speed), but to a lower degree than during the 15/19°C test.
The sediments get cleaned, but due to the re-attaching this method will be very time consuming to “push” everything “through” the beach and down to the waterline. Varying pressure so that you use high pressure to loosen the oil end then directly lower the pressure to get the oil to flow with the water seems to be more effective than only high pressure, but it requires some “experience” (trying and adapting). The oil builds up in the lower parts of the beach.
We are also somewhat sceptical to only using surf washing as a method at this temperature, because the oil seems to be sticking to the pebble/cobble when submerged at this temperature. The 2 methods combined, close to the water line, is considered as a practical good method.
This oil is without doubt a troublesome oil to work with in loose sediments as pebble/cobbles.
There is a need for an assistant turning the rocks parallel to the flushing. If not, you will only push the oil further down the sediments. The oil resembles a traditional IFO380 but seems to flow poorer (re-attaches quickly).
Comparable observations as during the 15/19°C but flushing at 25°C provides a much higher cleaning effect during all parts of the test.

3. **Sorbents**:

   n.a.

4. **Shoreline cleaning agent:**

The shoreline cleaning agent makes the oil less “re-attaching” and at this temperature the rock gets 100% clean very fast. However, the agent is probably best used as a finishing touch before flushing at smooth rock slopes and not in pebble/cobble beaches.

Recommendations at 25°C:

- Move the rocks down to the surf wash sone, pressure wash them in that area or even better tumble them in this area before letting the natural surf washing finish the job.
- Even better, make a closed of “tumbler-pool-system” and clean the people/cobbles before putting them back on the beach. Then you may also use much higher water temperatures (high pressure washer with a build in heater).
- The beach cleaning agent makes the oil less “re-attaching”.
- Looking back, the “hand polish test” with natural sorbents is still a recommendation. It is time consuming, but you have a high degree of control. And “all” oil can be collected for further burning or composting.
- At this and higher temperatures, surf washing might be a good enough and cost-effective solution. However, consider some pressure washing first down by the water line do release the thickest layers first.

Beach container test	**Water content in oil emulsion**	**0%**	**Not tested**
Oil type		**Date**	**Water temperature**
IM28 non emulsion		**31.03.2025**	**15, 19 and 25°C**
Comments			
We conducted the same tests as with the IM28 emulsion. Not much difference in principle when comparing emulsified oil to fresh oil. The non emulsion might be somewhat stickier than the emulsion but we are not able to support this with measured numbers.			

Beach container test	Water content in oil emulsion	51,3%	04.02.2025
Oil type		**Date**	**Water temperature**
IM29 emulsion		**27.03.2025**	**15°C**

Comments

1. **Flooding 30 mins:**

Some of the “loose” oil is released but at a very low effect. Areas where the droplets from the flooding system is hitting (thin water beams) gives more effect (extra kinetic energy added). Even though low/no effect it is recommended to use this method parallel with pressure washing to maintain a continuous water flow through the beach and its sediments.

2. **(High pressure) flushing (fire hose):**

The flushing gives immediately a good effect. A thin layer is left behind. The oil ending up in the water basin is quite “solid” (shoe cream).
Surprisingly good result at this temperature. It is the water pressure which gives the essential effect.

3. **Sorbents**:

This has a good effect. Working as we did with mechanised brushes Makes the result “clean enough” after flushing. Hand polishing is anyhow considered as more controlled method.

4. **Shoreline cleaning agent:**

No need for shoreline cleaning agent at this temperature

Recommendations/other observations at 15°C:

- Move the rocks down to the surf wash sone, pressure wash them in that area or even better tumble them in this area before letting the natural surf washing finish the job.
- Beach cleaning agents is not necessary.
- The disk skimmer used was not able to collect the oil. We used a handheld hoof to collect the oil in the basin. (Ref WP4)

Beach container test	**Water content in oil emulsion**	**0%**	**Not tested**
Oil type		**Date**	**Water temperature**
IM29 fresh			**15°C**
Comments			
Comparable as with the IM29 emulsion test			

Beach container test	Water content in oil emulsion	51,3%	04.02.2025
Oil type		**Date**	**Water temperature**
IM29 emulsion		**26.03.2025**	**25°C**

Comments

Based on observed effect in the 15°C test a 25°C was not necessary, however the 25°C test was carried out prior to the 15°C for practical purposes and therefor commented.

1. **Flooding 30 mins:**

Some of the "loose" oil is released but at a very low effect. Areas where the droplets from the flooding system is hitting (thin water beams) gives more effect (extra kinetic energy added). Even though low/no effect it is recommended to use this method parallel with pressure washing to maintain a continuous water flow through the beach and its sediments.

2. **((High pressure) flushing (fire hose):**

The flushing gives immediately a good effect. As with the other tests you must turn the rock parallel with the flushing for the oil not to get re-attached underneath them to some degree. The oil ending up in the water basing is fluid. The oil is now too "slippery" for the disk skimmer to collect. A vacuum pump is assessed to work much better. It is still the water pressure which gives the essential effect.

3. **Sorbents:**

Not tested.

4. **Shoreline cleaning agent:**

No need for shoreline cleaning agent at this temperature

Recommendations/other observations at 25°C:

- Move the rocks down to the surf wash sone, pressure wash them in that area or even better tumble them in this area before letting the natural surf washing finish the job.
- Beach cleaning agents is not necessary.
- The disk skimmer used was not able to collect the oil. A vacuum pump is assumed to work better.

Beach container test	Water content in oil emulsion	1%	04.02.2025
Oil type		**Date**	**Water temperature**
IFO380 (fresh)		01.04.2025	15°C

Comments

1. **Flooding 30 mins:**

No direct effect from flooding. Even though no direct effect it is recommended to use this method parallel with pressure washing to maintain a continuous water flow through the beach and its sediments.

2. **(High pressure) flushing (fire hose):**

The flushing gives immediately a good effect. The loosened oil is not re-attaching to the rocks close to the same degree as the IM28. A thin layer remains (1mm) on the rocks after the flushing which seems to be quite stuck. The oil appears as more elastic than the 3 test oils. The rocks are sticking more to each other with the IMO380 than with the test oils.

The oil is not "coagulating" like the IM-28 when flushed. It spreads out more "evenly" on the water surface in the basin. The oil follows the added water to higher degree and therefor it is easier to flush the oil all the way down to the water basin.

The result at this temperature is considered ok for further surf washing, if in exposed beaches, but not clean enough if the remaining oil is staying above the HW sone.

3. **Sorbents:**

It is adding to the cleaning prosses, and the result is even cleaner than only flushing. Hand polishing with sorbents (bark) leaves a 100% clean result.

4. **Shoreline cleaning agent:**

We sprayed with shoreline cleaning agents and let it sit for 5mins. When flushing the area afterwards it showed a very good result.

Recommendations at 15°C:

- To compare: Flushing ++ the IFO380 at 15°C water temperature left a cleaner result than we got at 25°C on the IM28 oil.
- The beach cleaning agent is very effective on the IFO380 oil at this temperature.
- If exposed area, there is no need for flushing or beach cleaning agent. Flushing before surf washing is assessed to be good enough.

Beach container test	Water content in oil emulsion	1%	04.02.2025
Oil type		**Date**	**Water temperature**
IFO380 (fresh)		**01.04.2025**	**19°C**

Comments

1. **Flooding 30 mins:**

No direct effect from flooding. Even though no direct effect it is recommended to use this method parallel with pressure washing to maintain a continuous water flow through the beach and its sediments.

2. **(High pressure) flushing (fire hose):**

The flushing gives immediately a good effect and leaves the remaining oil remains at a good/acceptable level.
Finishing up with surf washing is assessed to give a 100% cleaning result quite fast.

3. **Sorbents**

Were not tested based on result from the 15°C test.

4. **Shoreline cleaning agent:**

Not necessary to test

Recommendations at 19°C:

- Acceptable to good result with flushing at this temperature. Moving sediments for finishing surf washing is still recommended.

Assessment of applicability of different cleaning methods based on observations from task 5.6.

IM-27 Temp/ method	Remarks	Scrapes/ sorbents "clean as you survey"	Spades/ Sieves etc	Concrete mixer sea water	Concrete mixer or caterpillar siever with sorbents	Concrete mixer heated sea water closed off system	Flushing	Surf washing	Shoreline cleaning agents
<15°C	Random patties/patches is expected at these temperatures	Random patties/patches on hard surfaces and beach meadows	Random patties/patches on hard surfaces and beach meadows	On higher concentrations of oil in pebble/cobbles beaches	On higher concentrations of oil in pebble/cobbles beaches	On higher concentrations in pebble/cobbles beaches > Water temp heated to 20-25°C	On pebble/cobble beaches. Oiled sediments recommended to be moved close to water line before flushing.	As a finishing method if needed based on remains	Effective and recommended for low temperatures.
16°C-19°C	Random patties/patches is expected at these temperatures	Random patties/patches on hard surfaces and beach meadows	Random patties/patches on hard surfaces and beach meadows	On higher concentrations of oil in pebble/cobbles beaches	On higher concentrations of oil in pebble/cobbles beaches	On higher concentrations in pebble/cobbles beaches > Water temp heated to 20-25°C	On pebble/cobble beaches. Oiled sediments recommended to be moved close to water line before flushing.	As a finishing method if needed based on remains	Test if needed
20°C-25°C	Larger areas with continuous slicks expected. Less likely with random patches.	If random patties/patches on hard surfaces and beach meadows	If random patties/patches on hard surfaces and beach meadows	On higher concentrations of oil in pebble/cobbles beaches	On higher concentrations of oil in pebble/cobbles beaches	Probably not needed	On pebble/cobble beaches. Oiled sediments recommended to be moved close to water line before flushing.	As a finishing method if needed based on remains	Not needed
25°C-29°C	Larger areas with continuous slicks expected. Random patches not expected.	Not likely	Not likely	On higher concentrations of oil in pebble/cobbles beaches	On higher concentrations of oil in pebble/cobbles beaches	Probably not needed	On pebble/cobble beaches. Oiled sediments recommended to be moved close to water line before flushing.	As a finishing method if needed based on remains	Not needed
>29°C	Larger areas with continuous slicks expected. Random patches not expected.l	Not likely	Not likely	On higher concentrations of oil in pebble/cobbles beaches	On higher concentrations of oil in pebble/cobbles beaches	Probably not needed	On pebble/cobble beaches. Oiled sediments recommended to be moved close to water line before flushing.	As a finishing method if needed based on remains	Not needed

Recommended/likely situation	May be used but probably not the most efficient or may not be nessesary	Not recommended/not necessary/not likely situation

Assessment of applicability of different cleaning methods based on observations from task 5.6.

IM-28 Temp/ method	Remarks	Scrapes/ sorbents "clean as you survey"	Spades/ Sieves etc	Concrete mixer sea water	Concrete mixer or caterpillar siever with sorbents	Concrete mixer heated sea water closed off system	Flushing	Surf washing	Shoreline cleaning agents
<15°C	Random patties/patches is expected at these temperatures	Random patties/patches on hard surfaces and beach meadows	Random patties/patches on hard surfaces and beach meadows	On higher concentrations of oil in pebble/cobbles beaches – beach cleaning agent needed for effect	On higher concentrations of oil in pebble/cobbles beaches	On higher concentrations of oil in pebble/cobbles beaches > Water temp heated to >30°C	On pebble/cobble beaches. Oiled sediments recommended to be moved close to water line before flushing.	As a finishing method if needed based on remains	Probably needed at lower temperature before flushing or tumbling
16°C-19°C	Random patties/patches is expected at these temperatures	Random patties/patches on hard surfaces and beach meadows	Random patties/patches on hard surfaces and beach meadows	On higher concentrations of oil in pebble/cobbles beaches – beach cleaning agent needed for effect	On higher concentrations of oil in pebble/cobbles beaches	On higher concentrations of oil in pebble/cobbles beaches > Water temp heated to >30°C	On pebble/cobble beaches. Oiled sediments recommended to be moved close to water line before flushing.	As a finishing method if needed based on remains	Probably needed at lower temperature before flushing or tumbling
20°C-25°C	Larger areas with continuous slicks expected. Less random patches.	If random patties/patches on hard surfaces and beach meadows	If random patties/patches on hard surfaces and beach meadows	On higher concentrations of oil in pebble/cobbles beaches	On higher concentrations of oil in pebble/cobbles beaches	On higher concentrations of oil in pebble/cobbles beaches > Water temp heated to >30°C	On pebble/cobble beaches. Oiled sediments recommended to be moved close to water line before flushing.	As a finishing method if needed based on remains	Test if needed
25°C-29°C	Larger areas with continuous slicks expected. Random patches not expected.	Not likely	Not likely	On higher concentrations of oil in pebble/cobbles beaches	On higher concentrations of oil in pebble/cobbles beaches	On higher concentrations of oil in pebble/cobbles beaches > Water temp heated to >30°C	On pebble/cobble beaches. Oiled sediments recommended to be moved close to water line before flushing.	As a finishing method if needed based on remains	Test if needed
>29°C	Larger areas with continuous slicks expected. Random patches not expected.	Not likely	Not likely	On higher concentrations of oil in pebble/cobbles beaches	On higher concentrations of oil in pebble/cobbles beaches	Probably not needed	On pebble/cobble beaches. Oiled sediments recommended to be moved close to water line before flushing.	As a finishing method if needed based on remains	Not needed

Recommended/likely situation	May be used but probably not the most efficient or may not be necessary	Not recommended/not necessary/not likely situation

Assessment of applicability of different cleaning methods based on observations from task 5.6.

IM-29 Temp/ method	Remarks	Scrapes/ sorbents "clean as you survey"	Spades/ Sieves etc	Concrete mixer sea water	Concrete mixer or caterpillar siever with sorbents	Concrete mixer heated sea water closed off system	Flushing	Surf washing	Shoreline cleaning agents
<15°C	Random patties/patches is expected at these temperatures	Random patties/patches om hard surfaces and beach meadows	Random patties/patches om hard surfaces and beach meadows	On higher concentrations in pebble/cobbles beaches	On higher concentrations in pebble/cobbles beaches	On higher concentrations in pebble/cobbles beaches > Water temp heated to 20-25°C	On pebble/cobble beaches. Oiled sediments recommended to be moved close to water line before flushing.	As a finishing method if needed based on remains	Effective and recommended for low temperatures.
16°C-19°C	Random patties/patches is expected at these temperatures	Random patties/patches om hard surfaces and beach meadows	Random patties/patches om hard surfaces and beach meadows	On higher concentrations in pebble/cobbles beaches	On higher concentrations in pebble/cobbles beaches	Probably not needed	On pebble/cobble beaches. Oiled sediments recommended to be moved close to water line before flushing.	As a finishing method if needed based on remains	Probably not needed
20°C-25°C	Larger areas with continuous slicks expected. Less random patches.	If random patties/patches om hard surfaces and beach meadows	If random patties/patches om hard surfaces and beach meadows	On higher concentrations in pebble/cobbles beaches	On higher concentrations in pebble/cobbles beaches	Probably not needed	On pebble/cobble beaches. Oiled sediments recommended to be moved close to water line before flushing.	As a finishing method if needed based on remains	Not needed
25°C-29°C	Larger areas with continuous slicks expected. Random patches not expected.	Not likely	Not likely	On higher concentrations in pebble/cobbles beaches	On higher concentrations in pebble/cobbles beaches	Probably not needed	On pebble/cobble beaches. Oiled sediments recommended to be moved close to water line before flushing.	As a finishing method if needed based on remains	Not needed
>29°C	Larger areas with continuous slicks expected. Random patches not expected.	Not likely	Not likely	On higher concentrations in pebble/cobbles beaches	On higher concentrations in pebble/cobbles beaches	Probably not needed	On pebble/cobble beaches. Oiled sediments recommended to be moved close to water line before flushing.	As a finishing method if needed based on remains	Not needed

Recommended/likely situation	May be used but probably not the most efficient or may not be necessary	Not recommended/not necessary/not likely situation