Fraunhofer IFAM

Cleaning technologies as a complementary measure for hull performance management

Dorothea Stübing & Tim Heusinger von Waldegge

01

Motivation and background

Why is cleaning receiving more and more attention?

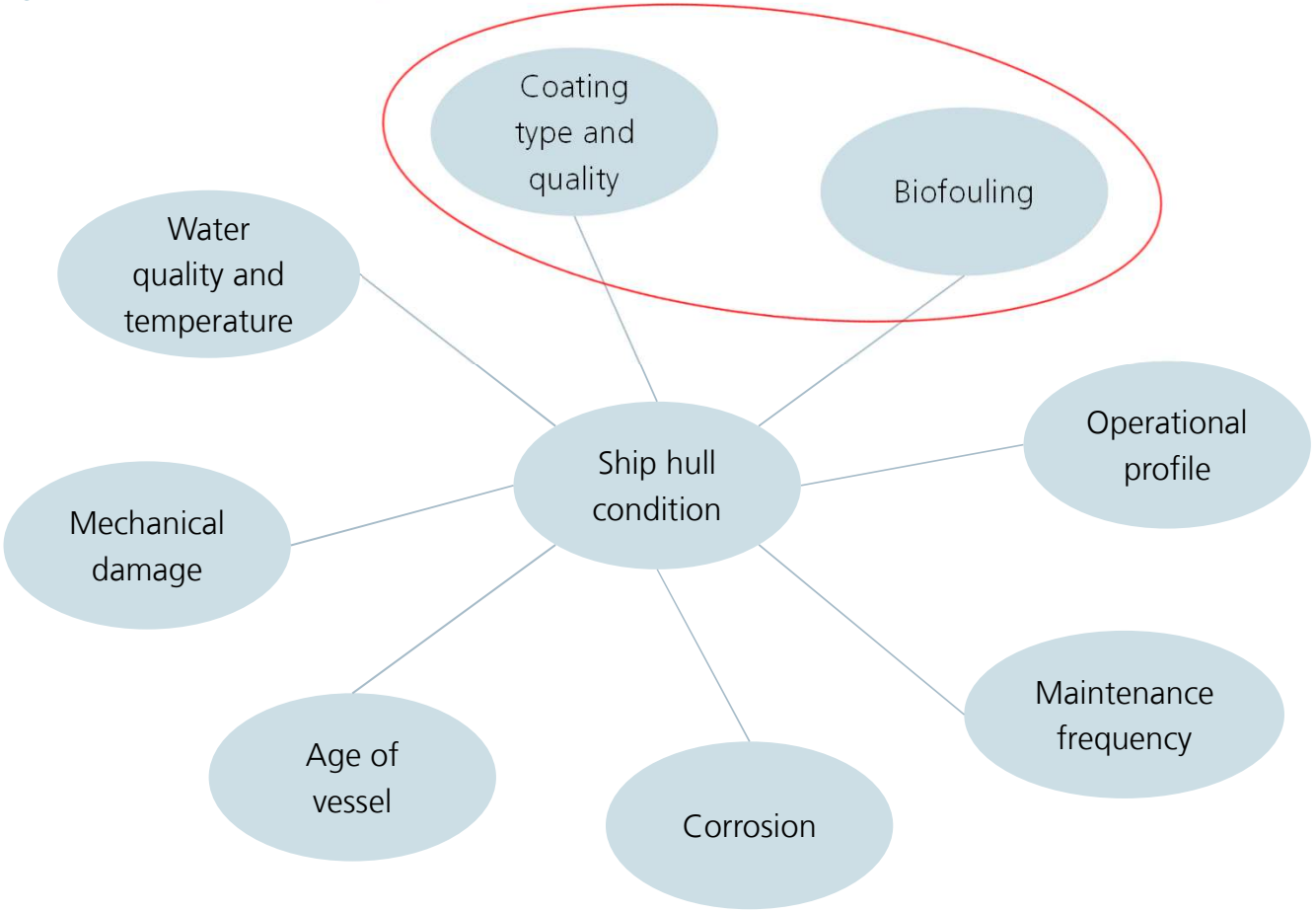
Ship hull management – indispensable and complex

Multifactorial relevance

- Fuel efficiency: A clean, well-maintained hull reduces drag and significantly lowers fuel consumption
- Operational costs: Lower fuel use and reduced maintenance needs cut overall operating expenses
- Environmental impact: Minimizing biofouling and drag reduces greenhouse gas emissions and the spread of invasive species
- Safety: Regular hull inspections help detect structural damage, corrosion, or cracks early, preventing accidents
- Regulatory compliance: Ships must meet international standards (IMO, class societies) for hull condition and anti-fouling measures
- Performance: A smooth hull improves speed, maneuverability, and overall vessel performance
- Asset value: Proper hull management extends the vessel's lifespan and preserves resale value

Ship hull management – indispensable and complex

Factors influencing ship hull condition



The biofouling challenge

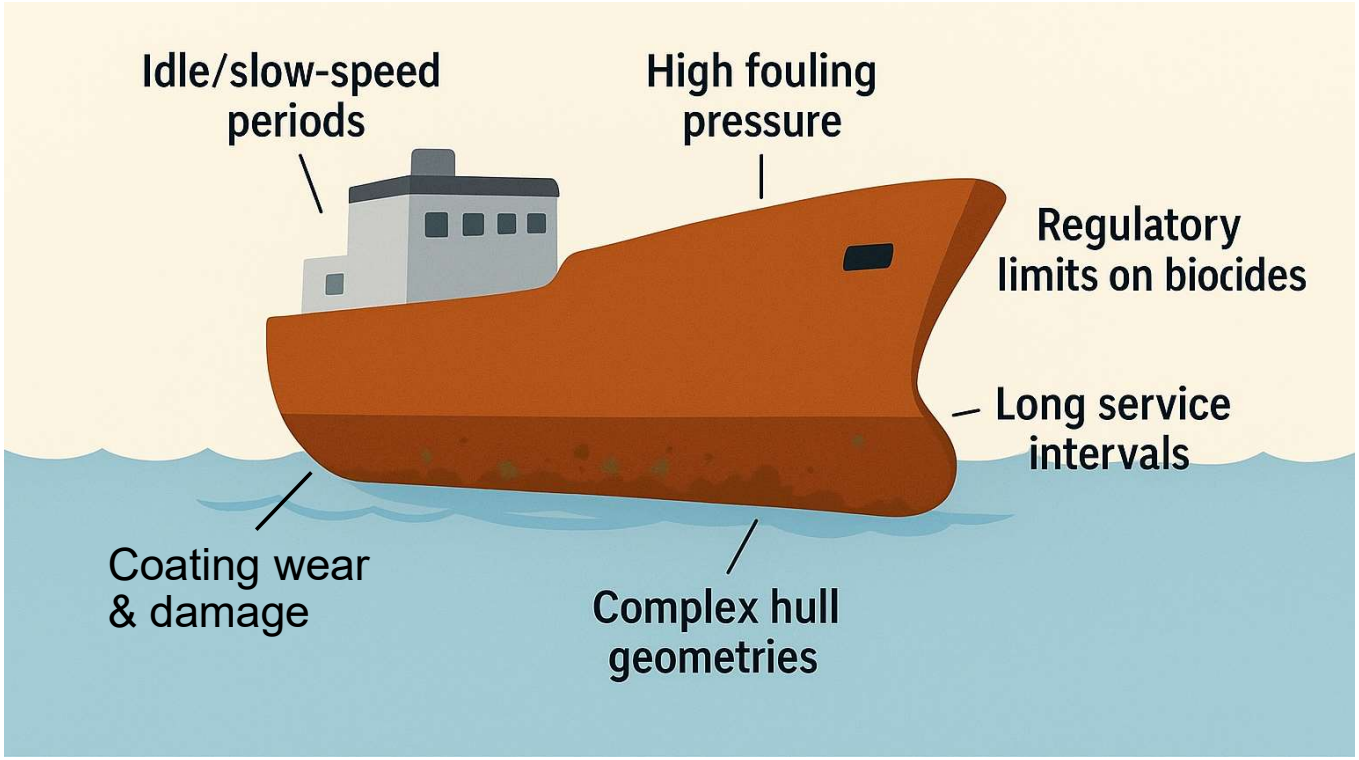
… and how to tackle it

Biofouling prevention is priority aim → selection of appropriate antifouling or fouling release coating system taking into consideration:

- Trading routes & water conditions → temperature, salinity, and nutrient levels influence fouling pressure
- Vessel operating profile → typical speed, time in port, idle periods, and frequency of voyages affect coating performance
- Fouling pressure → regions with high biological activity (tropical waters, estuaries) require stronger antifouling protection
- Type of coating technology → self-polishing copolymer (SPC), fouling-release silicone, hybrid systems, or biocide-free solutions
- Fuel efficiency goals → coating smoothness and hydrodynamic properties directly influence drag and fuel consumption
- Environmental & regulatory compliance → restrictions on specific biocides (e.g., copper regulations in some regions)

Cleaning as complementary measure for hull performance management

Factors negatively affecting the performance of protective coatings



02

In-water cleaning technologies

Brief overview

In-water cleaning technologies

Different methods and platforms

Platforms

- Diver-operated mechanical cleaning
- ROV/semi-autonomous solutions
- AUV-based systems

Methods

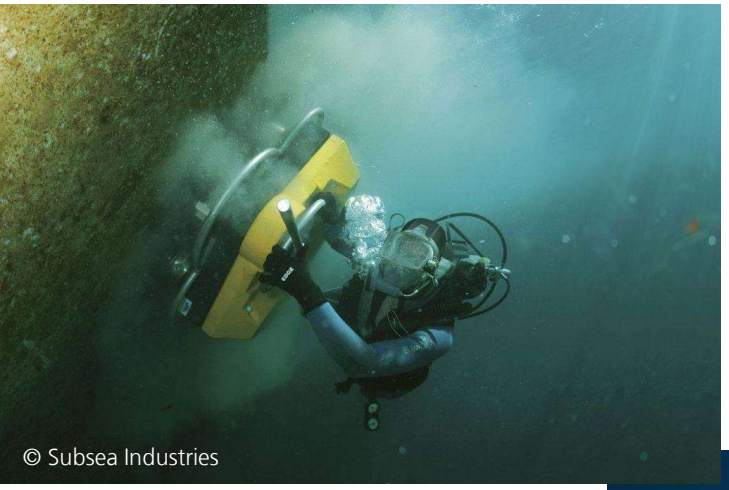
- Powered brushes (rotating)
- Waterjet / cavitation
- Ultrasonics
- Laser

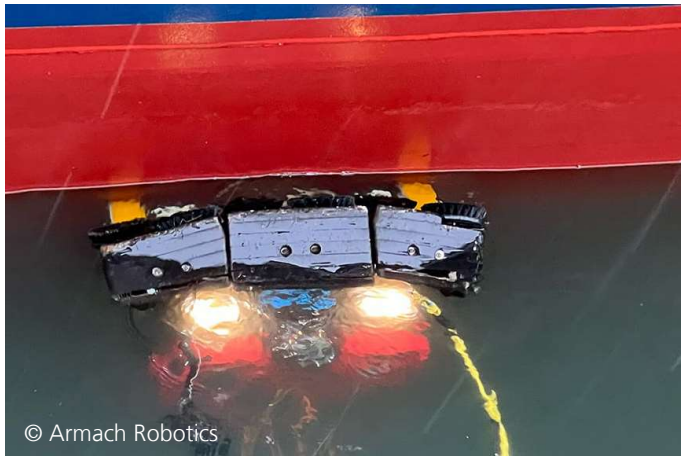
Schemes

- Reactive (removal of attached macrofouling)
- Pro-active / grooming (removal of biofilm/slime)

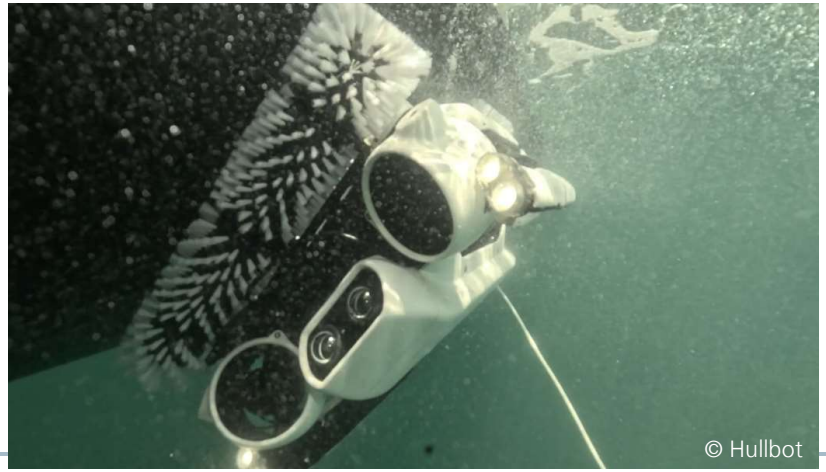
Brush-based cleaning – commercial solutions

Diver-, ROV- & AUV-based technologies


© Subsea Industries


© Armach Robotics

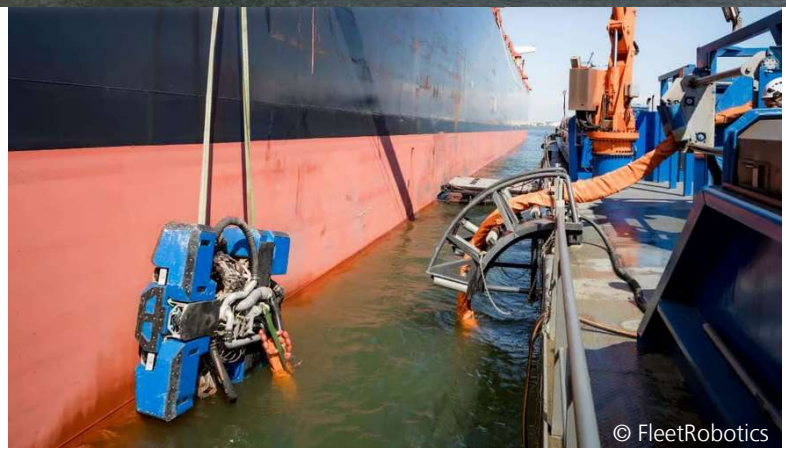

© Jotun


© Hullbot

Fraunhofer IFAM

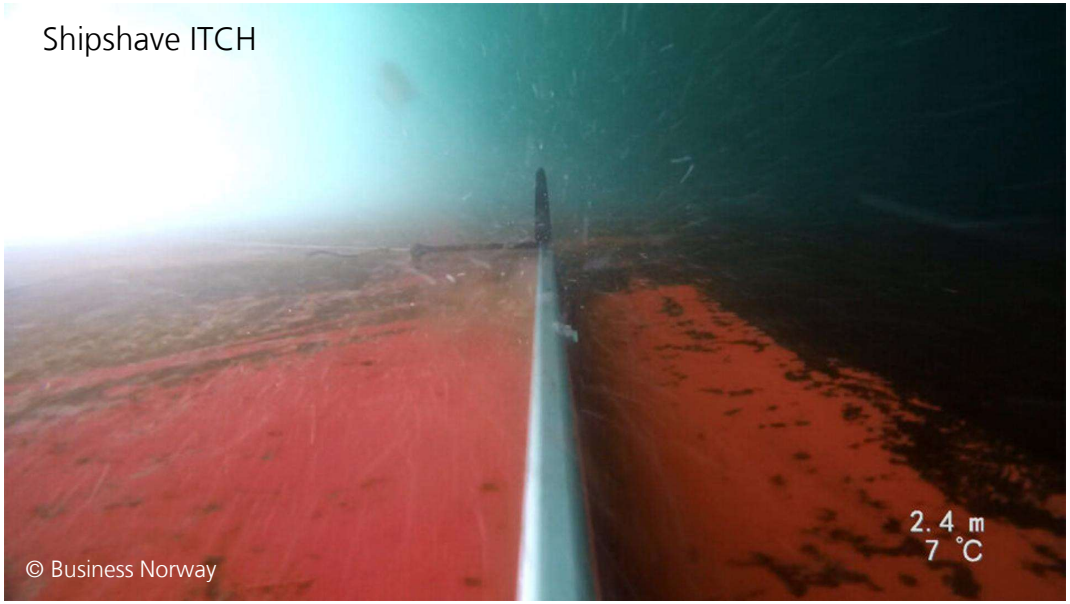
Waterjet cleaning

Diver- & ROV-based

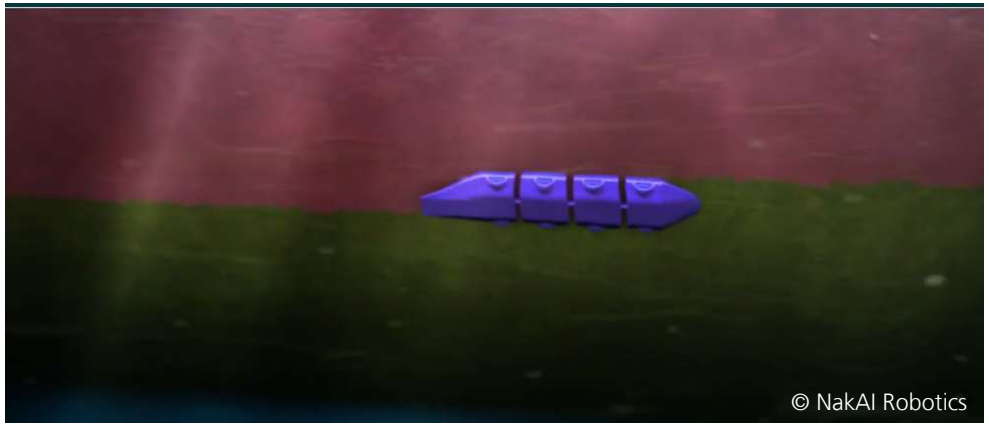


In-transit cleaning – emerging technology

Commercially available



Pre-commercial



Technology requirements

Objective: Continuous high cleaning efficiency without causing coating damage and wear

- Brush cleaning:
  - Brush type (bristle softness, orientation, density) → efficient removal of attached biofouling while avoiding entrapment of (calcareous) biofouling
  - Pressure control
- Waterjet cleaning:
  - Water pressure, jetting angle, nozzle diameter and distance to hull surface
- Waste management:
  - multistage waste capture and filtration and effluent treatment are critical for regulatory compliance and environmental protection

03

Cleaning and its impact on coating condition

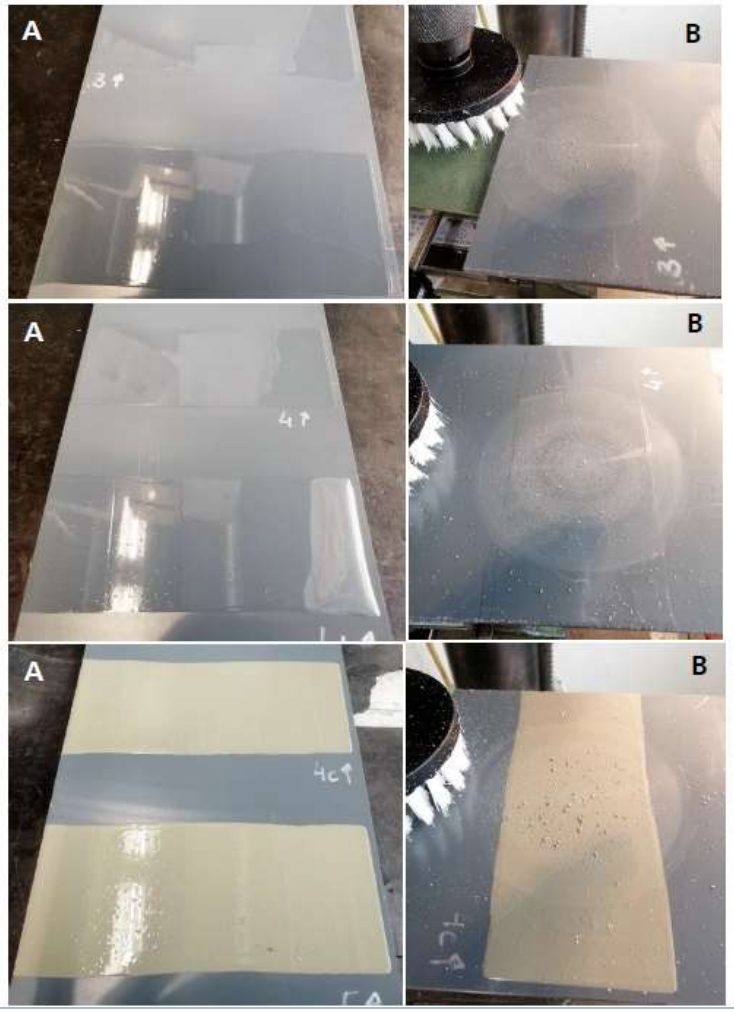
Own projects and results, literature findings

Impact of cleaning on coating condition

Investigations from the ROBUST project

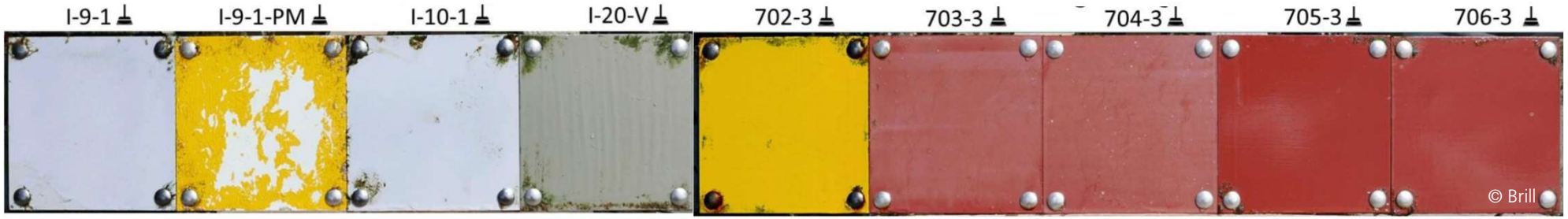
- Laboratory brush tests simulating extended cleaning over coating lifetime

- Investigation of mechanical stability of different coatings (PDMS, PU, epoxy)
- Standardised conditions with adjustable rotation speed, pressure, and test duration
- Changeable brushes with different hardness
- Post-test coating characterisation (surface roughness, optical microscopy, contact angle, …)



In-water cleaning efficiency and impact on coating

Investigations from the ROBUST project – rotating brush



In-water cleaning efficiency and impact on coating

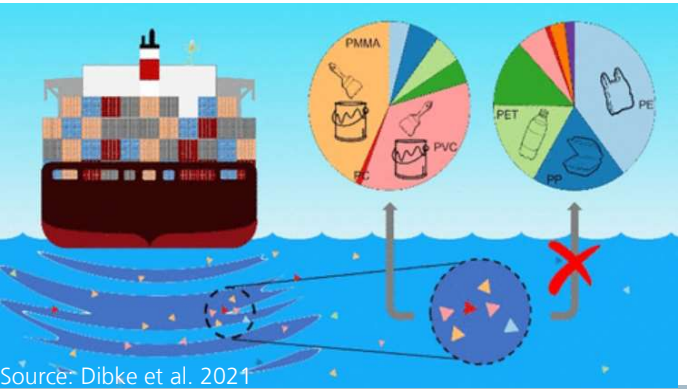
Investigations from the ROBUST project – high-pressure water jet

Development of SPCs and cleaning-resistant biodegradabe coatings

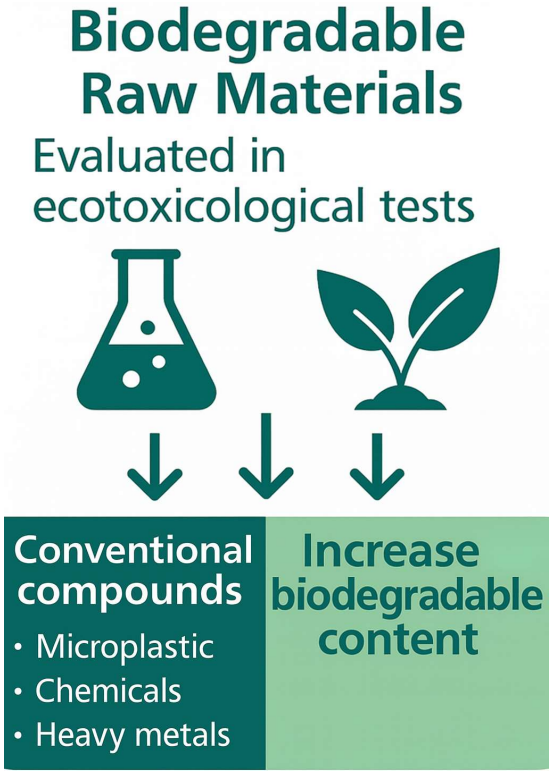
The BioSHIP project

Motivation: reduce the release of persistent microplastics from antifouling coatings into the environment

- Synthesis of new biodegradable additives and formulation of coatings based on biodegradable binder components
- Ecotoxicity and biological degradability tests with eluates and eroded particles
- Biofouling tests (static and dynamic) in different geographical regions to investigate fouling control performance
- Cleaning trials for assessing mechanical stability



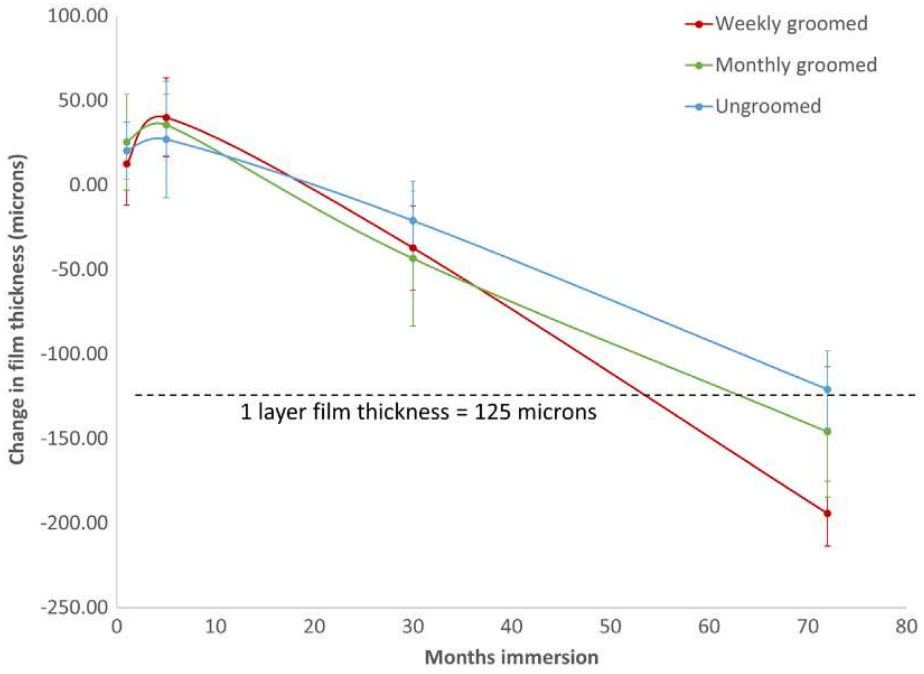
Source: Dibke et al. 2021

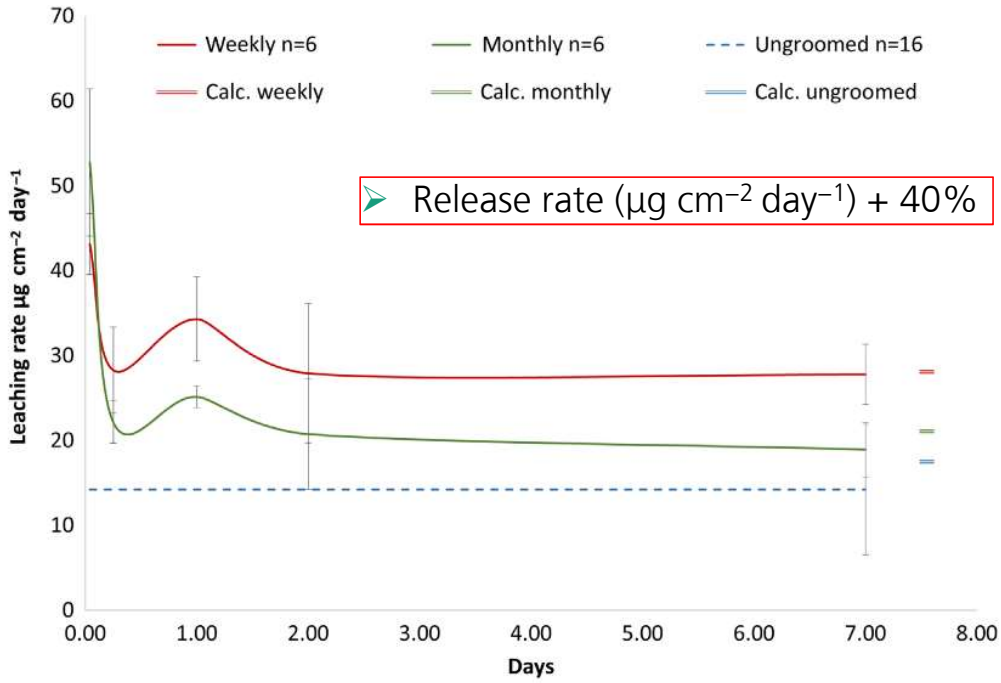


Impact on coating condition

Selected literature results (transparent minimal-impact approach)

- SPCs: Dry film thickness loss and copper release rate increased with grooming (Tribou & Swain 2017)





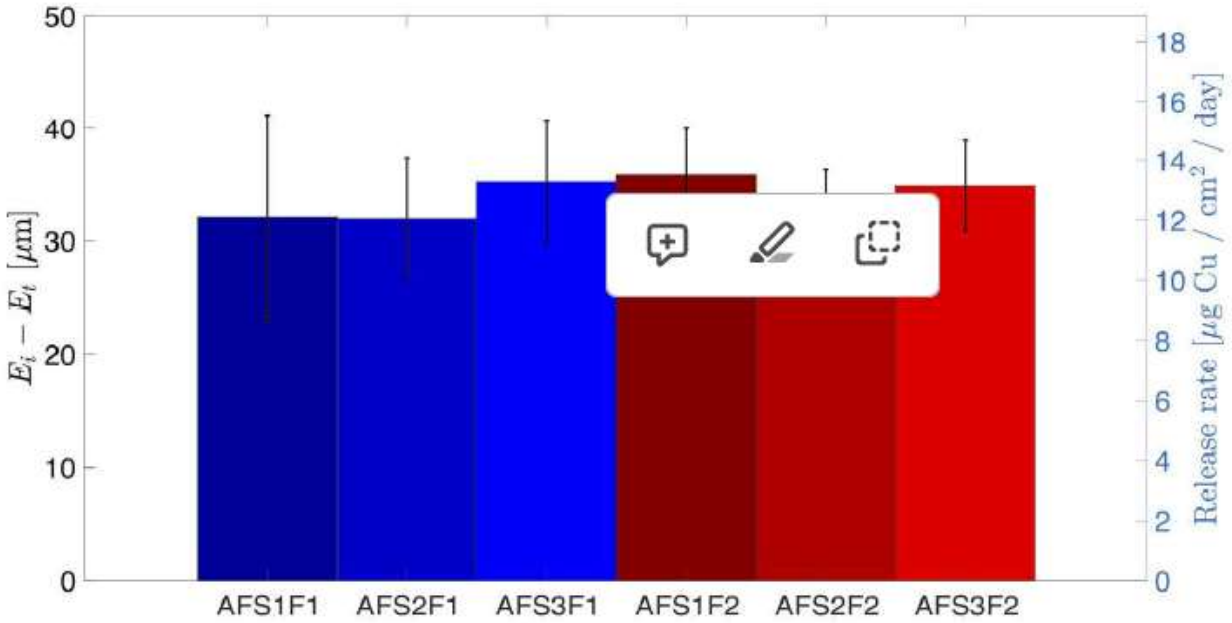
➢ Release rate (µg cm^{-2} day^{-1}) + 40%

Fraunhofer IFAM

No impact on coating condition

Self-polishing copolymers and fouling release coatings

- Mild waterjet cleaning did not adversely affect coating condition and wear (Oliveira & Grenhag 2020)



- No difference between monthly and bimonthly cleaned samples
- No values for uncleaned reference
- Tenacious biofilm may have lead to lower polishing rates

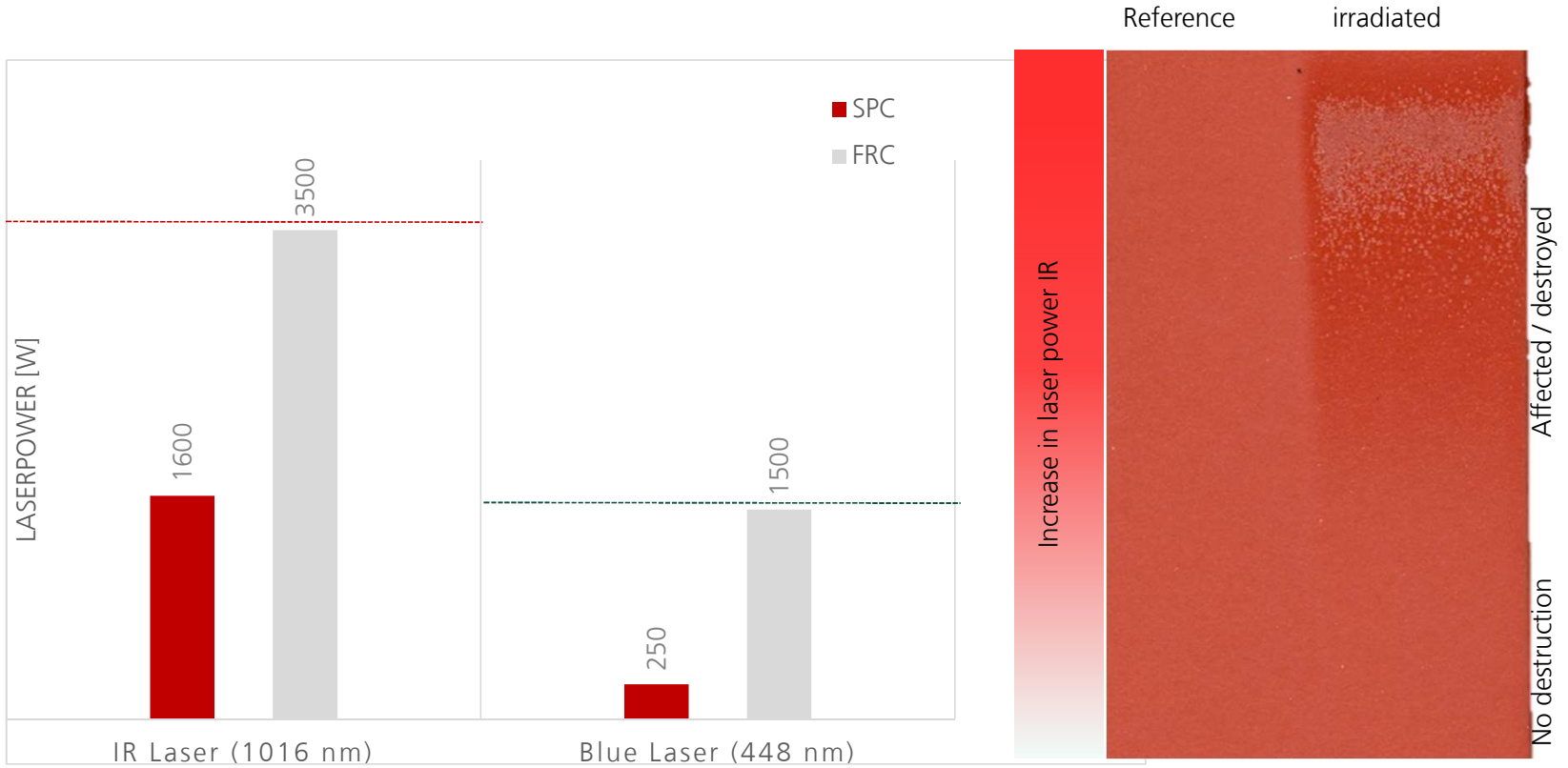
In-water cleaning by blue laser

The FoulLas projects – development and demonstration of an underwater laser-based cleaning technology

- Laser beam lethally damages biofouling organisms
- Damaged biofouling gradually detaches from the surface by flow-induced shear
- High transmission of blue laser (448 nm) in water -> high distance tolerance
- Contactless method: no mechanical interaction with coating surface
- No waste
- No risk of introducing invasive species

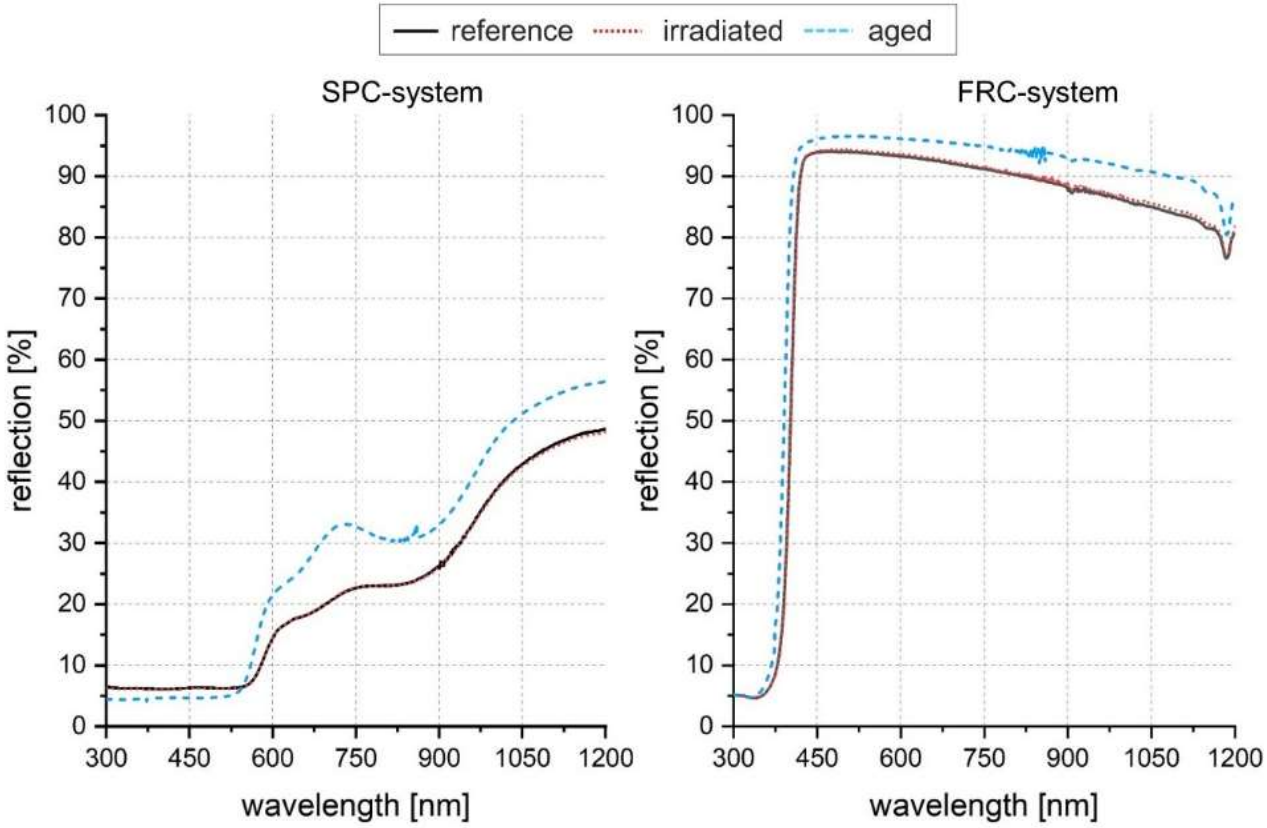
FoulLas – underwater laser-based cleaning of biofouling

Determination of damage threshold of different coatings



FoulLas – underwater laser-based cleaning of biofouling

Reflection properties determine laser tolerance

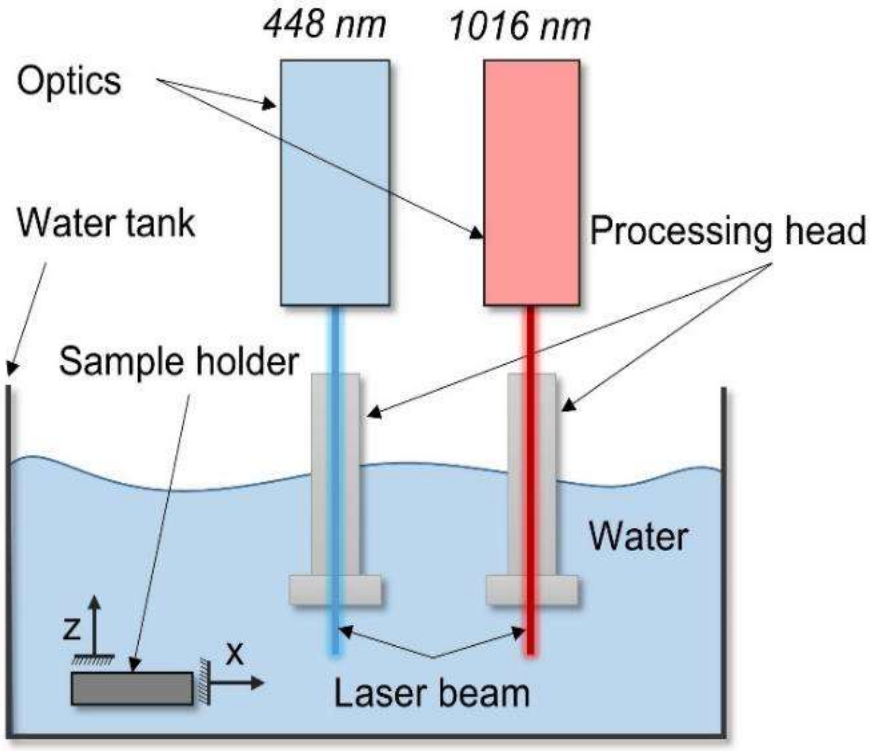


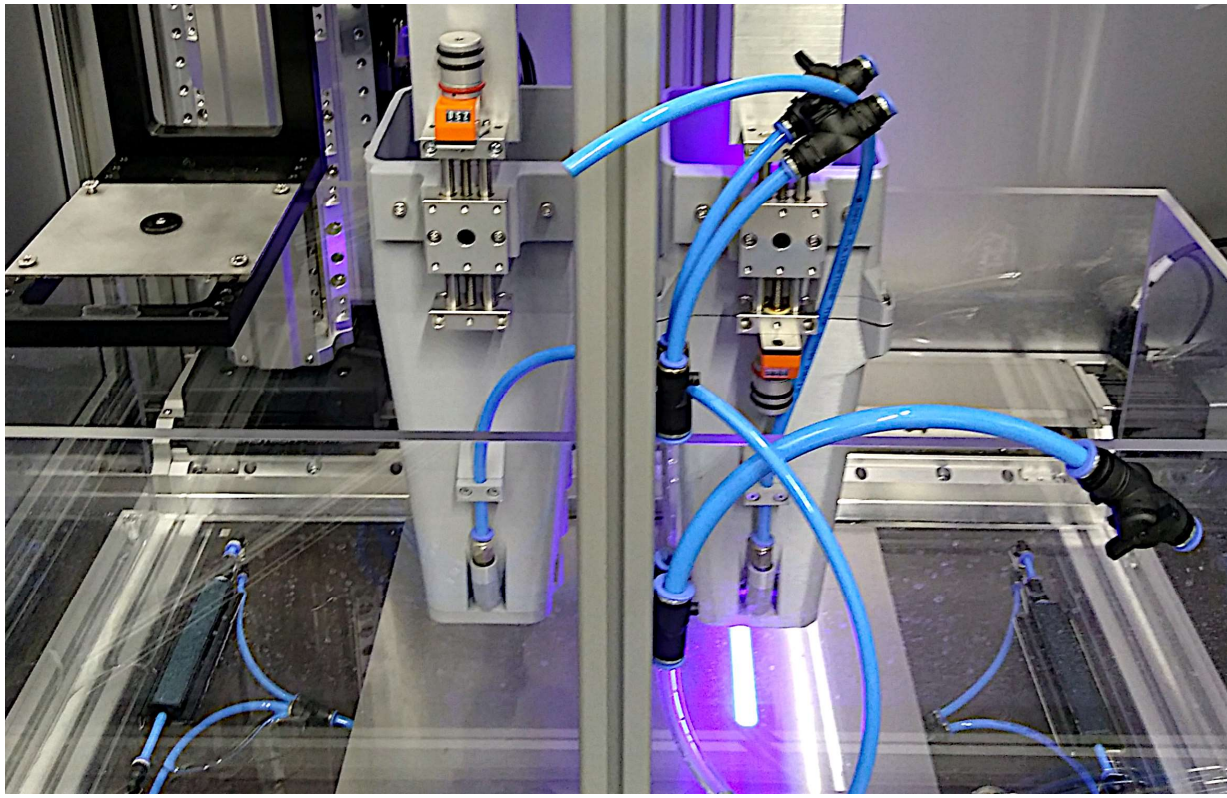
Comparison of reflection properties:

- SPC: colour: dark red
- FRC: colour: white, right

FoulLas – underwater laser-based cleaning of biofouling

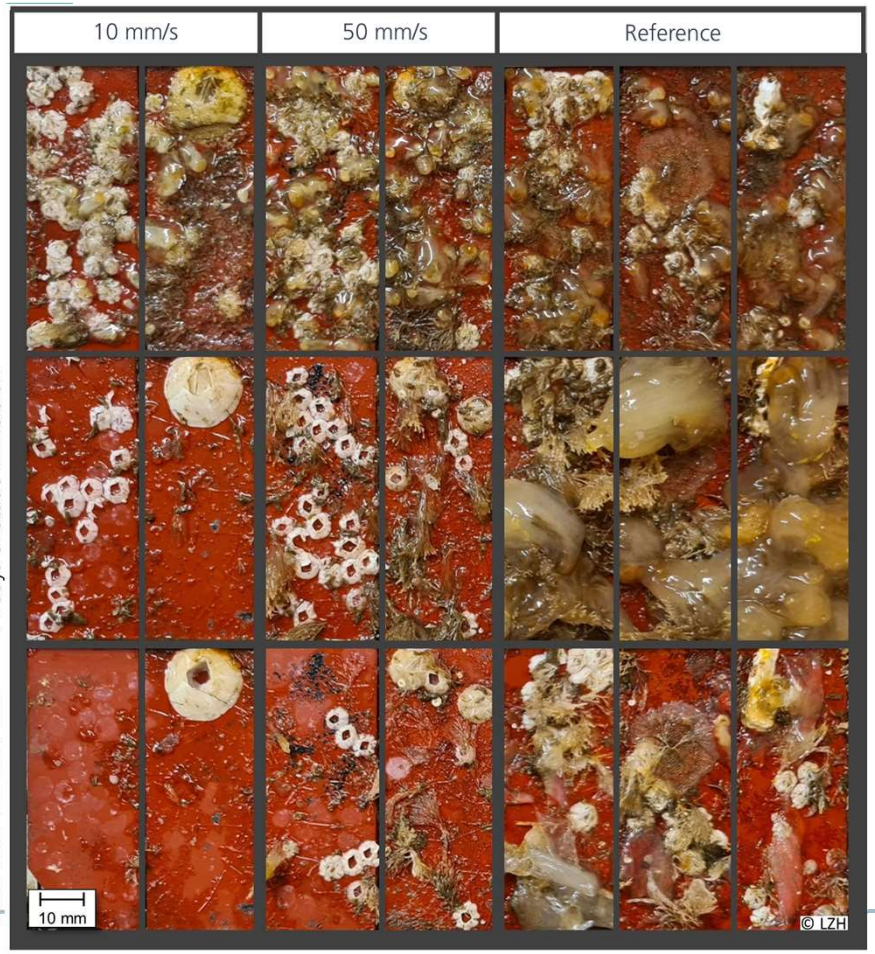
Functional laser demonstrator





FoulLas – underwater laser-based cleaning of biofouling

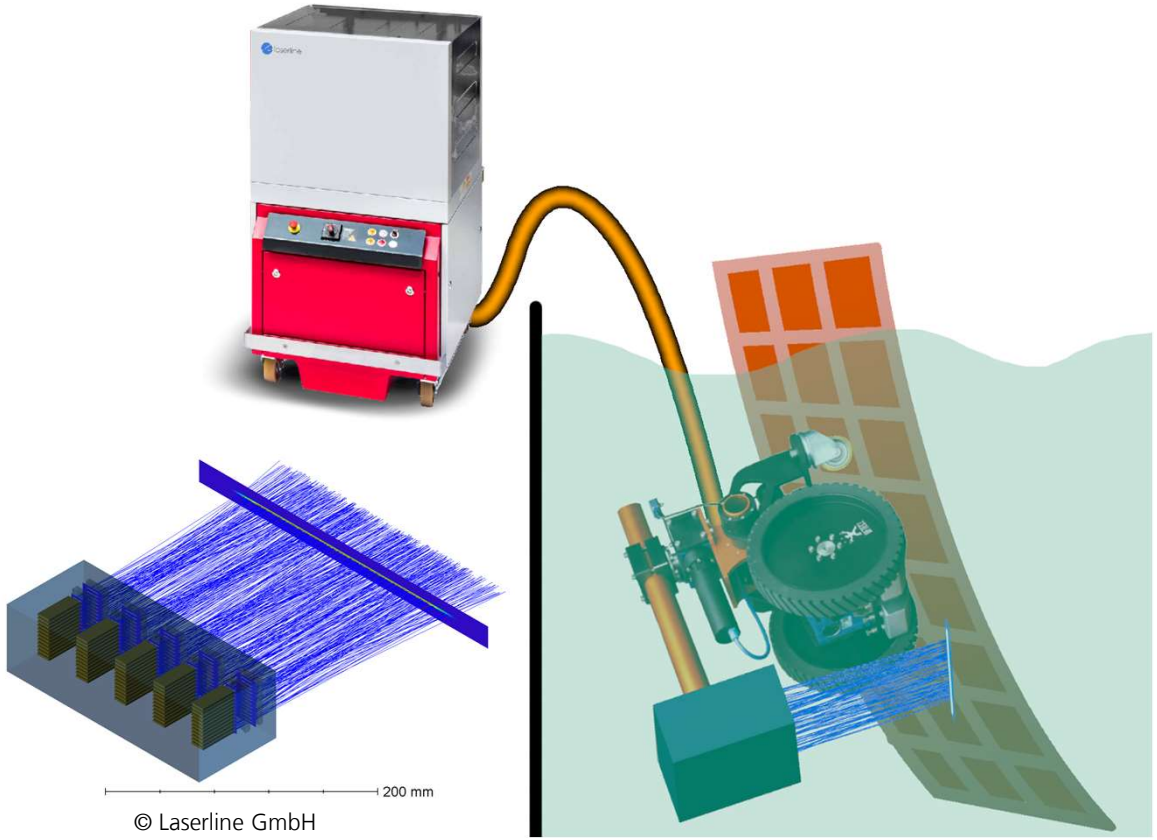
Cleaning results at different process velocities



- Effective lethal damage even to advanced macrofouling organisms and at lower irradiation doses
- Subsequent disintegration of adhesive compounds leads to detachment even under static conditions
- Recolonization slowed down
- Subjection to turbulent shear flow enhances fouling release

FoulLas2 – from lab to field

Upscaling and ROV-based cleaning device



© Laserline GmbH

- Optimization of laser source for increased area output and cleaning speed
- Laser safety
- Magnet crawler for semi-autonomous underwater operation
- Compliance with regulations and documentation
- Establishment of an underwater simulation testbed
- Laser process control for the integration of laser and crawler

04

Summary and conclusions

Balancing cleaning efficiency and impact on coating quality

- The lower the cleaning force the lower the impact on coating quality and wear
- Lower cleaning forces require regular, ideally pro-active cleaning
- At high biofouling pressure, coatings with poor biofouling resistance may require a very high cleaning frequency
- Trade-off between mechanical robustness and biofouling resistance

Summary and conclusions

- Hull surface quality is the key to shipping efficiency
- Cleaning is a proven measure to optimize hull performance in between coating maintenance cycles and seems to become an integral element in the hull performance management toolbox
- Many emerging in-water cleaning services, in-transit cleaning
- Different technologies with specific advantages and disadvantages – chose the right product for the right use case
- Impact on coatings can be minimized by pro-active gentle cleaning/grooming -> importance to not miss the right time -> requires good knowledge on biofouling pressure and hull condition
- Synchronous development of coating and appropriate cleaning technology

Thank you

Part of the work was funded by the Federal Ministry for Economic Affairs and Climate Action/Energy (BMWK/BMWE) in the projects "ROBUST"(03SX490), "FoulLas" (03SX489), "FoulLas² (03SX597), BioSHIP (03SX625). The authors would like to express their sincere thanks to the funding agencies, research partners and companies involved for their committed and productive cooperation and support.

Contact

Dr. Dorothea Stübing
Fraunhofer IFAM
Antimicrobial coatings and biofouling control
Tel. +49 151 59092836
dorothea stuebing@ifam.fraunhofer.de