Final Conference - Malta

Shoreline response

Fanny CHEVER

19.11.25

WP5

Shoreline response
Objectives

- **Identify possible gaps and solutions** within shoreline clean-up methods and/or equipment
- **Study the potential toxicity** of LSFOs absorbed in rocks on marine organisms
- **Give operational recommendations** by categorizing the different types of LSFOs and associated response options

WP5

Shoreline response
6 Tasks

- Hard substrate/ Rocky shores: cleaning operations, natural degradation, potential release of toxic compounds (NCA, Transport Malta and Cedre)

- Sediment beaches (sand, gravel, pebbles): interaction with sediments and tests on practical cleaning techniques (NCA and Cedre)

WP5

Shoreline response
6 Tasks

- Hard substrate/ Rocky shores: cleaning operations, natural degradation, potential release of toxic compounds (NCA, Transport Malta and Cedre)

- **Sediment beaches (sand, gravel, pebbles): interaction with sediments and tests on practical cleaning techniques → Presentation from NCA**

Oils tested

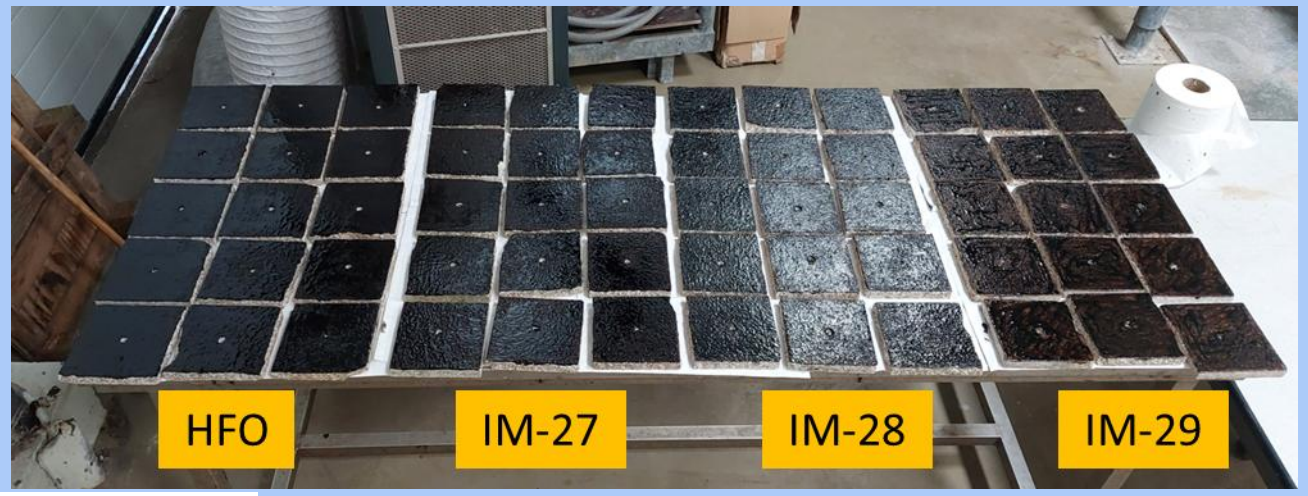
	Pour point (°C)	Visc. 50°C CoA (mm^2/s)	Visc. 25°C ($10s^{-1}$, mPa.s)	Visc. 15°C ($10s^{-1}$, mPa.s)	Asphaltenes (%)	Waxes (%)
IM-27 (VLSFO)	12°C (9-24°C)	322	7 592	16 600	2.1	7.6
IM-28 (VLSFO)	27°C (21-30°C)	124	21 221	54 813	1.5	14.1
IM-29 (ULSFO)	27°C (15-24°C)	39	331	10 559	0.4	13.3
HFO	-	-	-	79 733	-	-

Trials performed at Cedre

Cleaning of rocky shore

Rocky shoreline simulated by using granite tiles, 15 x 15 x 2 cm

3 grams of each heated oil added (0.01 g/cm^2)



Drying time

Cleaning of rocky shore

Tiles washed following:

- 2 conditions of temperature (~15°C and 50°C) and
- 2 conditions of pressure (50 bars and 100 bars)

- + Control tiles: polluted tiles not cleaned

$$\text{Cleaning efficiency} = \frac{\text{amount of oil extracted after the washing robot cleaning}}{\text{amount of oil extracted from the control tiles}}$$

Trials performed at Cedre

Cleaning of rocky shore

After 5 months of drying

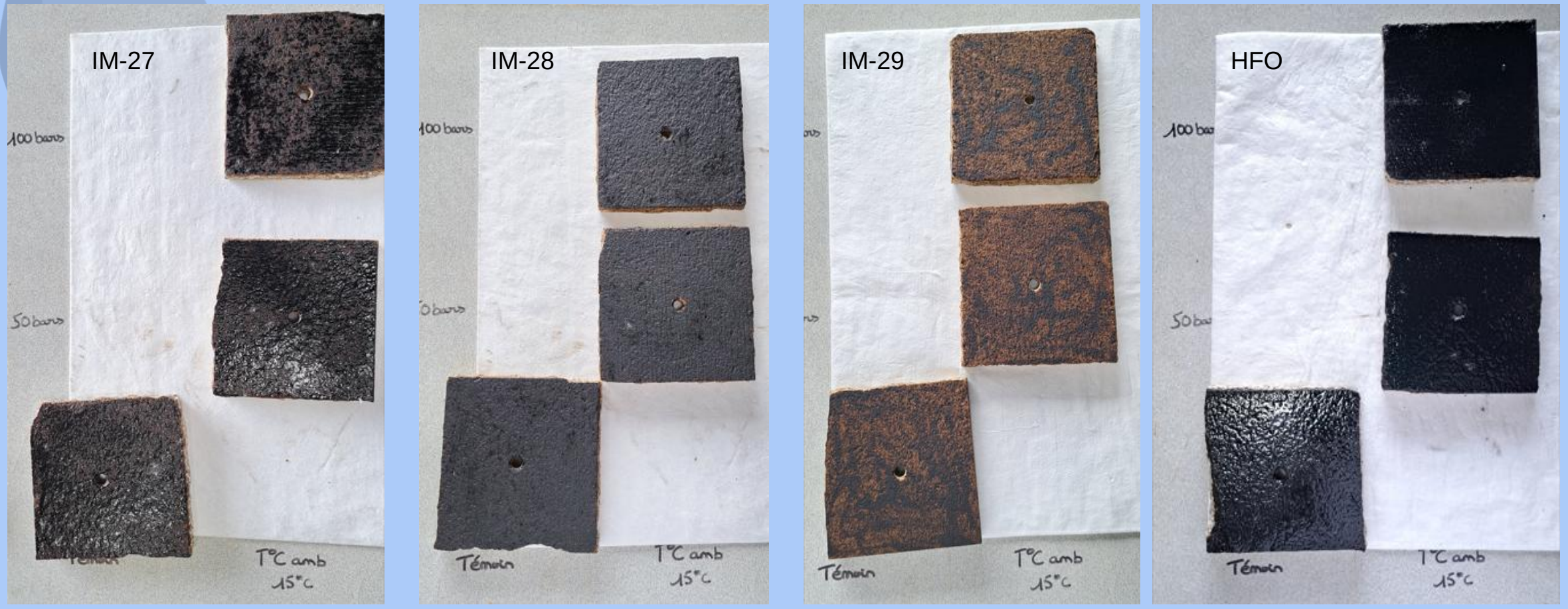
- High penetration for the 3 LSFOs

	Mass of oil recovered after drying (g)	Oil recovered after drying (%)
IM-27	2.2	**72**
IM-28	1.0	**36**
IM-29	0.6	**24**
HFO	2.5	**89**

Trials performed at Cedre

Cleaning of rocky shore

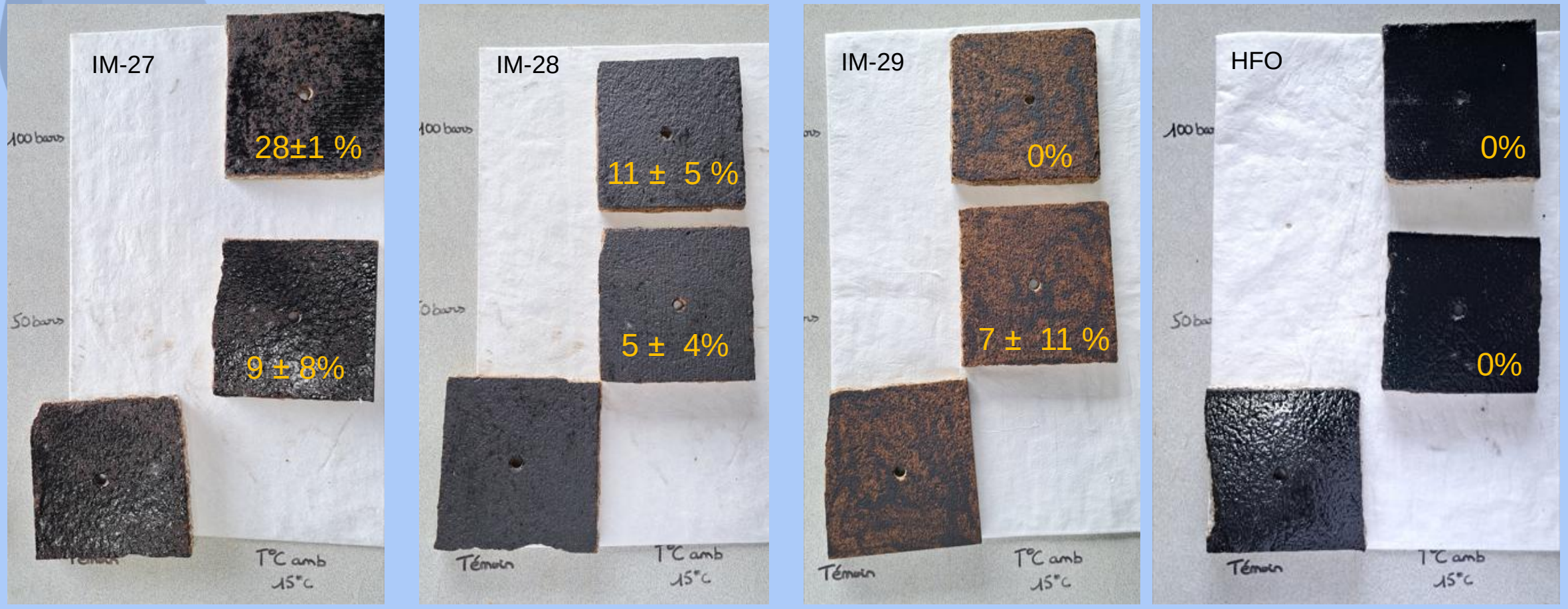
- Washing efficiency -



Trials performed at Cedre

Cleaning of rocky shore

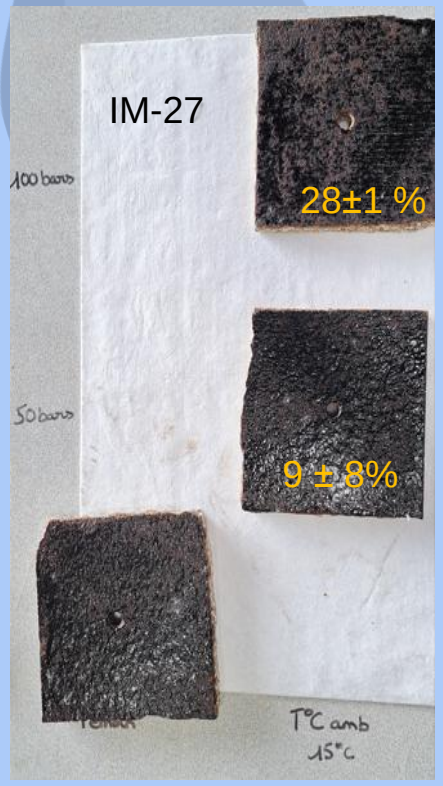
- Washing efficiency -

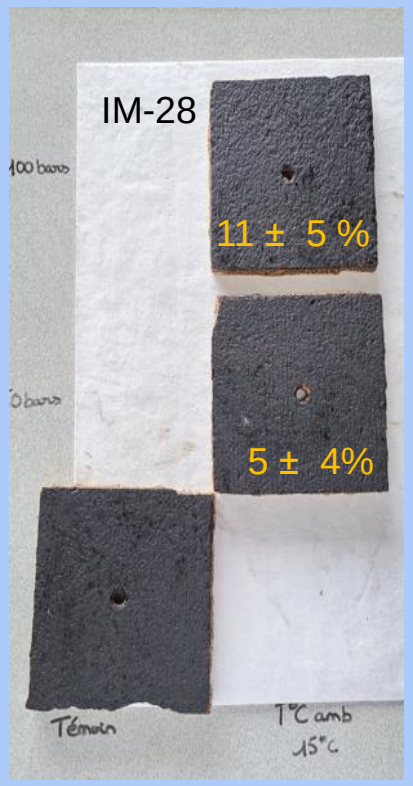


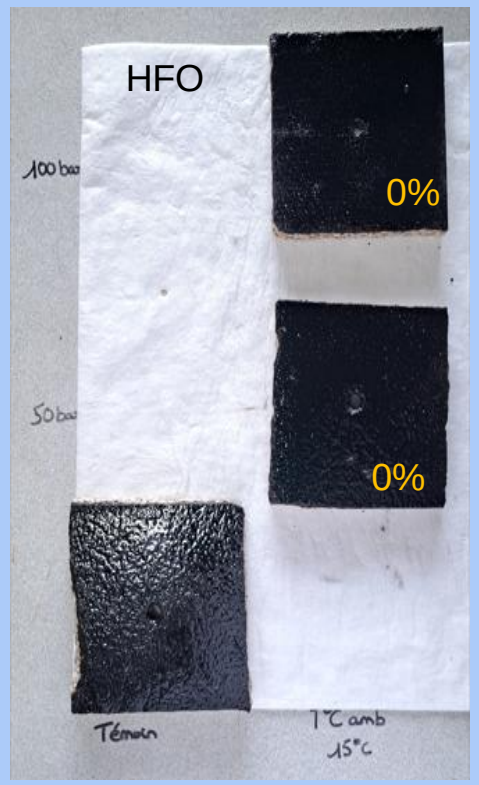
Trials performed at Cedre

Cleaning of rocky shore

- Washing efficiency -







	50°C 50 bars	50°C 100 bars
IM-27	27 ± 12	37 ± 3
IM-28	13 ± 7	0
IM-29	16 ± 2	9 ± 15
HFO	17 ± 7	7 ± 2

- High variability (rock heterogeneity)
- Penetration and stronger adherence due to drying time leads to low washing efficiency

Trials performed at Sintef

Cleaning of rocky shore

- Efficiency of cleaning agent -

- Tiles: Slate, 10 x 10 cm
- Amount of added oil: 10 g
- Drying time: 1 day
- Washing conditions: 50 bars, 9°C and 25°C
- Scenario: Cleaning of fresh available oil

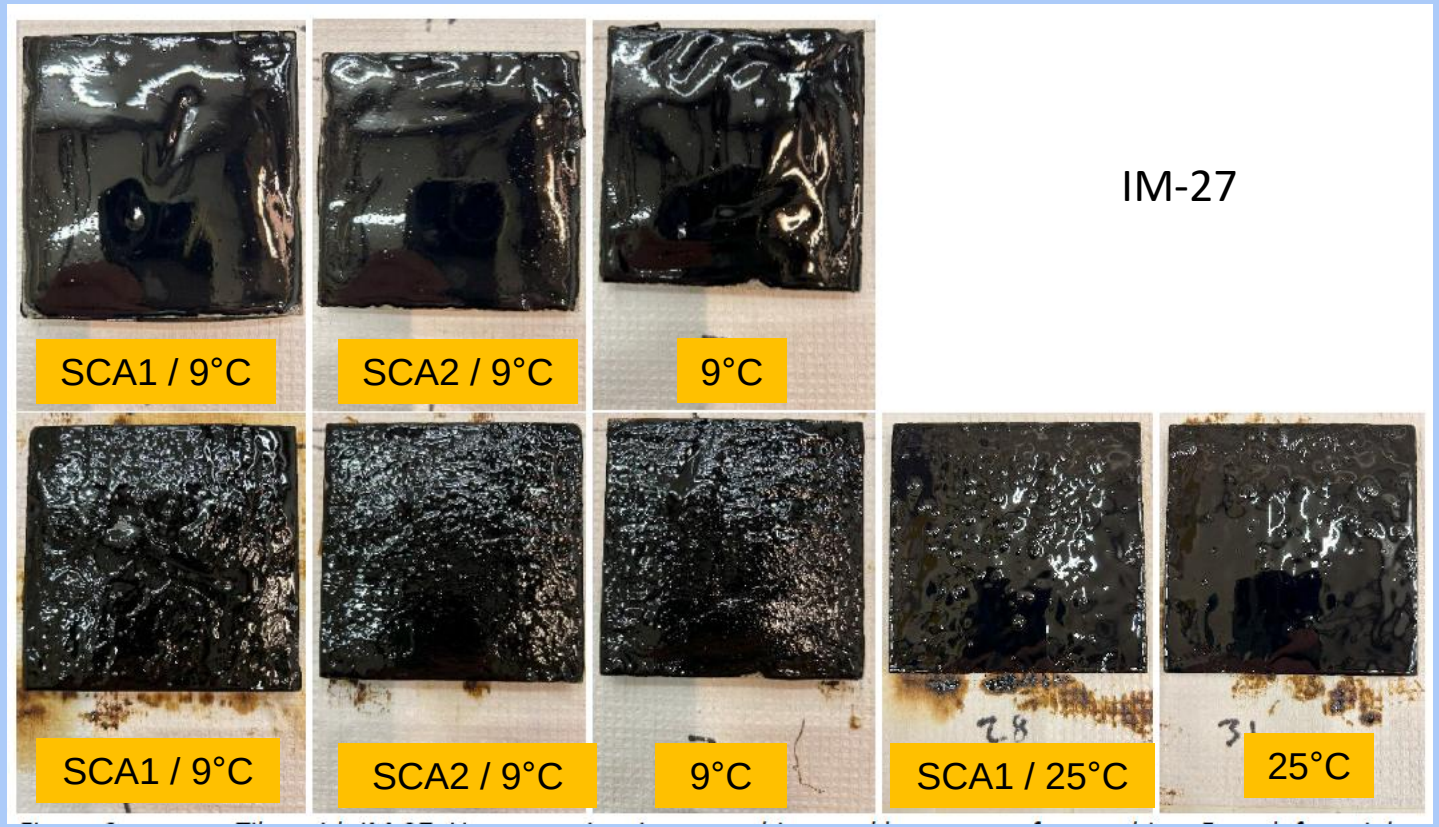
Trials performed at Sintef

Cleaning of rocky shore

- Efficiency of cleaning agent -

Prior to washing

After washing

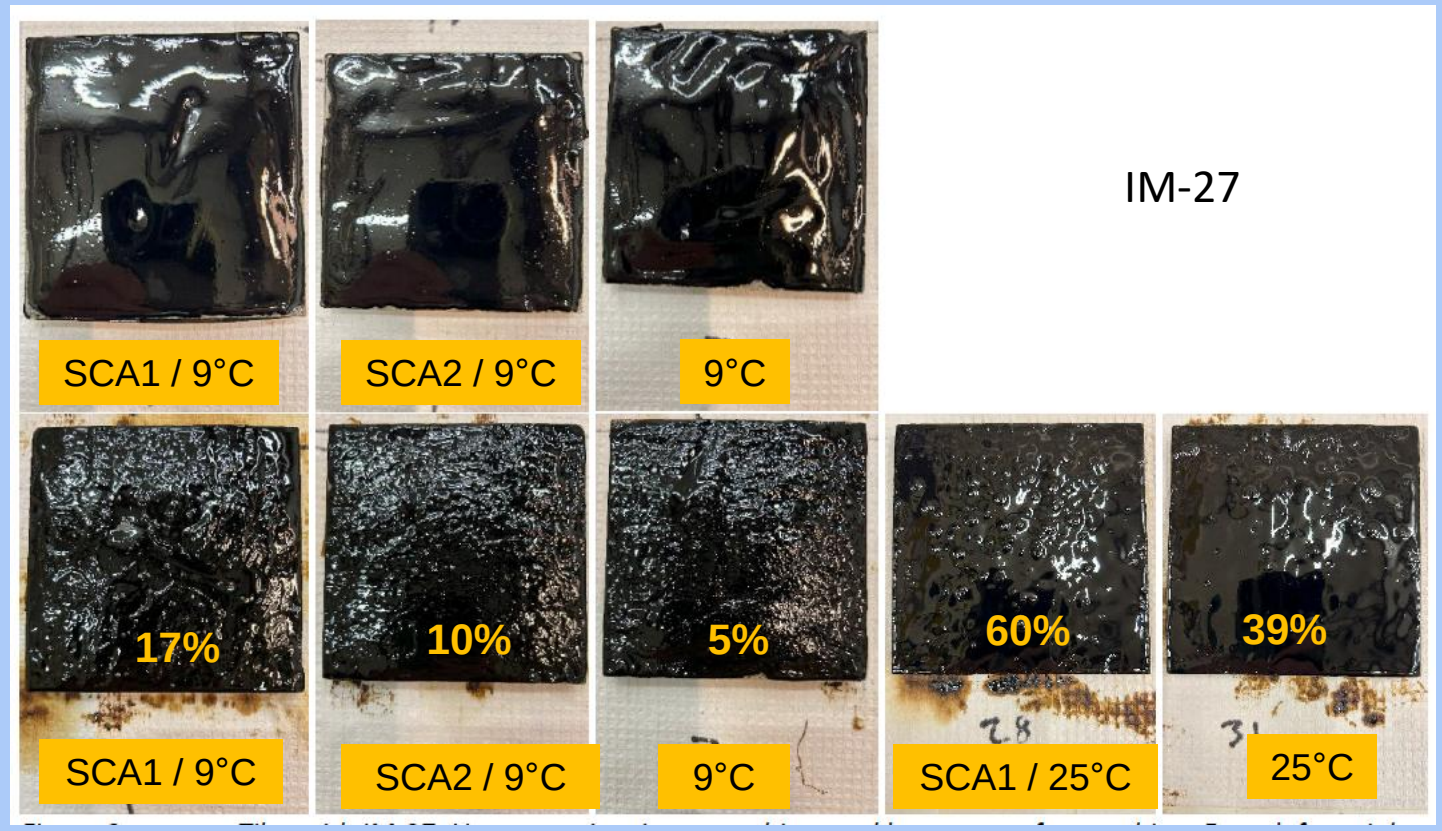


Source: Sintef report

Trials performed at Sintef

Cleaning of rocky shore

- Efficiency of cleaning agent -

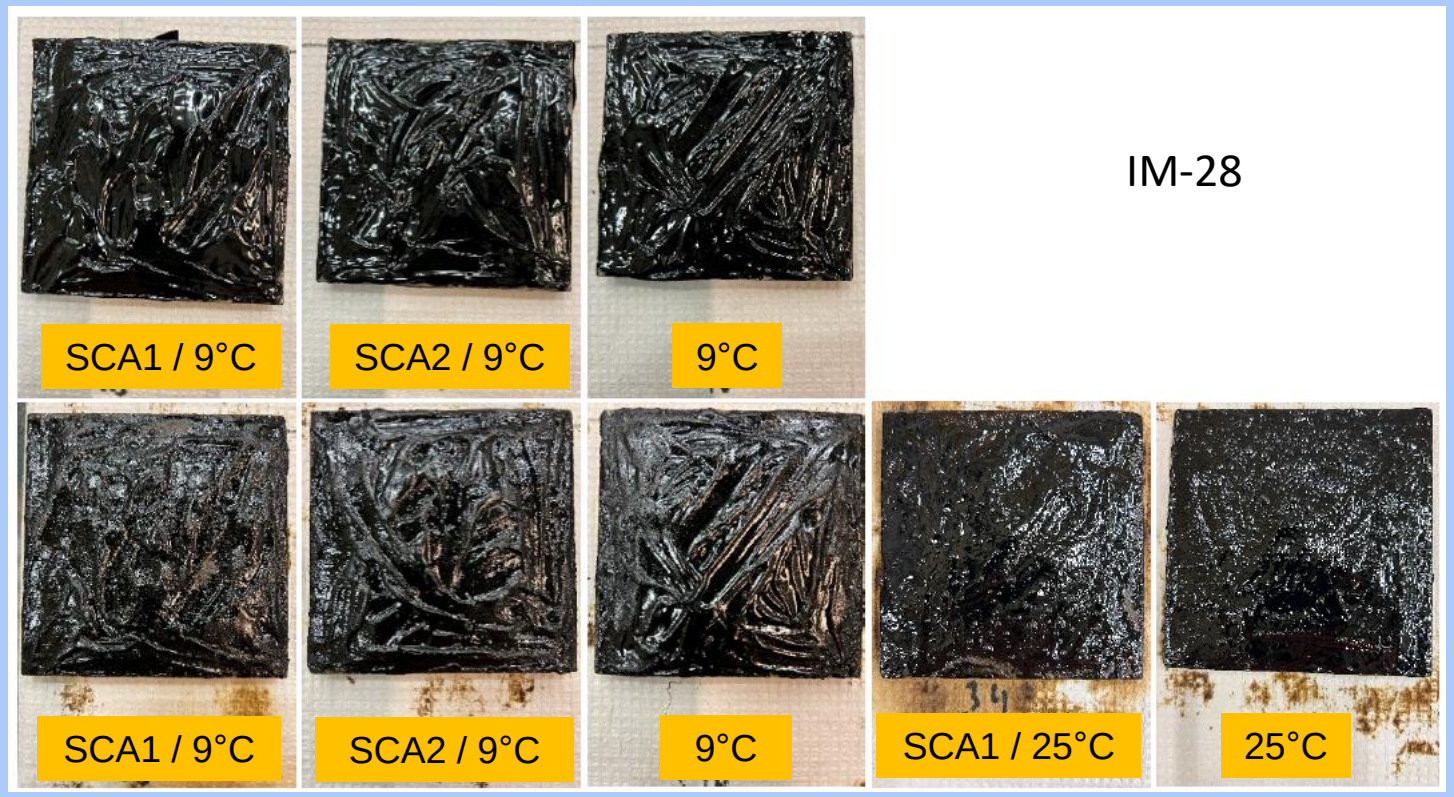


Source: Sintef report

Trials performed at Sintef

Cleaning of rocky shore

- Efficiency of cleaning agent -

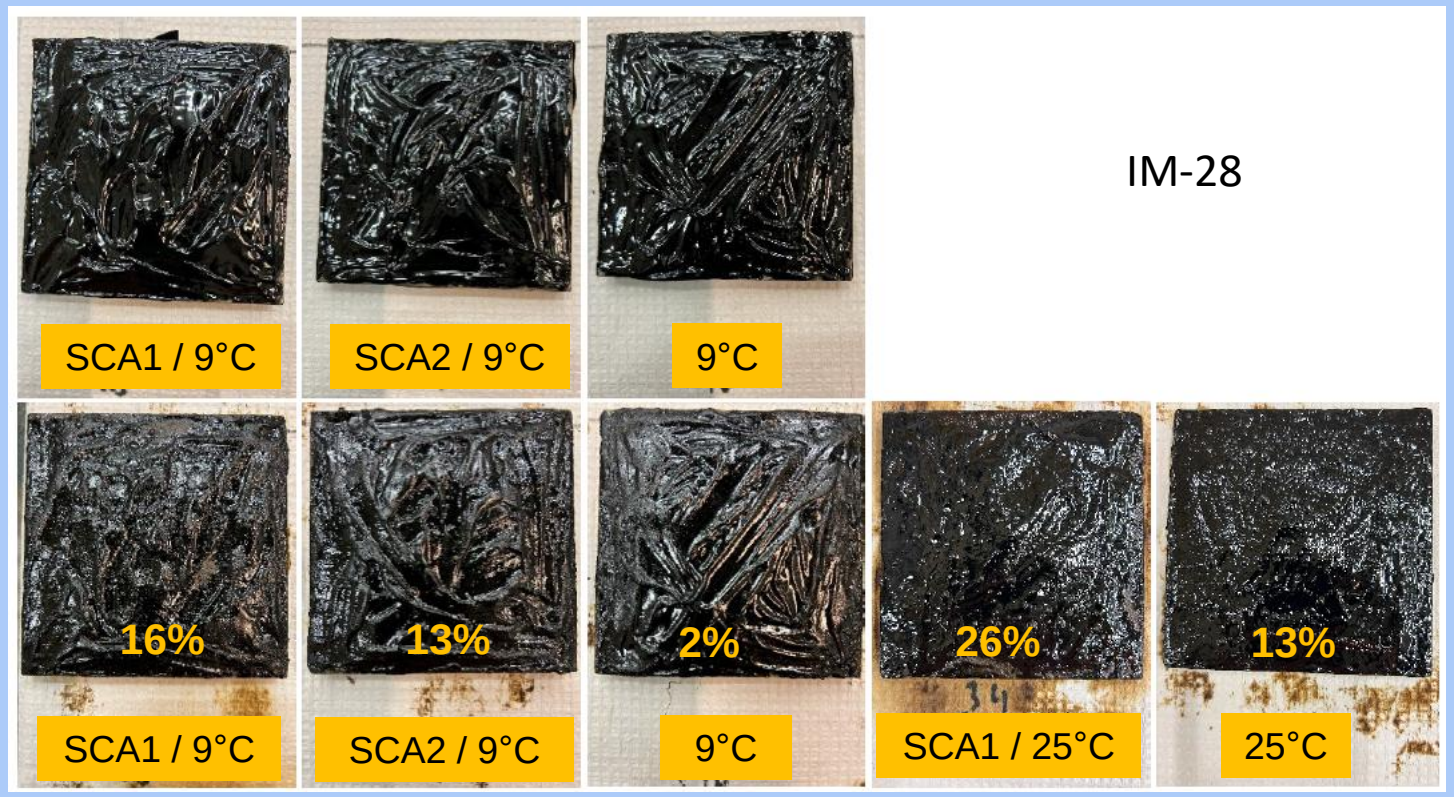


Source: Sintef report

Trials performed at Sintef

Cleaning of rocky shore

- Efficiency of cleaning agent -



Source: Sintef report

Trials performed at Sintef

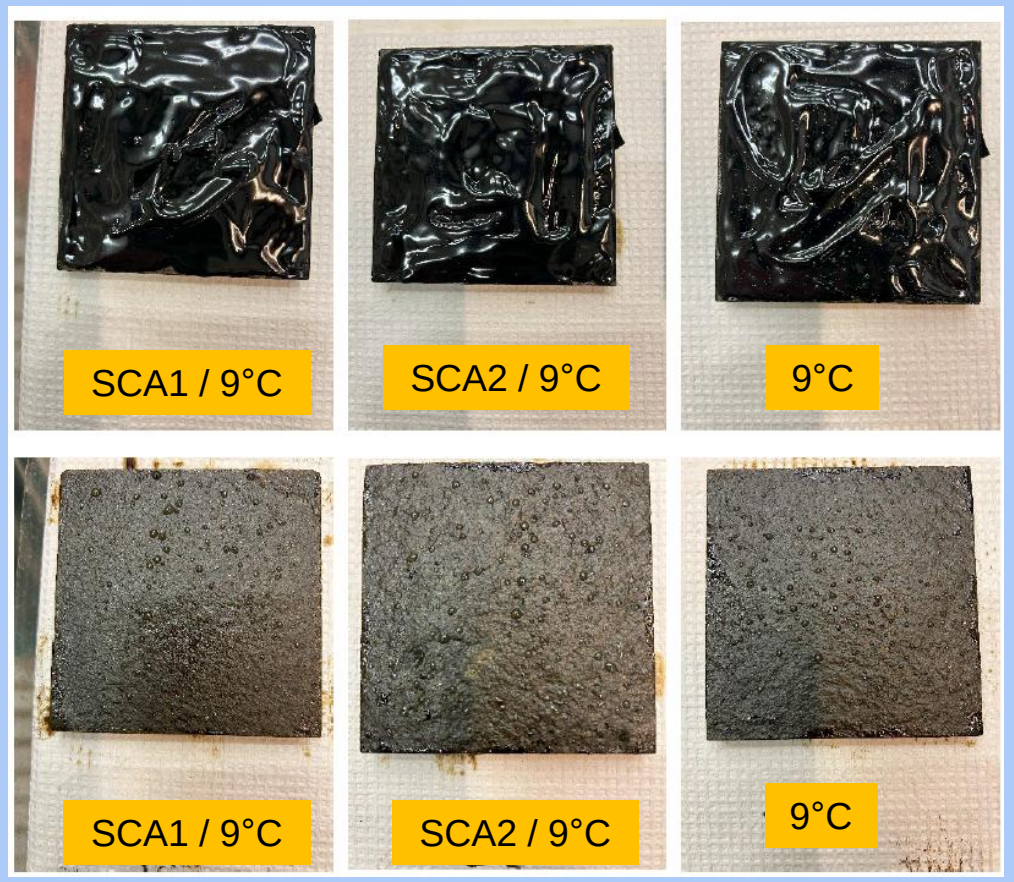
Cleaning of rocky shore

- Efficiency of cleaning agent -

IM-29

Prior to washing

After washing



Source: Sintef report

Trials performed at Sintef

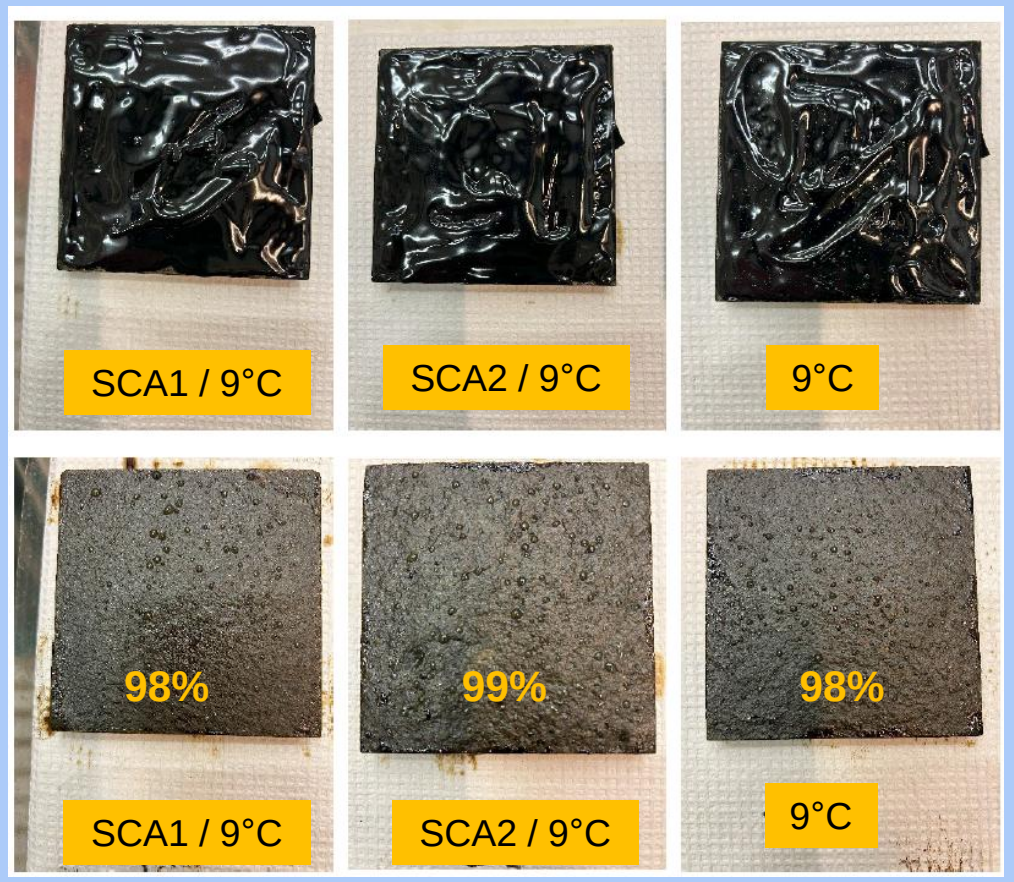
Cleaning of rocky shore

- Efficiency of cleaning agent -

IM-29

Prior to washing

After washing



Source: Sintef report

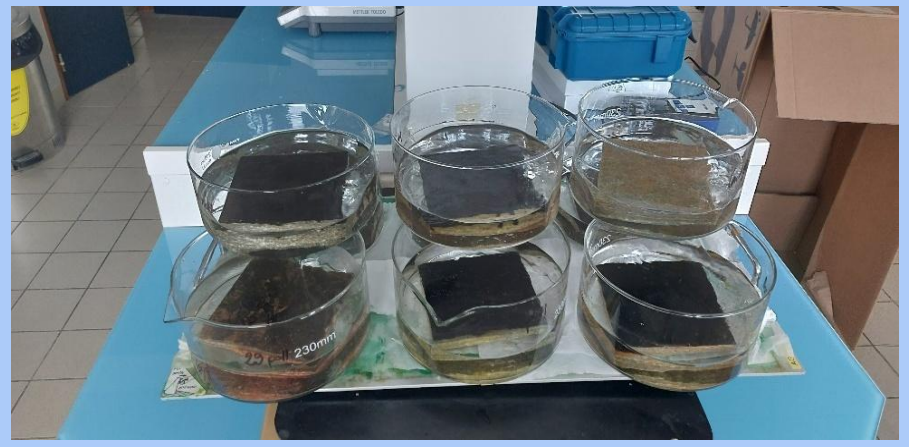
Cleaning of rocky shore
- Main comments -

- Results are oil and substrate dependent
- On fresh and « available » (significant layer without penetration) fluid oils (IM-29): good washing efficiency, no need for SCA
- On fresh high pour point / viscous / semi-solid oils, washing efficiency is highly reduced (<10%), SCA can enhance the efficiency but still far from satisfactory (<20%)
- Increasing the water temperature helps (30-60%)
- Penetration in some rocks will occur, efficiency of cleaning operations will be highly reduced

- **Necessity to rapidly locate the impacted areas and launch cleaning operations**
- **The use of SCA and, when possible, warm water can help**
- **Tainting may persist**
- **Importance of this technique for Initial clean-up operations**
- **Do not have excessive expectations, we will not return to the initial level**

Release of toxic compounds from polluted rocky shores

- Evaluate if oil trapped in rocks could be released in seawater & Induce an inhibition of algal growth and/or a mortality of copepods



- Polluted tiles
- Polluted tiles cleaned with high pressure washer (50°C/100 bars)
- Not polluted tiles (control)

→ Gently mixing for 24 hours in the dark: recovery of the water for culture media for algae and copepods

- Closed system / small volume: **do not mimic natural exposition of marine organisms** to polluted rocky substrates. 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

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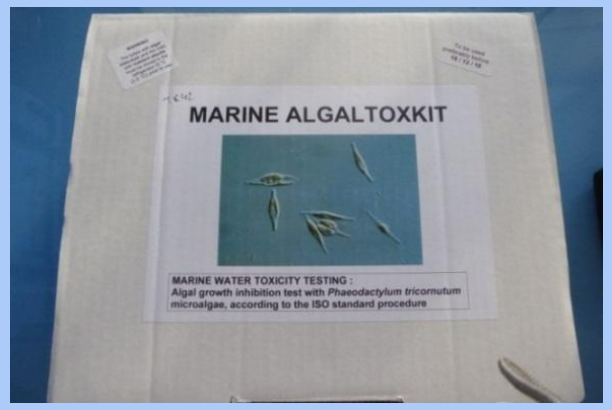
Cedre

Release of toxic compounds from polluted rocky shores

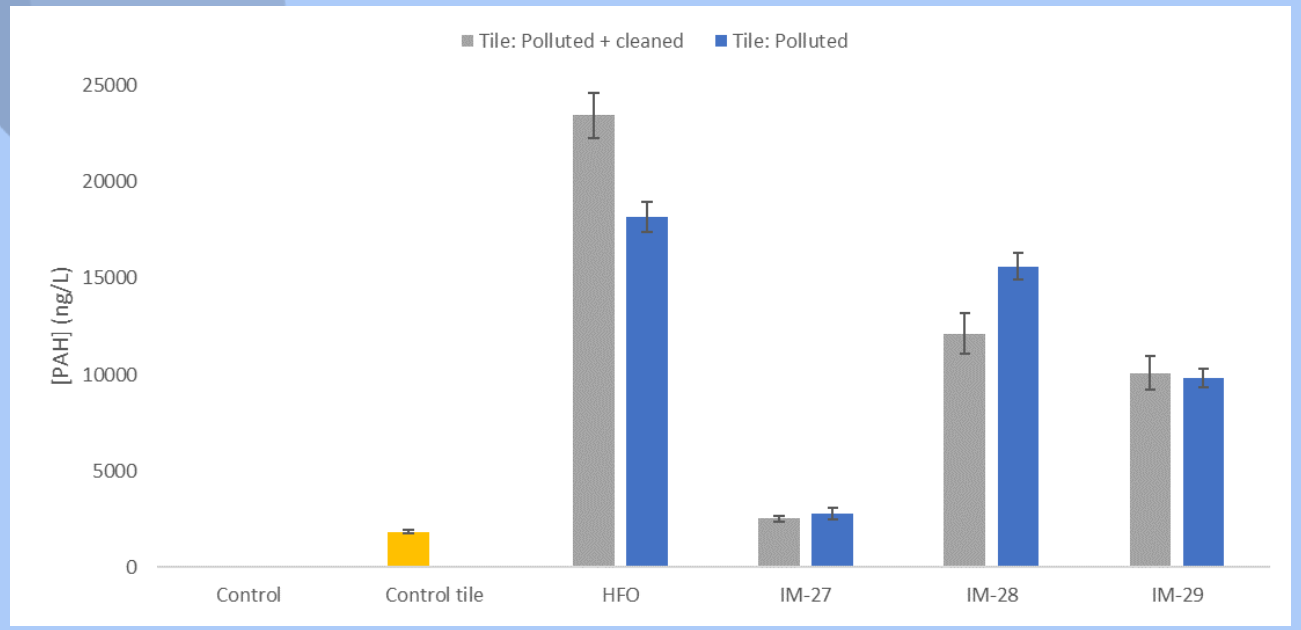


Marine diatom
Phaeodactylum tricornutum
(adapted ISO 10253: 2016 standard)

Marine copepod *Acartia tonsa*
(adapted ISO 14669: 2003 standard)

- Tests validated (controls, positive controls)

Release of toxic compounds from polluted rocky shores

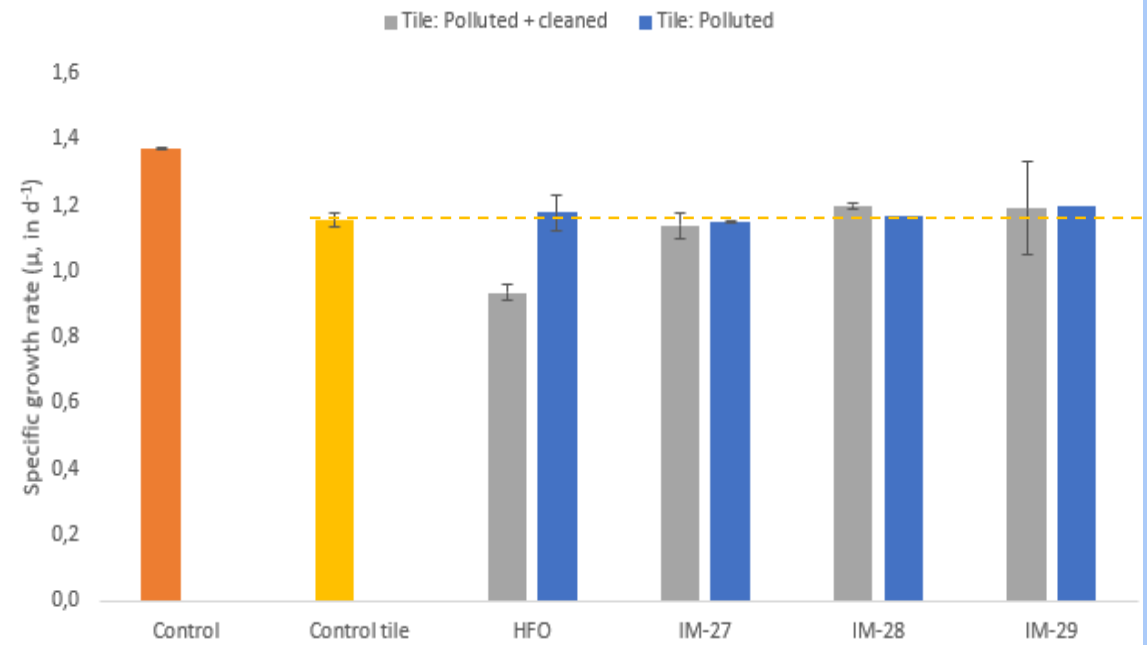


← Example of [PAH] measured in the culture media used for algae

- LSFOs compared to HFO: same levels of PAH, or even lower
- Globally, no effect of washing on [PAH] (in agreement with low washing efficiency)

Release of toxic compounds from polluted rocky shores

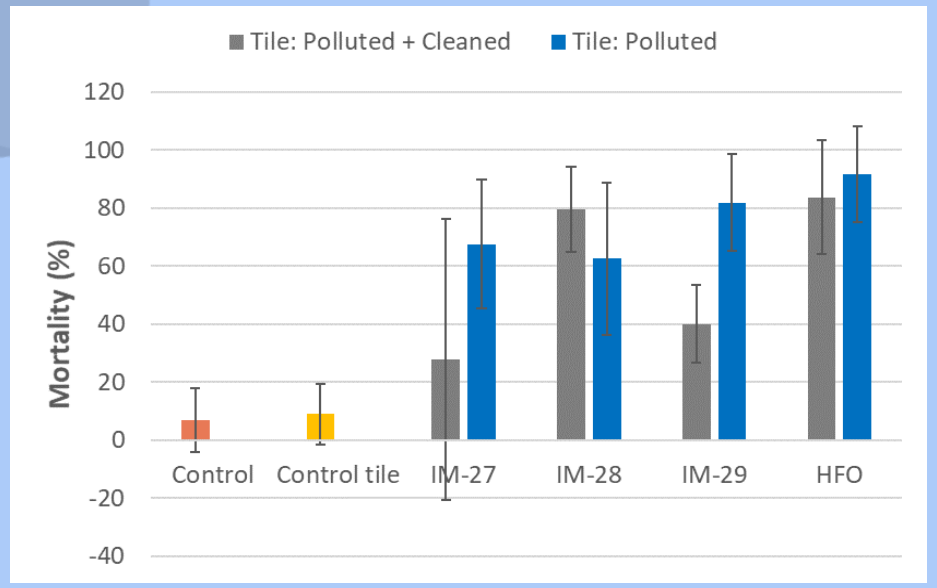
Algae



- No toxicity observed, except for HFO/washed tile (i.e. highest [PAH] : 23 µg/L)
- The levels of [PAH] in the culture media do not impact the algal growth until a certain point

Release of toxic compounds from polluted rocky shores

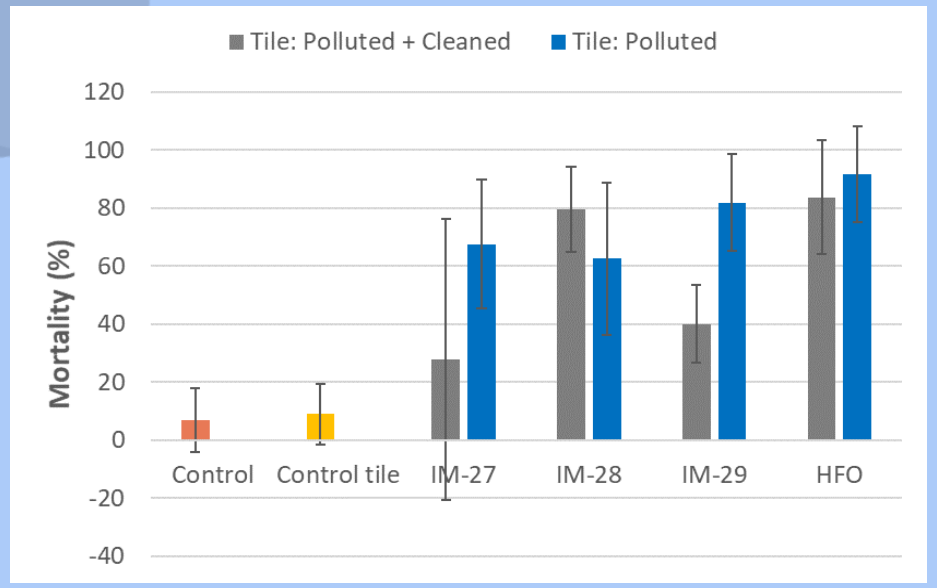
Copepods

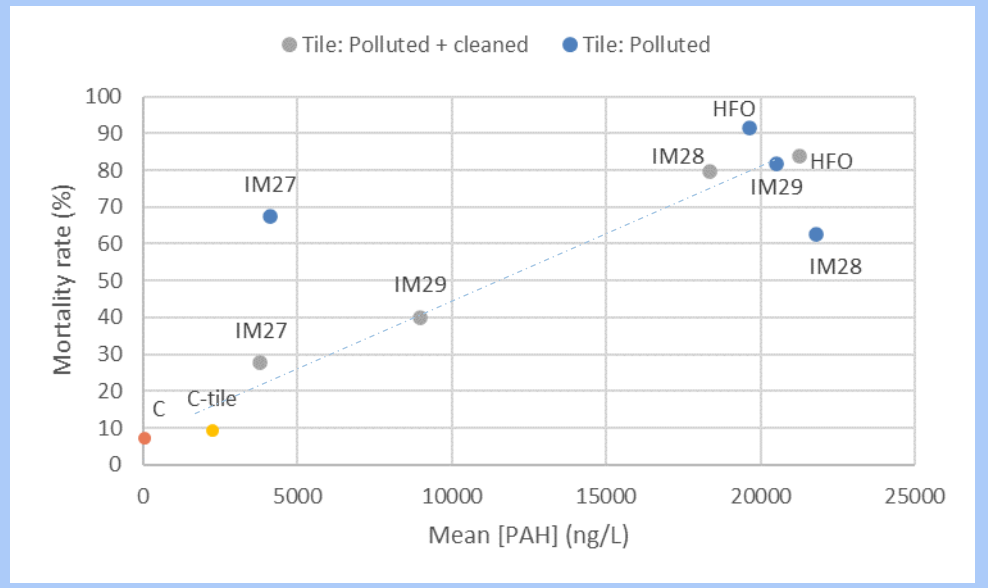


- Copepods growing in water in contact with polluted tiles exhibit higher mortality rates compared to controls
- Mortality rate in the same range, even lower, as HFO

Release of toxic compounds from polluted rocky shores

Copepods





- Copepods growing in water in contact with polluted tiles exhibit higher mortality rates compared to controls
- Mortality rate in the same range, even lower, as HFO
- Correlation between mortality rate and [PAH]

Release of toxic compounds from polluted rocky shores
- Main comments -

- Results in agreement with IMAROS and from a study from SINTEF*, that showed that LSFOs were not more toxic than traditional HFOs
- Even small quantities of remaining oil (after penetration, washing) can lead to a remanent toxicity on some marine organisms

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

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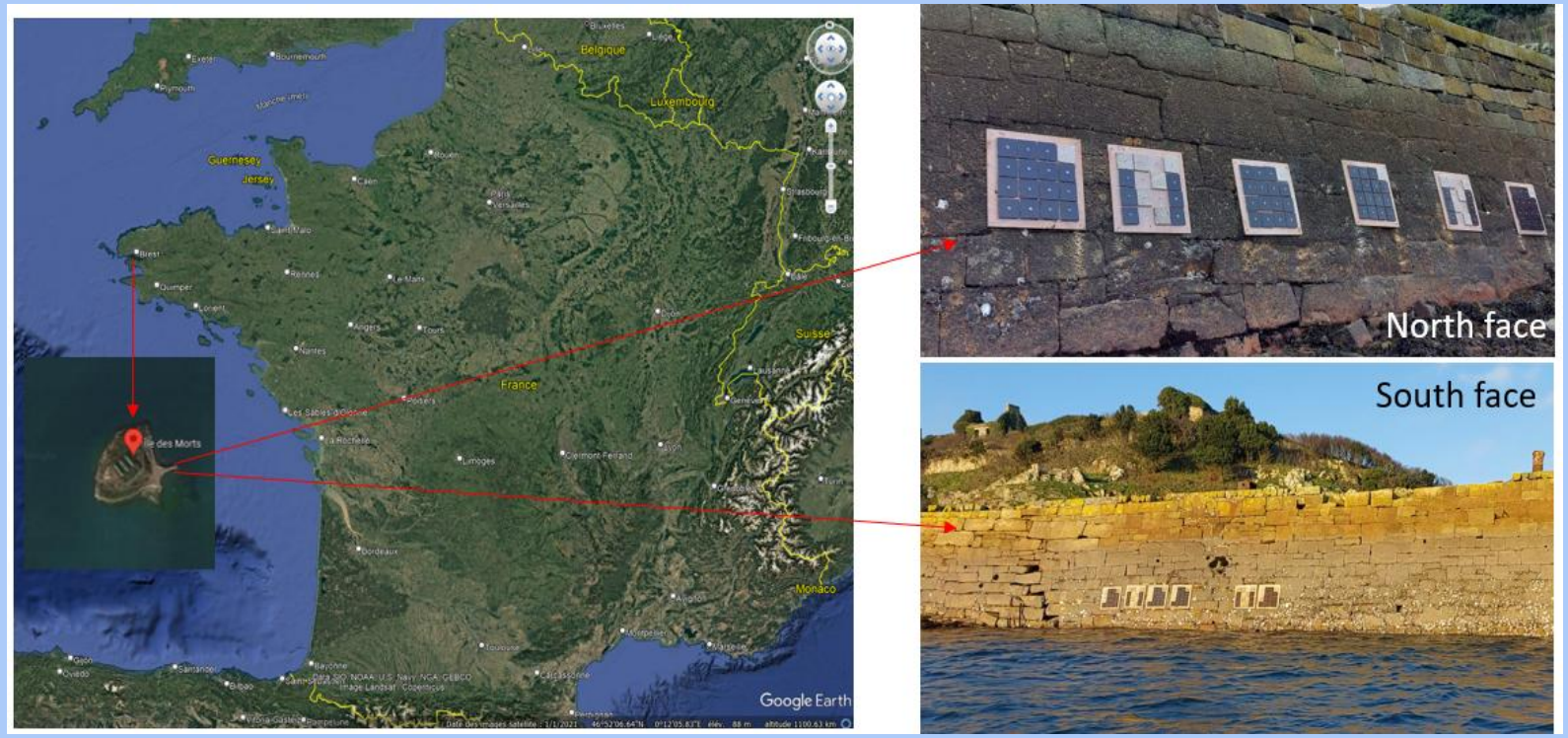
Cedre

Natural degradation on rocky shore

3 sites

France:

- Granite tiles
- Tiles submerged twice a day
- Subsampling of tiles at different time step over 11 months



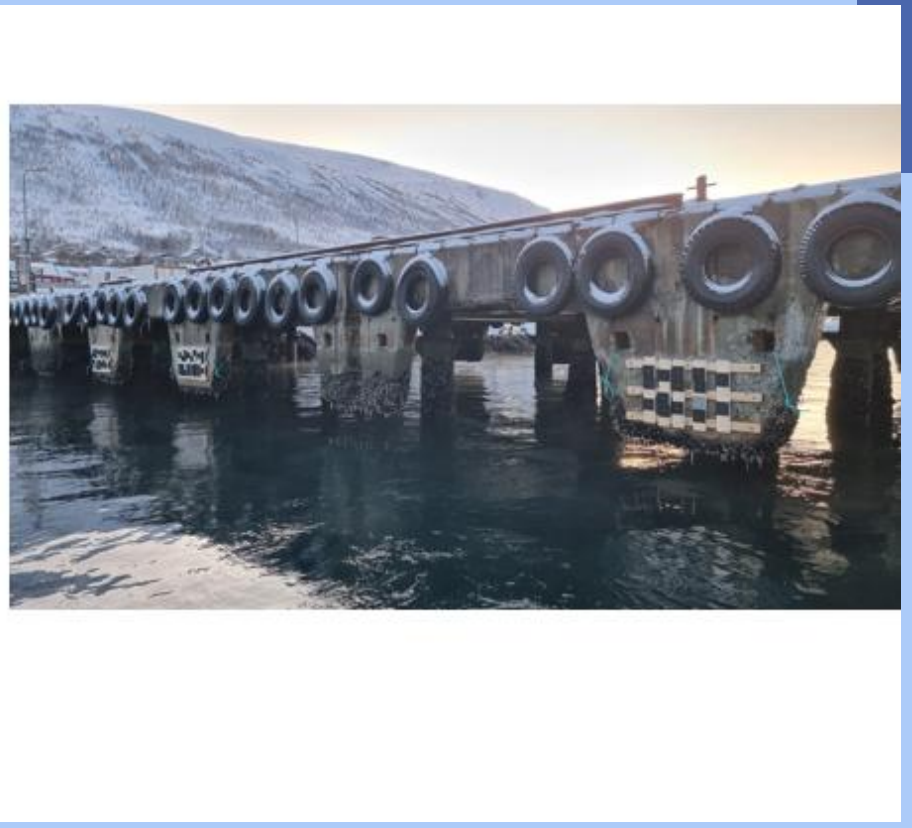
Autorisation from the French Navy / with the support of Ceppol

Natural degradation on rocky shore

3 sites

Norway:

- Slate tiles
- Tiles submerged everyday
- Subsampling of tiles at different time step over 8 months



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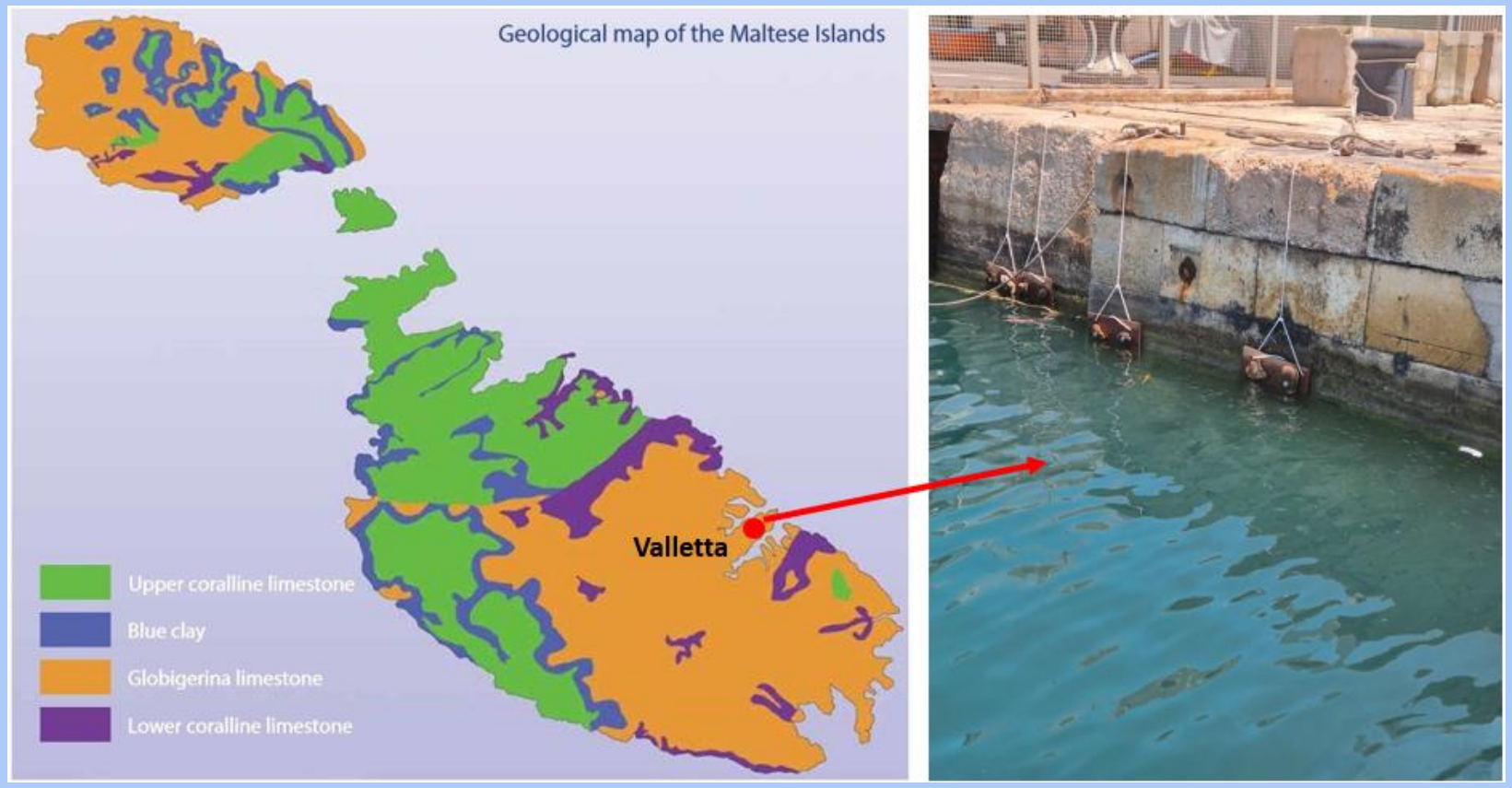
Cedre

Natural degradation on rocky shore

3 sites

Malta:

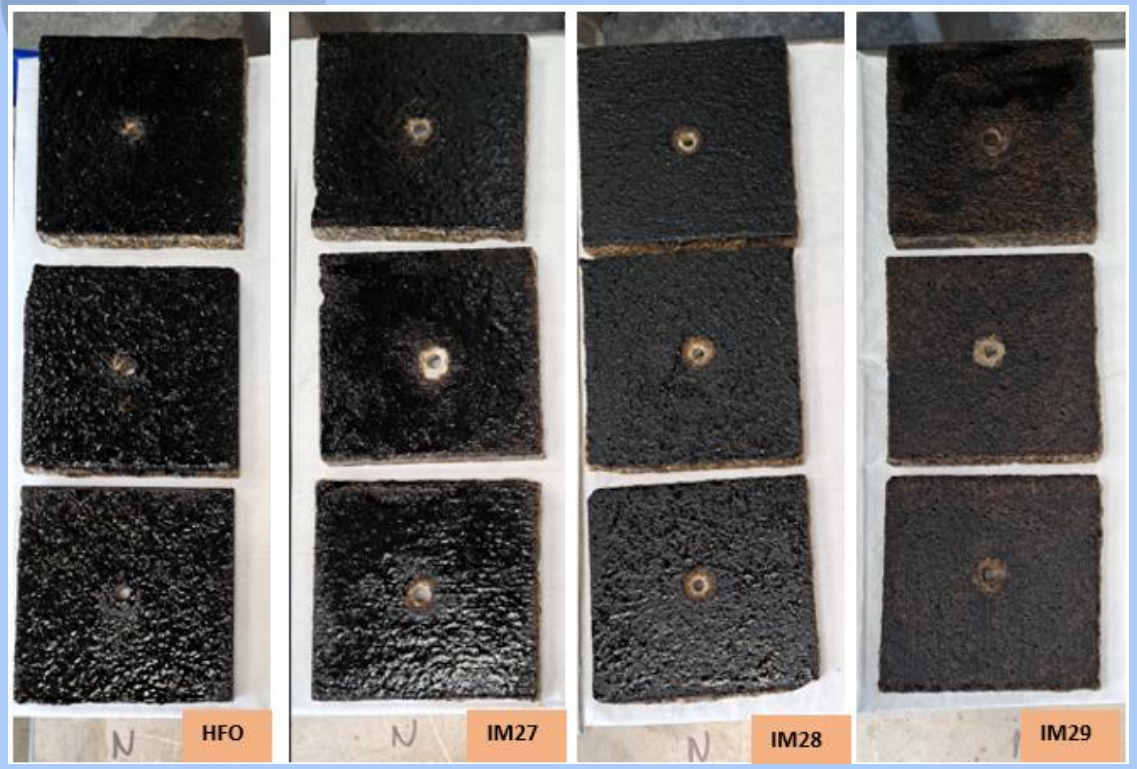
- Simplified experiment
- Globigerina and lower coralline limestone rocks
- No subsampling
- 3 months experiment



Natural degradation on rocky shore

France
North Face

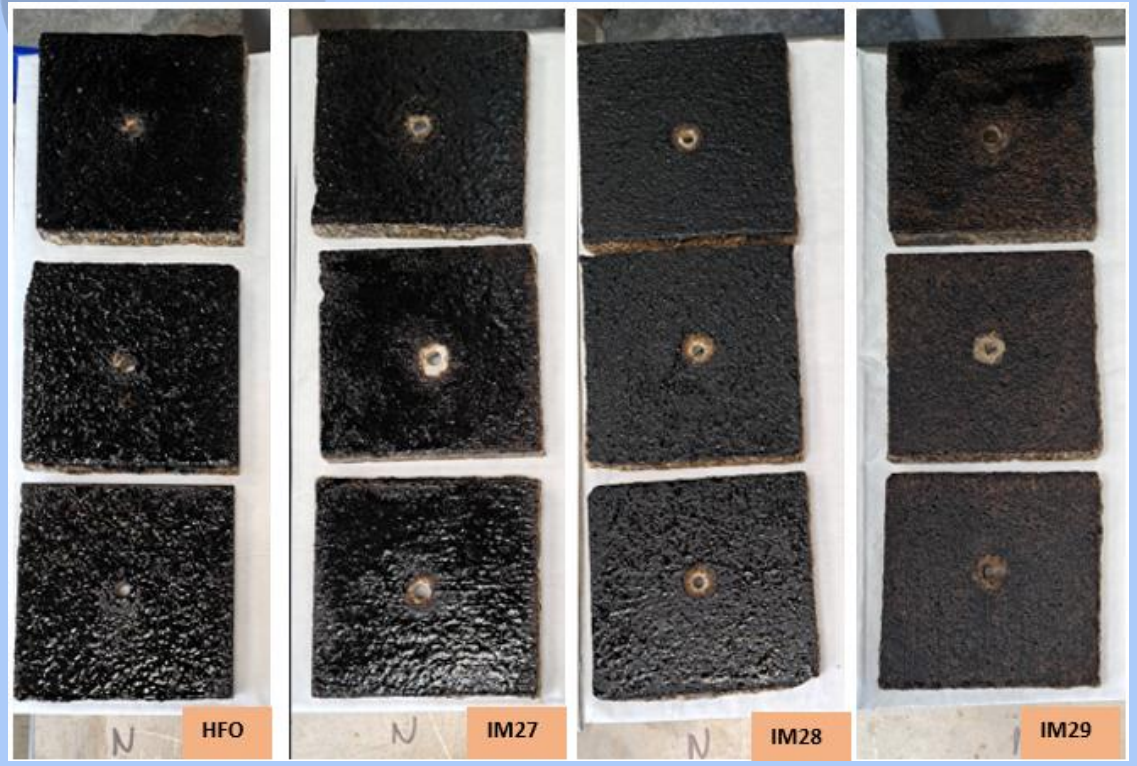
T0



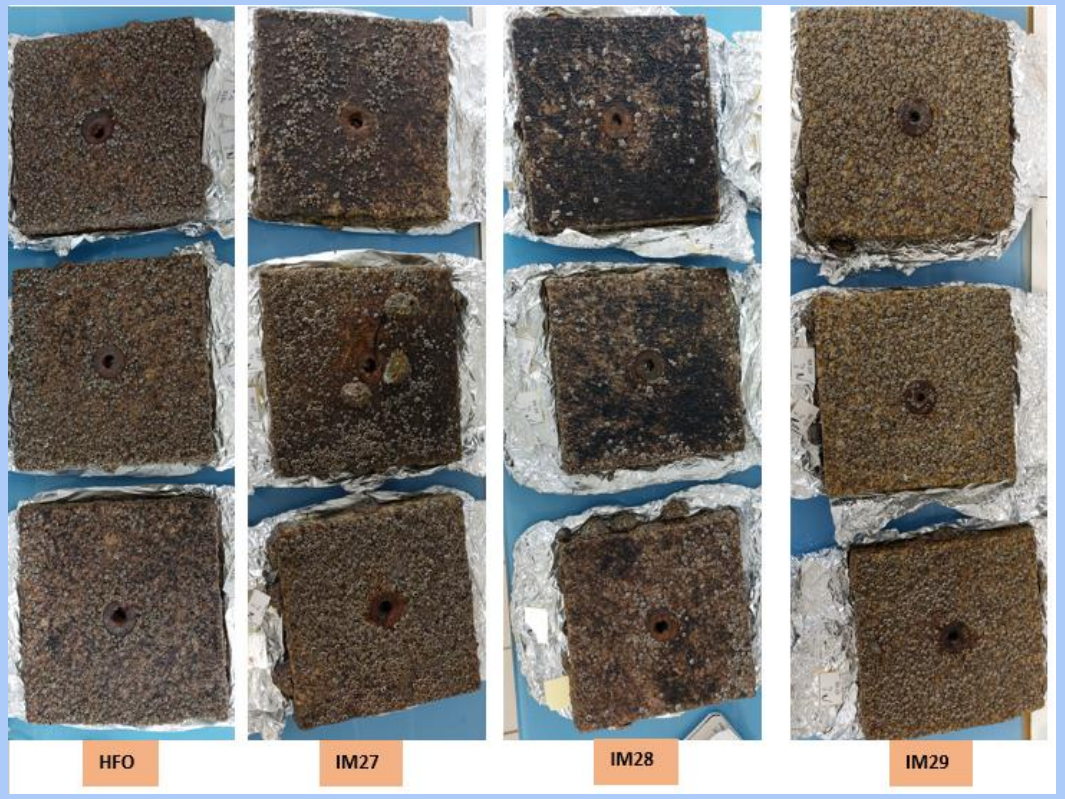
Natural degradation on rocky shore

France
North Face

T0



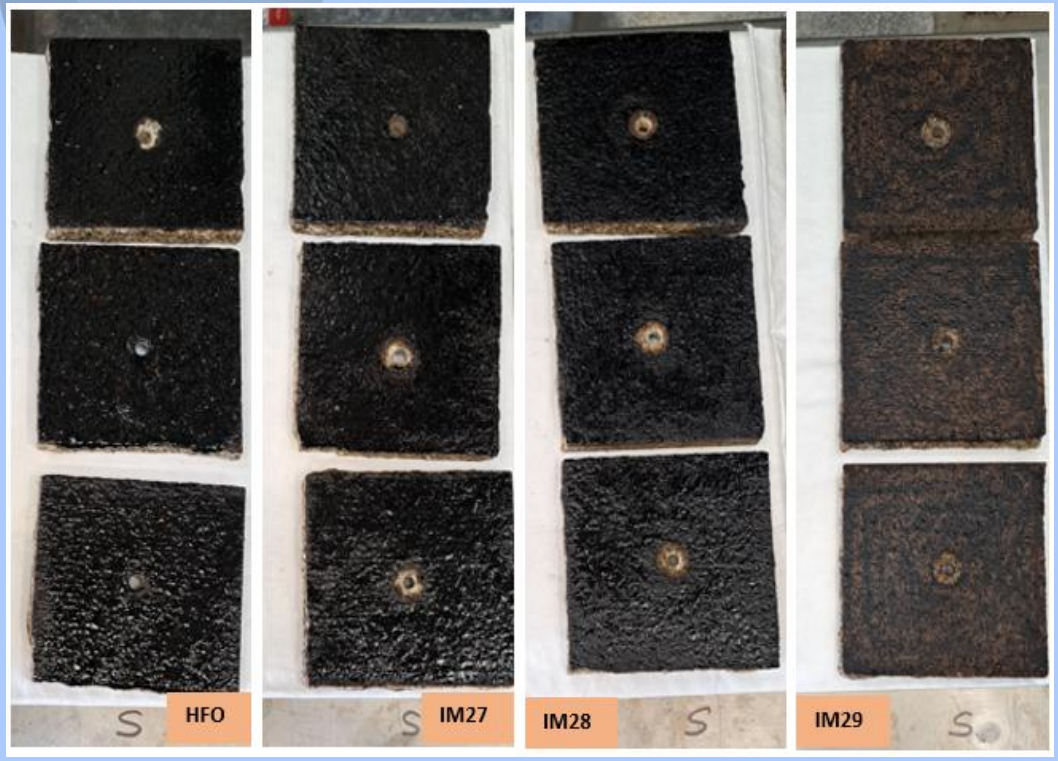
Tf (+ 11 months)



Natural degradation on rocky shore

France
South Face

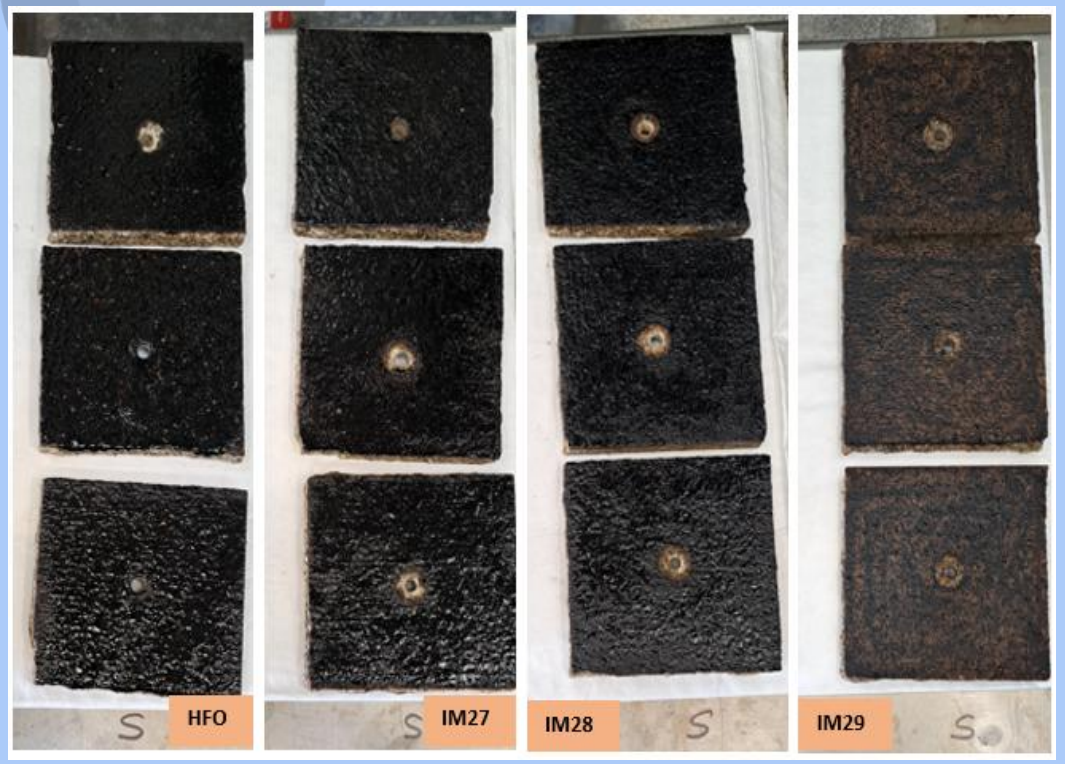
T0



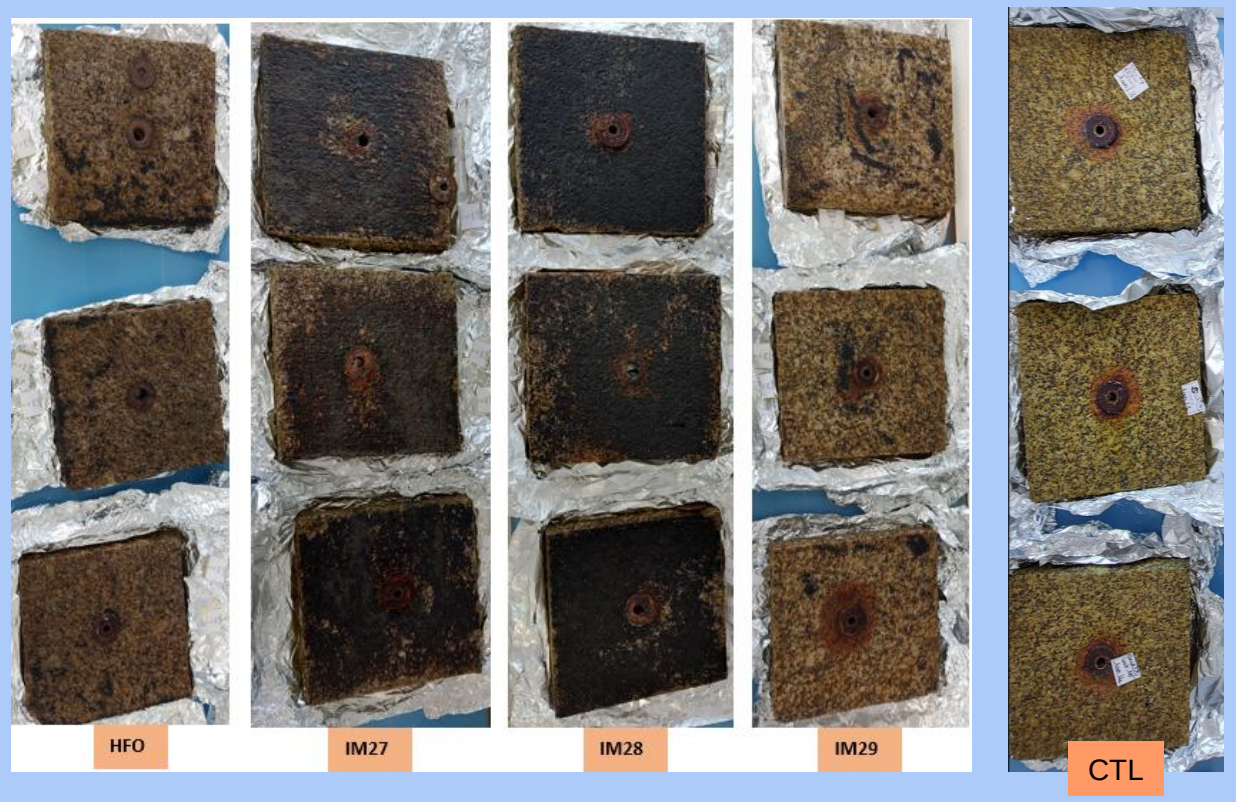
Natural degradation on rocky shore

France
South Face

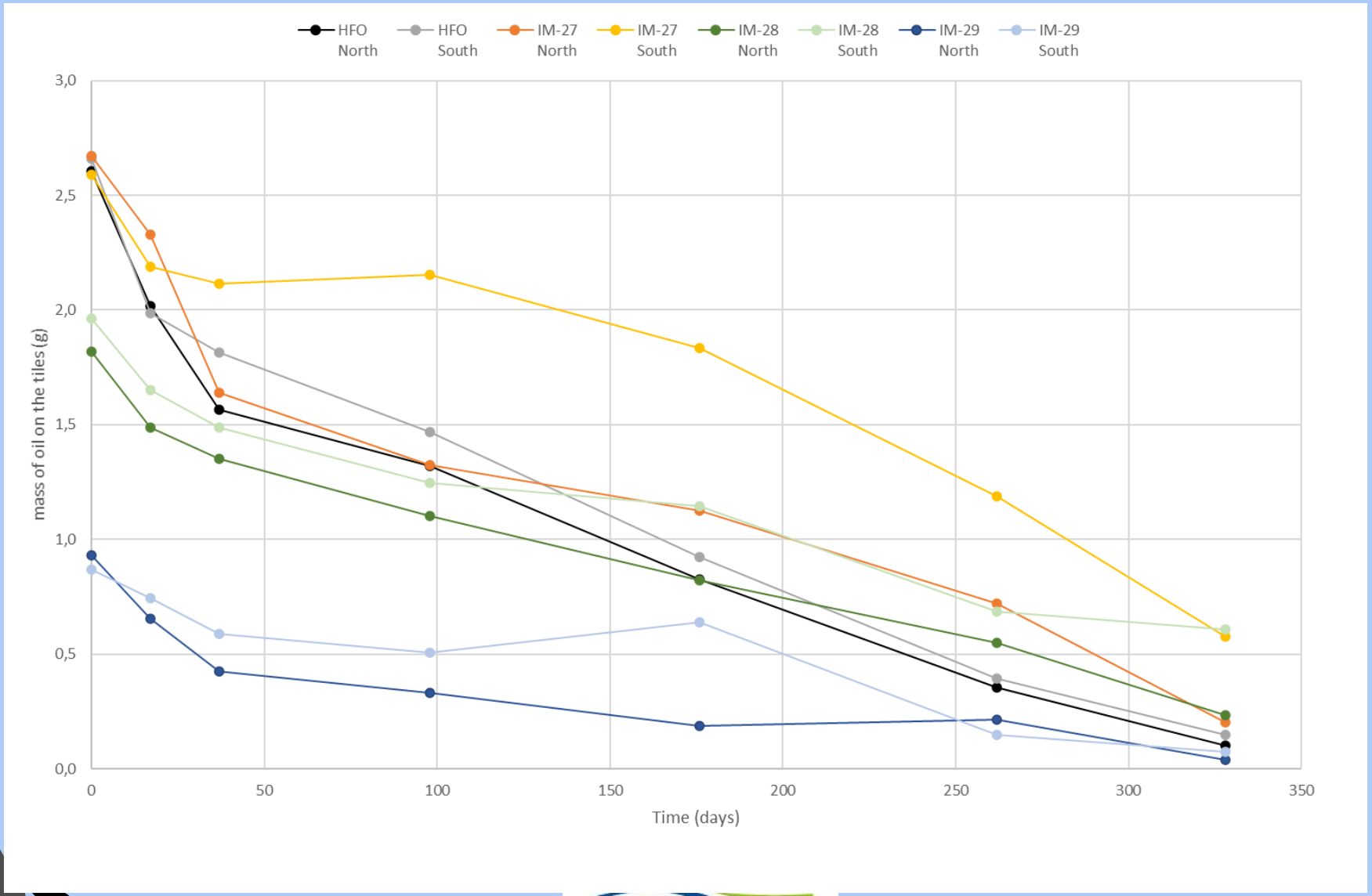
T0



Tf

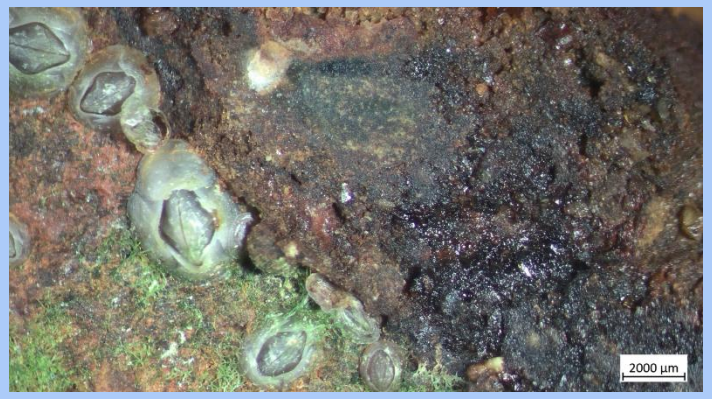


Natural degradation on rocky shore

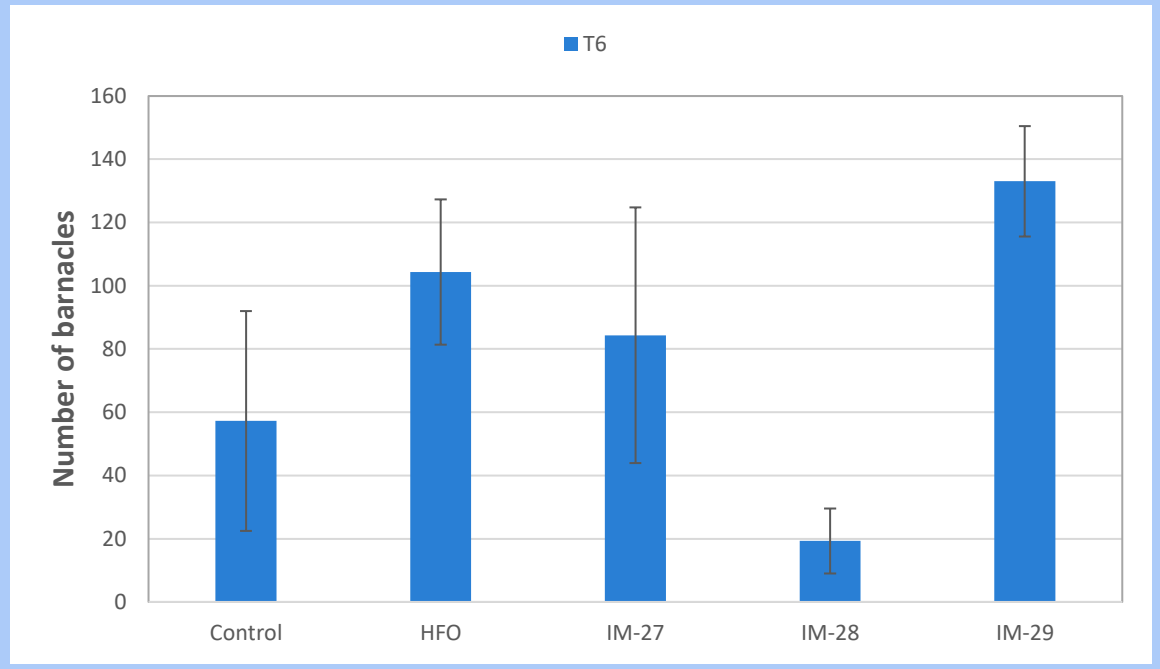


France
North Face

Natural degradation on rocky shore
Recolonisation on the north face



Beginning of colonisation at T4 (6 months, May)

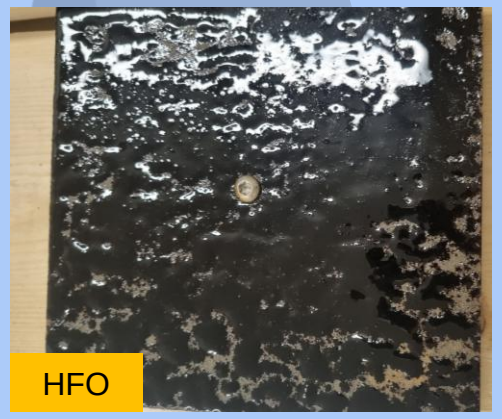


- More barnacles on IM-29 (formation of bacterial film?)
- Less barnacles on IM-28 (effect of the residual oil layer?)

Natural degradation on rocky shore

Norway

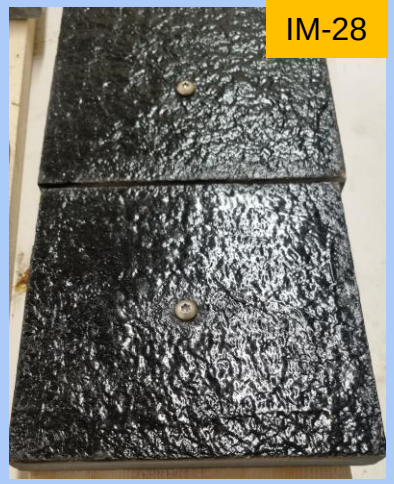
T0



HFO

IM-27

IM-28

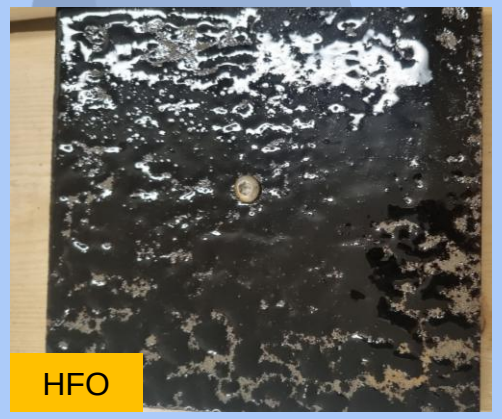


IM-29

Natural degradation on rocky shore

Norway

T0



HFO

IM-27

IM-28

IM-29

Tf (+ 8 months)

HFO

IM-27

IM-28

IM-29

Natural degradation on rocky shore

Norway

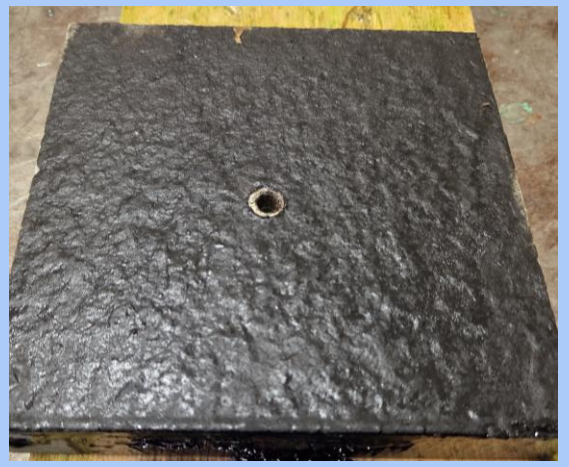
IM-27

Sampling T1 – 15 days
25 days in field

Sampling T2 – 1 month
39 days in field

Sampling T3 – 3 months
100 days in field

Sampling T4 – 6 months
142 days in field



Sampling T5 – 8 months
212 days in field

KYSTVERKET
NORWEGIAN COASTAL ADMINISTRATION

Norway

Natural degradation on rocky shore

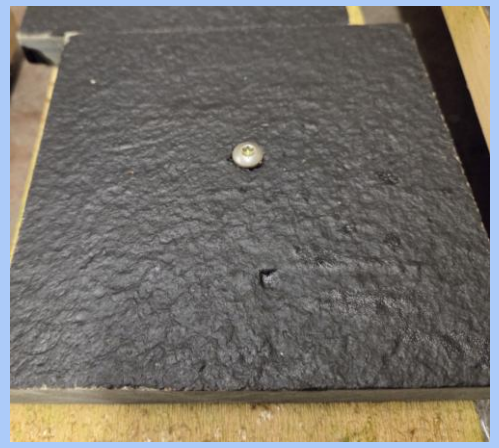
IM-28

Sampling T1 – 15 days
25 days in field

Sampling T2 – 1 month
39 days in field

Sampling T3 – 3 months
100 days in field

Sampling T4 – 6 months
142 days in field



Sampling T5 – 8 months
212 days in field

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KYSTVERKET
NORWEGIAN COASTAL ADMINISTRATION

Norway

Natural degradation on rocky shore

IM-29

Sampling T1 – 15 days
25 days in field

Sampling T2 – 1 month
39 days in field

Sampling T3 – 3 months
100 days in field

Sampling T4 – 6 months
142 days in field

Sampling T5 – 8 months
212 days in field

KYSTVERKET
NORWEGIAN COASTAL ADMINISTRATION

Norway

Natural degradation on rocky shore

HFO

Sampling T1 – 15 days
25 days in field

Sampling T2 – 1 month
39 days in field

Sampling T3 – 3 months
100 days in field

Sampling T4 – 6 months
142 days in field

Sampling T5 – 8 months
212 days in field

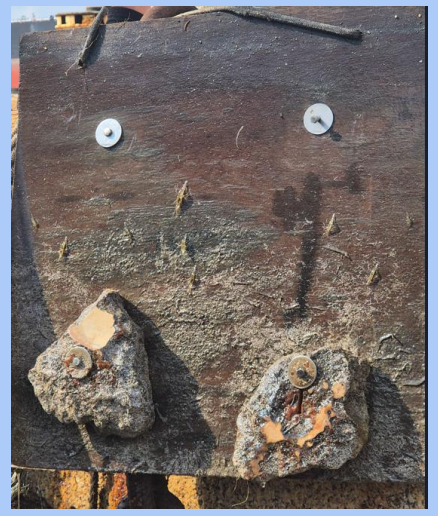
KYSTVERKET
NORWEGIAN COASTAL ADMINISTRATION

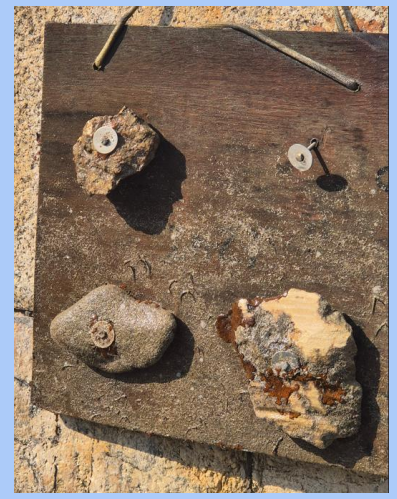
Natural degradation on rocky shore

Malta

T0

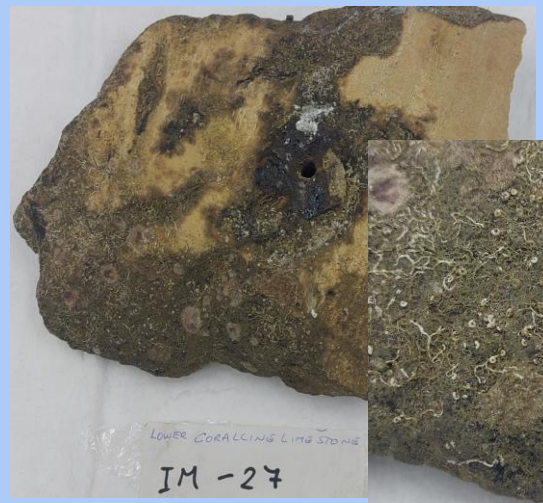
Tf

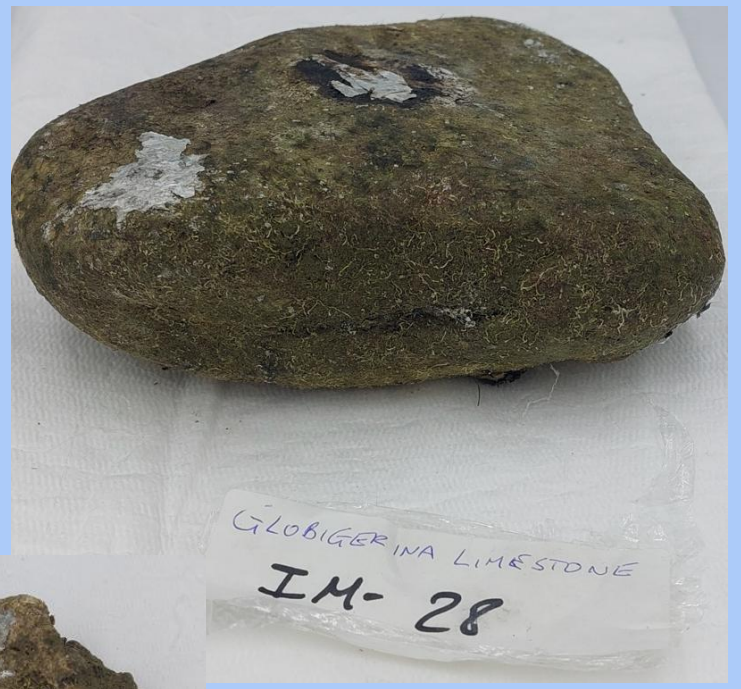


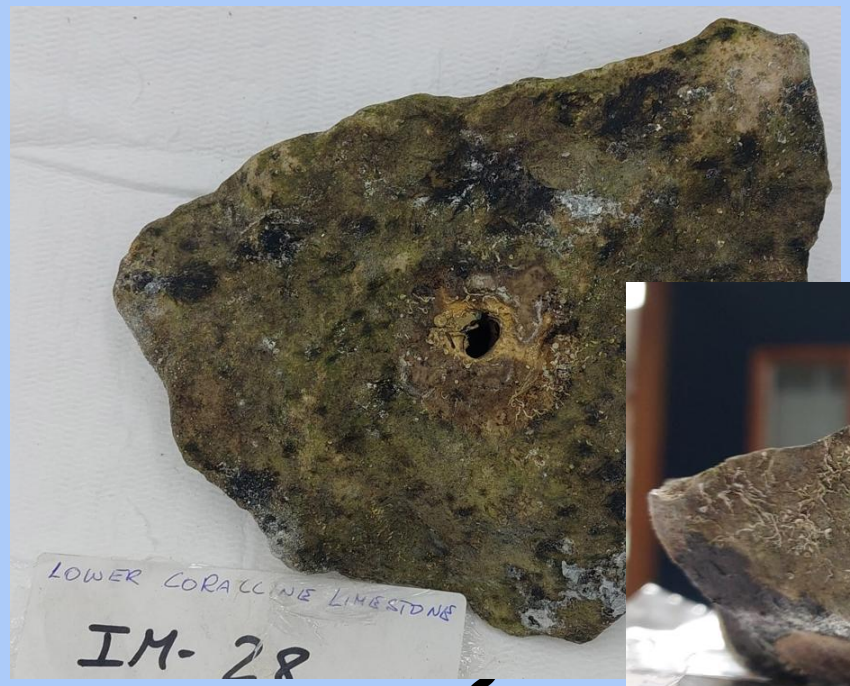


Malta

Natural degradation on rocky shore







Malta

Natural degradation on rocky shore

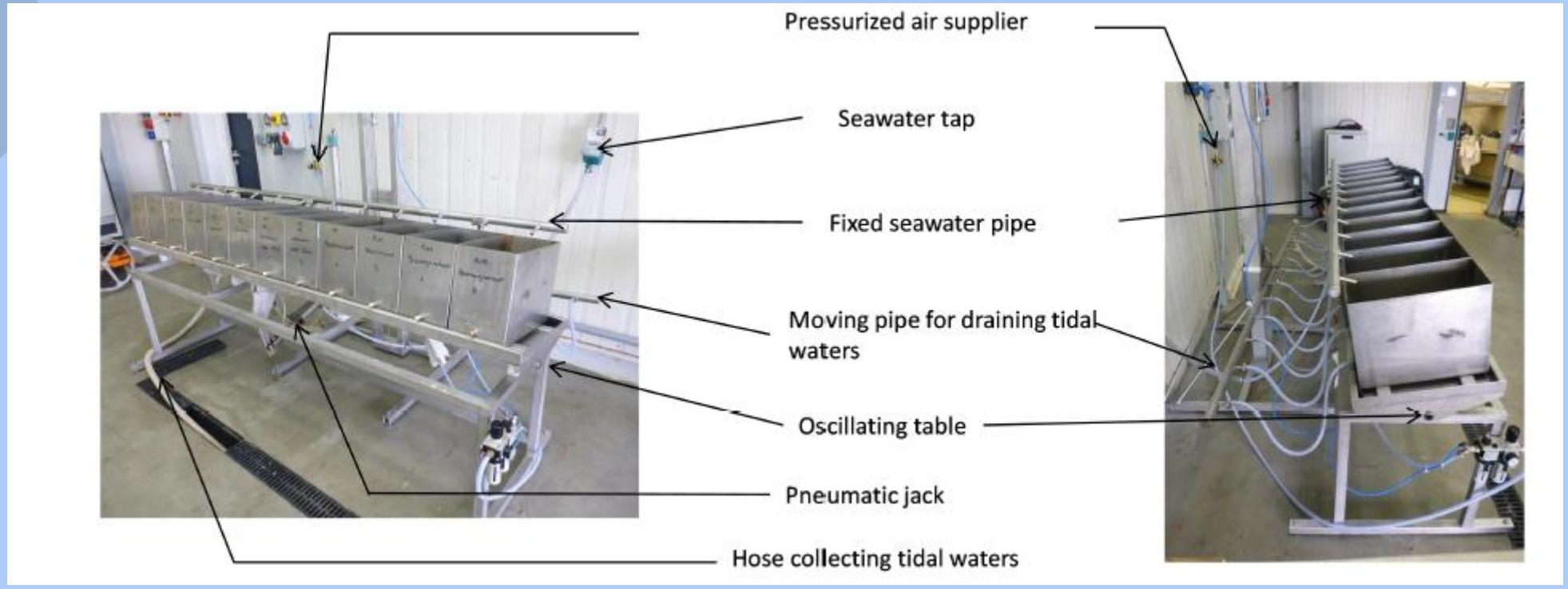
- Difficulty to see remaining oil (for the 3 oils and the 2 rocks)
- No differences between the 3 oils and the 2 rocks
- Rocks covered by organic matter (algae and other material)
- No differences between the top polluted face and the sides

- After ~3 months of exposure traces of LSFOs are hardly visible and colonisation of the polluted rock faces is as intense as the faces not polluted
- Oil extraction for quantification and chemical analysis is in progress

Natural degradation on rocky shore
- Main comments -

- Natural degradation is temperature dependant with higher removal rates in warm environments
- In cold climate, even if signs of oil removal is visible, tiles are still highly coloured. Biota recolonisation was not observed, neither on the polluted tiles, nor 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 are noticed between the oils.
- In warm climate, even after only 3 months of exposure, oil is hardly visible and rocks are all covered with a thick layer of organic matter (oil extraction for quantification and chemical analysis is in progress)

T5.5 – Shoreline response / Interaction with sediments



Shoreline test bench

Interaction with sediments

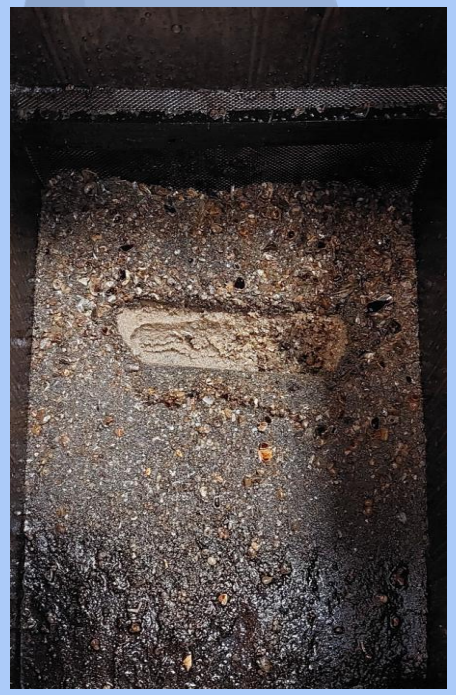
Shoreline Test Bench

- 3 different substrates (2.5 - ~5 kg)
- Tidal cycles (water added)
- Oil poured at 50°C (400 g)

- Oil spilled directly on the sediment (dry and wet)
- **Temperatures (air and water): 20 – 25°C**
- Visual observation

Interaction with sediments

Observations on Sand



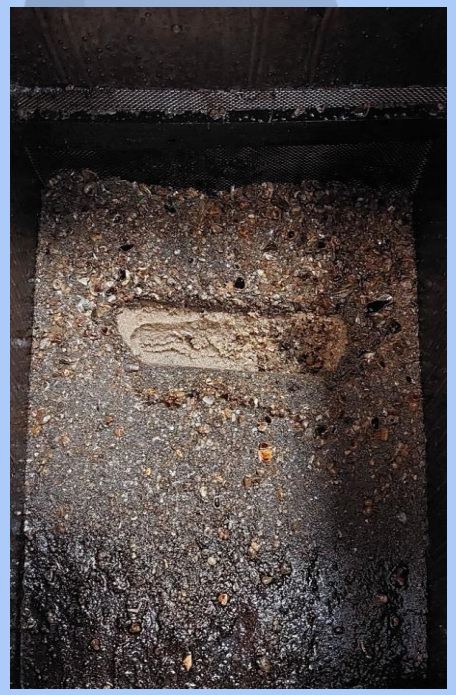
IM-29

IM-28

- 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.

Interaction with sediments

Observations on Sand



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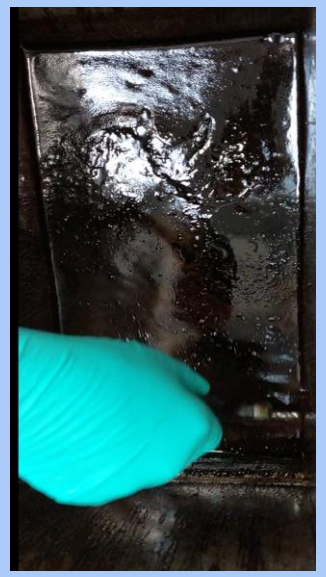

IM-29

IM-28

- Addition of water and agitation of the sediment allow the remobilisation of the oils. Higher energy is needed for oils like IM-28

Interaction with sediments

Observations on Gravel / Pebbles

- 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). Addition of water + manual agitation of the sediment allows a remobilisation of the trapped oil, leaving cleaned sediments.

Response options

- Based on those pilot-scales trials, surfwashing operations 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.
- 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.

imaros$_2$

Cedre

Thank you for your attention