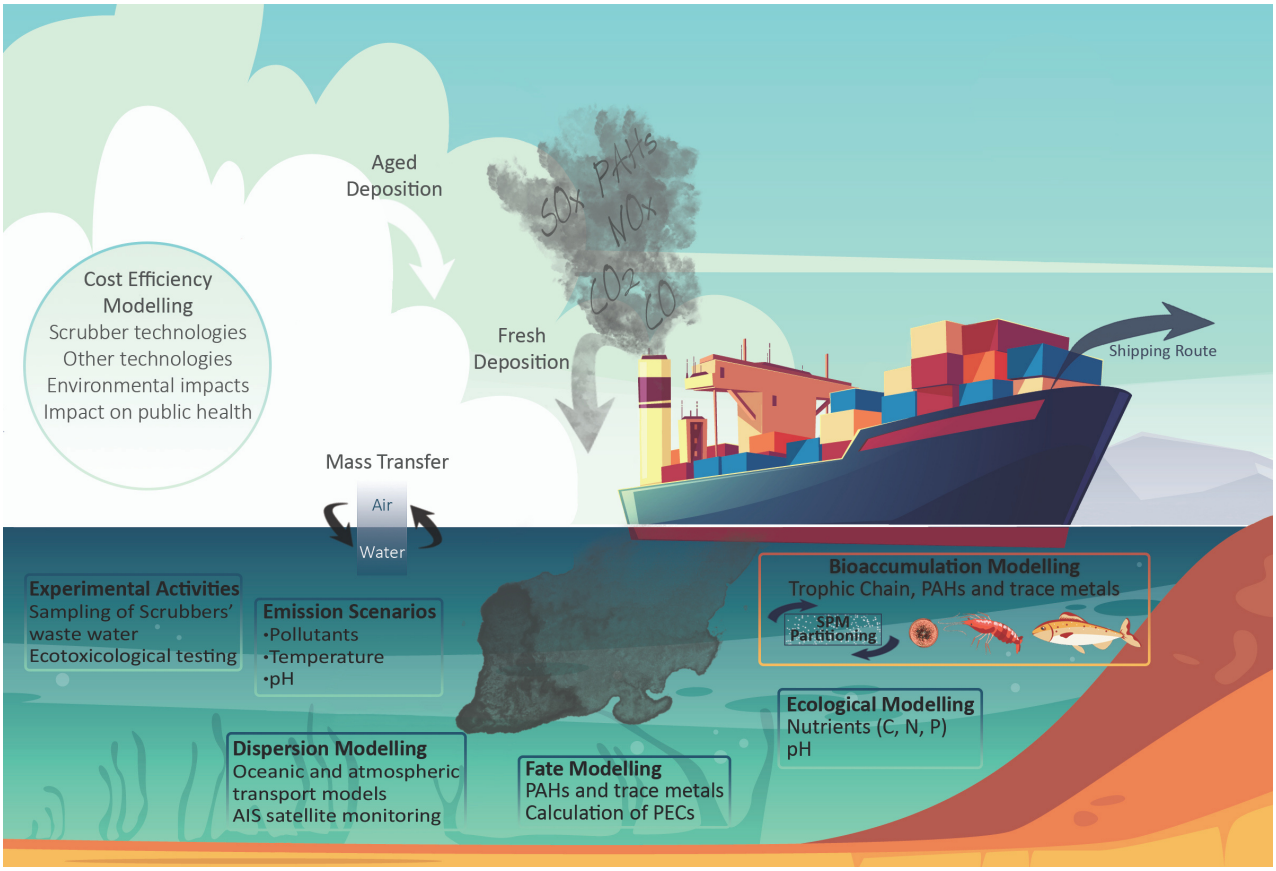
EMERGE

Evaluation, control and Mitigation of the EnviRonmental impacts of shippinG Emissions

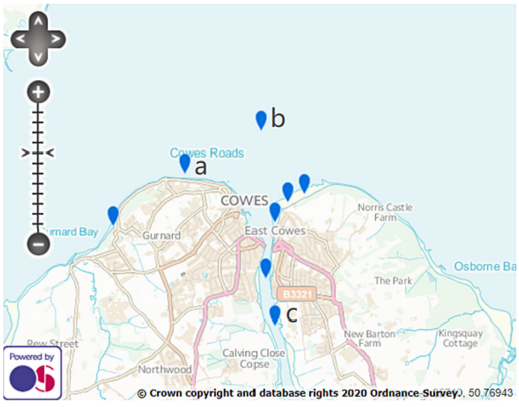


IMPLEMENTATION

The project will include measurements and modelling on actual vessels. Those will focus on abatement techniques and will include emissions to, and concentrations in water, air and marine biota.
A wide spectrum of models will be used, including those for ocean circulation, biogeochemical processes, atmospheric dispersion and the bioaccumulation of pollutants.

The impact of an annual major recreational boating event on water quality in the Solent Strait.

Baseline study work is crucial for studies such as EMERGE since they: i) enable characterization of an area prior to the development of a project and ii) establish its initial environmental status. Historical air and water data has been reviewed from 2000 to 2020 to establish trends in relevant regulations, emissions, concentrations and impacts for the Solent Case Study. The first "baseline paper", which studied the impacts of recreational boating on marine surface water quality during a famous international regatta in the Solent Strait (Cowes Week), has been published:

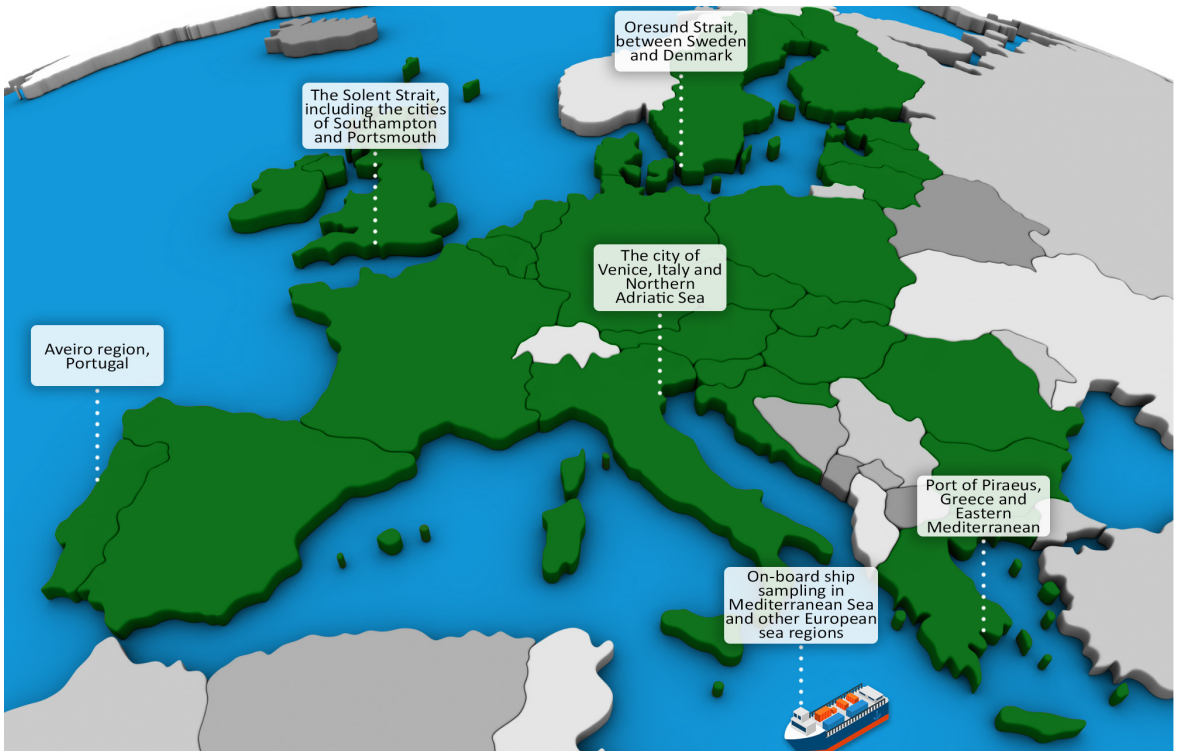


Sample sites around Cowes selected for study; a) Cowes b) Cowes shellfishery c) Medina shellfishery

Xiong, D.; Williams, I.D.; Hudson, M.D.; Osborne, P.E. and Zapata Restrepo, L. (2023). **The impact of an annual major recreational boating event on water quality in the Solent Strait.** Marine Pollution Bulletin, 186, 114450 Read here.

The study showed that sewage discharge from recreational boats is the key contributor to localised faecal contamination of marine surface waters, putting bathers and shellfisheries at risk, and provides crucial context for the regional EMERGE experimental studies.

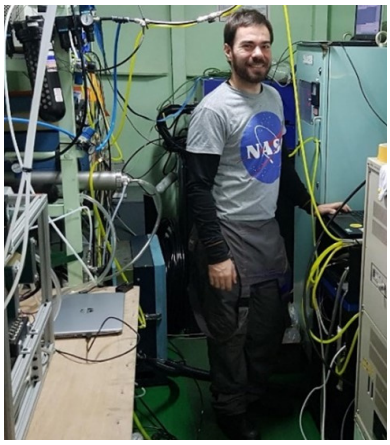
CASE STUDIES, MODELLING AND EXPERIMENTS



Case study map

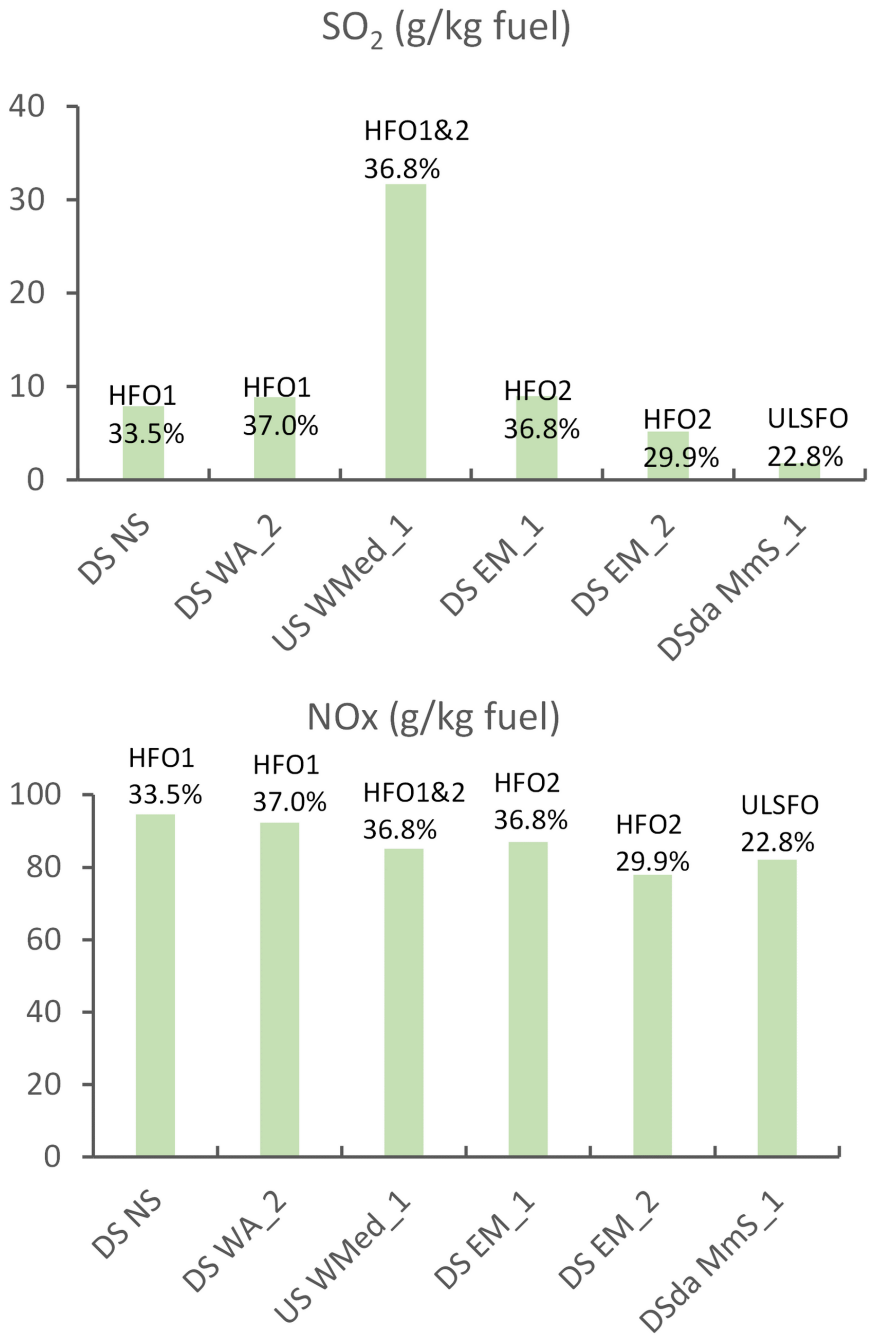
SELECTED OUTCOMES

The on-board measurement campaign in EMERGE was conducted between the 14th to 24th of November 2021 on-board Danaos container vessel Leo C, equipped with open-loop scrubber, during a voyage from Antwerp (Belgium), via Rotterdam (Netherlands) to Gebze (Turkey).



On-board air and water sampling

After completion of the campaign, EMERGE partners focused on processing and analyzing the extensive measurement dataset.
Three types of fuel were tested for emission characterization, as the ship sailed at different geographical regions during the voyage. The fuel effect on emissions was examined using two batches of Heavy Fuel Oil (HFO) with high sulphur content and one batch of Ultra Low Sulphur Fuel Oil (ULSFO), compliant with SECA regulation.
In addition to this, particulate and gaseous measurements were performed upstream and downstream of the scrubber to reveal the effect of the particular emission control technology.
A novel element of the campaign was the first-ever on-board utilization of two thermal treatment instruments, a thermodenuder and a catalytic stripper, to identify solid particles.
Overall results showed decrease of SO2 downstream of the scrubber, while no effect of the scrubber was observed on NOX, CO and THC. PN and PM were found in increased concentrations downstream the scrubber. Particle number size distributions varied between fuel and scrubber effect, while nanoparticles in nucleation mode were found to be the dominant particles downstream of the scrubber.
Detailed results are provided in deliverables D3.1 and D3.2 of the EMERGE project.



Indicative SO2 and NOx emissions factors results

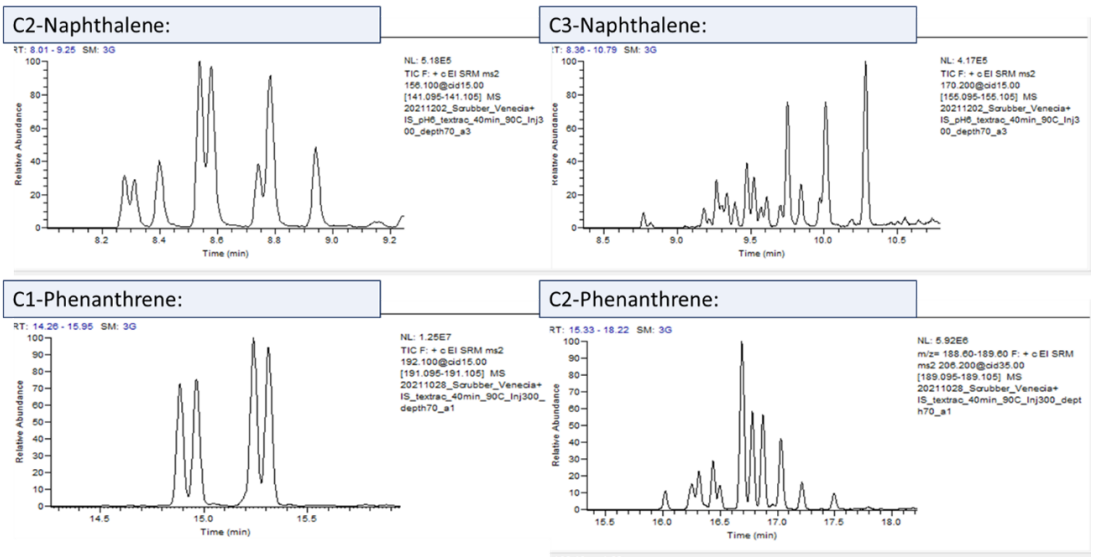
Chemical characterization of waste streams to water from shipping

Work conducted at Catalan Institute for Water Research (ICRA)

A target analytical method to identify the 16 US EPA priority PAHs and 25 alkyl PAHs, representative for different alkyl groups (C1, C2, C3 and C4 compounds) and number of benzene rings has been developed. The method was based on solid phase microextraction followed by gas chromatography and tandem mass spectrometry (SPME-GC-MS/MS) offering advantages of automatization, low sample volumes requirements and possibility to analyse both filtered and non-filtered samples, while providing low limits of detection (LODs) and quantification (LOQ).

The developed method was used to analyse PAHs and alkyl derivatives in scrubber and sea water samples from different case studies, together with metals, along the main shipping routes in Europe. The areas studied include: (i) the Öresund strait, between Denmark and Sweden and (ii) the Saronic Gulf in Greece, and (iii) a mobile on-board case study, at Danaos container vessel Leo C between Antwerp (BE), Rotterdam (NL) and Gebze (Turkey).

Results showed that PAHs and alkyl PAHs were almost not detected in any of the sea waters. However, high concentrations of both the parent and alkyl-derivatives were present in scrubber water simples. For the 16 priority PAHs, naphthalene and phenanthrene were the compounds present at the highest concentrations, followed by fluorene, acenaphthene and pyrene. Regarding the alkyl PAHs, several compounds were detected, being C1, C2 and C3 naphthalene and phenanthrene, and C1 and C2 fluorene, the most relevant in terms of concentration and ubiquity. Zn and Fe were the elements present at the highest concentrations, followed by U, V, Cu, As, and Mn.



Clusters of alkylated PAHs detected in scrubber water

Ecotoxicological effects of waste streams

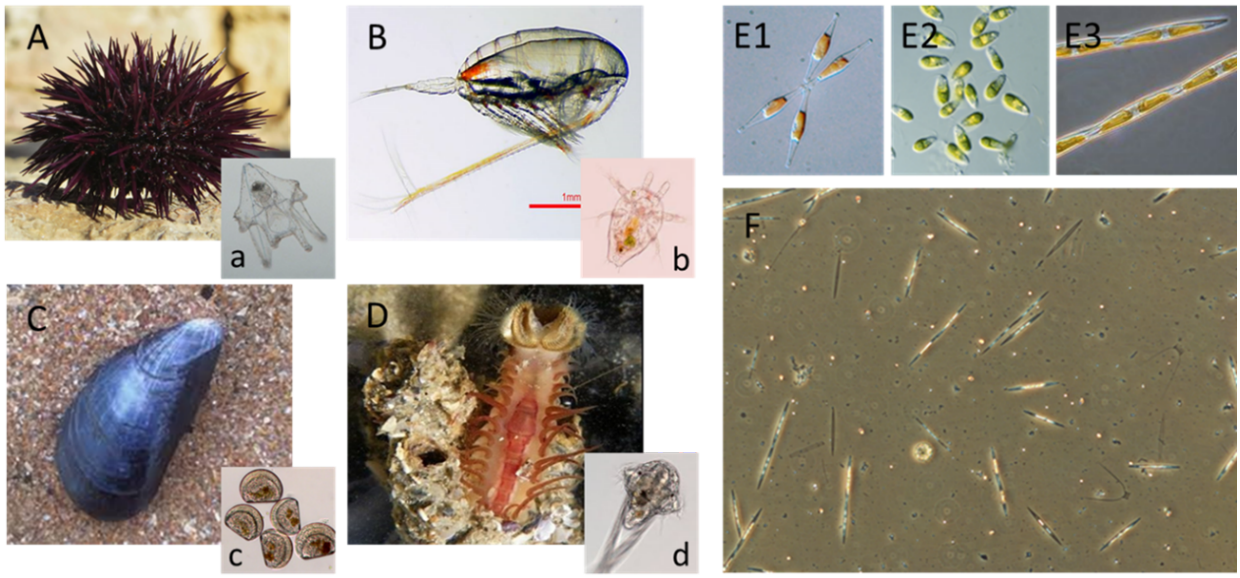
Work conducted at University of Aveiro, Aristotle University of Thessaloniki, University of Venice, University of Southampton and IVL Swedish Environmental Research Institute

Ecotoxicological experiments and tests were conducted to quantify effects of scrubber water on a range of marine organisms, including bacteria, microalgae, various species and life stages of invertebrates as well as on pelagic communities of marine organisms. Experiments were designed to provide new scientific insight into scrubber water toxicity while also providing relevant data fit for risk assessment (i.e., provide LOEC, NOEC, EC10 and EC50 values). Single species tests involved marine algae, marine invertebrates (various life stages), or marine bacteria.

Of these, copepods (Acartia tonsa and Calanus helgolandicus), and phytoplankton (Phaeodactylum tricornutum and Dunaliella tertiolecta) are truly pelagic while sea urchins (Strongylocentrotus droebachiensis, Paracentrotus lividus), polychaetes (Sabellaria alveolata) and blue mussels (Mytilus galloprovincialis, Mytilus edulis) are benthic with planktonic eggs and larvae.

The ecotoxicological data showed that invertebrates are more sensitive to scrubber water than phytoplankton. Some of the early invertebrate life stages also appear much more sensitive to scrubber water than others. Toxic effects of scrubber water were detected at considerably lower concentrations than previously reported.

The large difference in sensitivity to scrubber water between the different measured endpoints that were tested in EMERGE highlights the importance of executing experiments on a variety of species and life stages to identify the sensitive parts of the marine ecosystems.



Images of some species, some of their larvae and planktonic communities used in the ecotoxicological experiments and tests with scrubber water. A: Sea urchin (Paracentrotus lividus, Echinodermata) with pluteus larva (a), B: Copepod (Calanus sp., Crustacea) with nauplius larva (b), C: Blue mussel (Mytilus sp., Mollusca) with veliger larva (c), D: Polychaete (Sabellaria alveolate, Annelida) with trochophore larva (d), E: Microalgae of the species Phaeodactylum tricornutum (E1), Dunaliella tertiolecta (E2) and Pseudo-nitzschia sp. (E3), F: Phytoplankton community dominated by the microalga Pseudo-nitzschia cf. pungens (live and dead – empty cells) in 10% scrubber water (station 11) (micrograph by M. Moustaka).

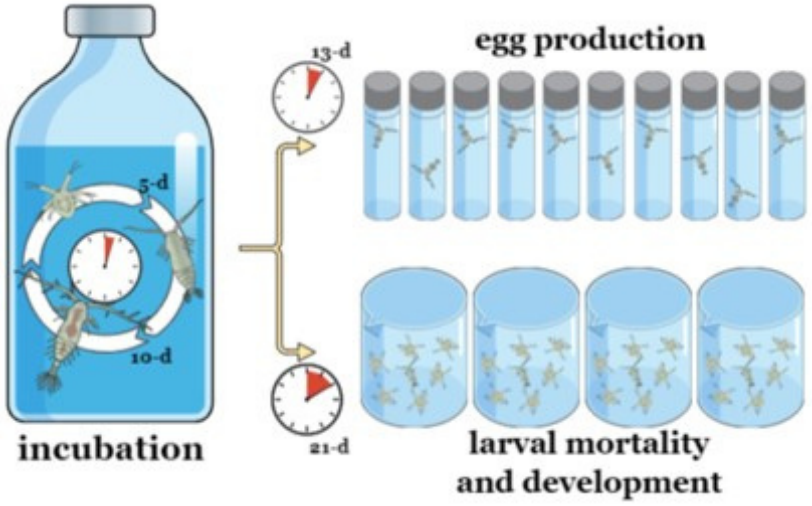
Ecotoxicological experiments for the North Adriatic case study

In the frame of the activities related to the Northern Adriatic case study, a set of ecotoxicological experiments on two types of scrubber water have been successfully completed at the University Ca' Foscari of Venice (Dept. of Environmental Sciences, Informatics and Statistics), with the aim of exploring acute and chronic effects of scrubber effluents on selected planktonic indicators. A sample of scrubber water produced by a pilot scrubber system at the Chalmers University of Technology using seawater collected in the Gulf of Venice was tested using a suite of four tests, namely Microtox test with Aliivibrio fischeri and three different tests on the copepod Acartia tonsa. Then, an enlarged suite of seven bioassays (including also algal growth tests and a larval development test with the bivalve Mytilus galloprovincialis) was used to investigate the effects of a scrubber water sample collected in the Mediterranean during the "Leo C" onboard campaign.

The copepod Acartia tonsa, a planktonic species generally reaching high abundance in estuaries and coastal areas of the Adriatic Sea

The exposure of planktonic indicators to scrubber water proved concentration-dependent effects on most of the explored endpoints. Acute effects on bacteria, algae, and copepods were observed at relatively high concentrations. Conversely, effects on larval stages of mussel and copepods occurred at scrubber water concentrations sensibly lower than acute effects. Results highlighted that exposure to scrubber water significantly affects A. tonsa at very low concentrations (dilution <0.1% scrubber water), mainly by reducing its reproductive success (low egg production) and retarding its larval development. These findings raise concerns about consequences of scrubber water expousre at the population level and potential impacts at higher trophic levels for marine coastal ecosystems.

A paper presenting these results has been recently submitted to a peer-review journal.



Experimental design of the chronic bioassay with A. tonsa (long-term exposure to scrubber water)

Updates on modelling

As a last link of the modelling chain, WP7 is defining data needs and interfaces between different ship discharge, atmospheric transport, marine transport and integrative models (STEAM, SILAM, OpenDrift and GAINS) needed to represent shipping scenarios.

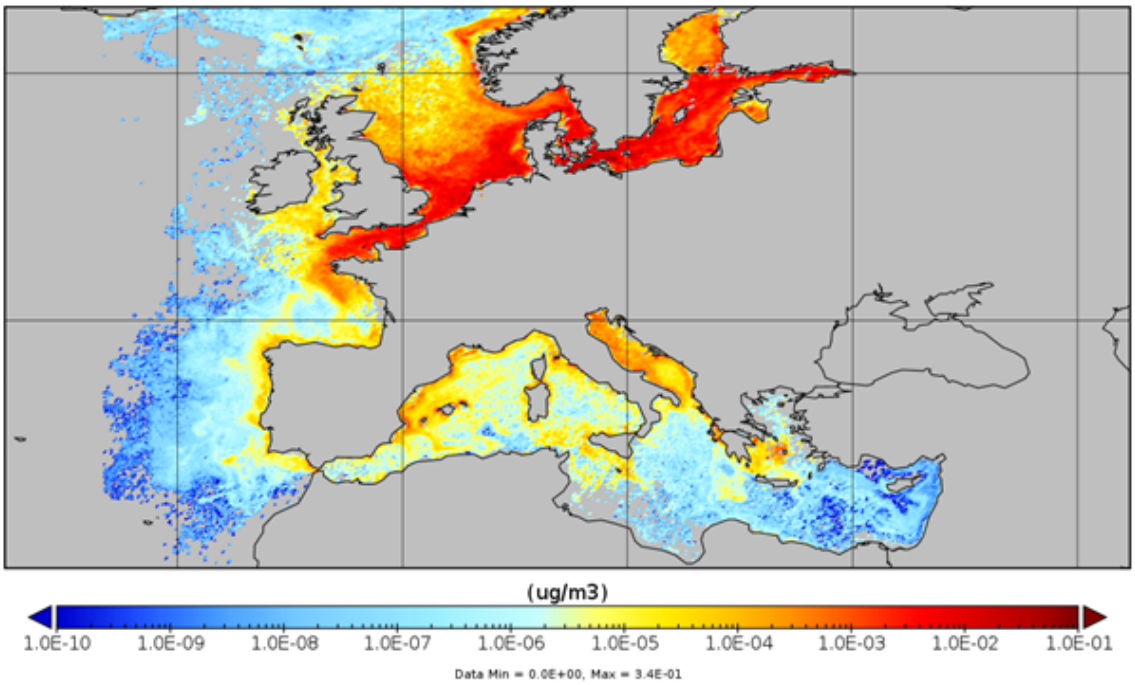
Progress has been made in implementing the impact assessment scheme for the marine environment in GAINS. Together with Chalmers, IIASA developed a critical loads framework using two impact indicators: (i) The critical levels of heavy metals and PAHs as indicators of the aquatic biota toxicity and (ii) the calcite saturation state as an indicator of ocean acidification. These impact indicators can be quantified in three steps: (i) characterizing area and derivation of maximum permissible concentration/load per grid cell, (ii) determining loads, specifically those from ship discharges (from coupling the STEAM and OpenDrift models to estimate concentrations per grid cell) and (iii) estimating potential exceedance of critical levels.

Preliminary results applied to the Karlshamn-Klaipeda shipping lane demonstrate that (i) ambient concentrations of benzo[a]pyrene already exceed critical levels for parts of the area, and (ii) open loop scrubber discharges modelled for 2018 cause some additional exceedance for benzo[a]pyrene in the study area.

Water modelling

ChemicalDrift, a new Lagrangian model for transport and fate of chemicals in the aquatic environment, has been developed by the Norwegian Meteorological Institute in collaboration with Ca' Foscari as a contribution to EMERGE (Aghito et al., 2022). The model is implemented as a new module and is fully integrated within the open-source framework OpenDrift, in order to combine the newly implemented chemical processes with the framework's advanced hydrodynamical capabilities. (Introduction to OpenDrift).

The modelled chemical processes include a dynamic partitioning between the different phases that pollutants can be associated to in the aquatic environment, chemical removal by degradation and volatilization, as well as sedimentation and
resuspension of chemicals. Target chemicals are modelled as Lagrangian elements that are transported and exposed to changing environmental conditions as, e.g., temperature and salinity. ChemicalDrift is used to provide concentrations of selected toxic compounds on regional and European scale for a baseline year (2018) and future scenarios.



Daily mean concentration of dissolved phenanthrene after one year of direct emissions from open-loop scrubbers (January-December 2018) as simulated by ChemicalDrift with ocean forcing from the EU Copernicus Marine Environmental Service (CMEMS) and STEAM.

Aghito, M., Calgaro, L., Dagestad, K.-F., Ferrarin, C., Marcomini, A., Breivik, Ø., and Hole, L. R.: ***ChemicalDrift 1.0: an open-source Lagrangian chemical fate and transport model for organic aquatic pollutants****, Geosci. Model Dev. Discuss. [preprint], in review, 2022. Read here.*

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