# 1st Port In-Water Cleaning Conference

# PortPIC'20

**Hamburg, 14-15 September 2020**

Edited by Volker Bertram

**Sponsored by**

www.jotun.com

tutech.de

www.hullwiper.co

www.hasytec.com

www.c-leanship.com

www.akzonobel.com

www.idealship.de

www.fleetcleaner.com

# Index

# A Short History of Hull Cleaning and What's Next

**Simon Doran**, HullWiper Ltd, Dubai/United Arab Emirates, simon.doran@hullwiper.co

**Abstract**

*This paper offers an overview of hull cleaning from the its beginnings right up to present and alternative approaches to hull cleaning. Remotely Operated Vehicle (ROV) hull cleaning is becoming widely available. It is a method that uses seawater under variable pressure as the cleaning medium instead of abrasive brushes which can add micro plastics into the water column and result in potential damage to the antifouling surface.*

## 1. Introduction

The shipping industry is under pressure to increase its sustainability, improve operational efficiencies, and reduce its impact on the environment. Regulation, rising fuel costs and pressure from charterers and shippers to improve levels of sustainability within the supply chain are key factors driving ship owners and operators to increase efficiencies.

The global maritime community is striving for greener ports with cleaner waters, reduced localised air pollution and a greater contribution from the shipping and port community towards meeting climate change targets.

The state of a vessel's hull plays an integral role in the rise and fall of its efficiency and overall performance. A vessel with a clean hull consumes less fuel and produces fewer GHG (Greenhouse gas) emissions.

Traditionally, underwater hull cleaning was undertaken by a diver armed with a plastic or wire brush driving a brush-cart around the submerged hull of a vessel. While the practice remains widespread, it presents a range of challenges including safety concerns, damage to antifouling coatings and limitations in cleaning locations due to the increased environmental restrictions placed on hull cleaning.

Hull cleaning and its importance are still widely not appreciated and understood in shipping circles. I have been told "it's only hull cleaning" and the "barnacles on my propeller make it grip the water better" or "we only need to clean our ships in dry dock".

## 2. Where it began

Ancient Egyptians were renowned for their shipbuilding skills, Fig.1, and their most famous achievement, the Khufu ship whose hull was coated with arsenic and sulphur. Likewise, the Vikings "beached" their long boats. From those early beginnings up to today's "grooming" of LNG vessels, the issue of biofouling and the need for hull cleaning has always been around and will continue to be.

Buccaneers recognised the benefit of a clean ship. They would "careen" their ships, Fig.2, by moving the cannons and all cargo from port to starboard and vice versa onto low-lying bays in the Caribbean to clean the hulls. Sailors would use steel blades to scrape off the fouling and dig out teredo worms before recoating the hull with a mixture of tar, tallow and sulphur. They knew that a clean smooth hull was faster in the water so they could the catch commercial vessels trying to outrun them, or themselves escape pursuit by navy vessels sent to sink them.

Lord Nelson was a gifted naval tactician even though the Admiralty did not always agree with his unconventional tactics. Prior to the Battle of Trafalgar, he ordered his fleet to have their hulls cleaned.

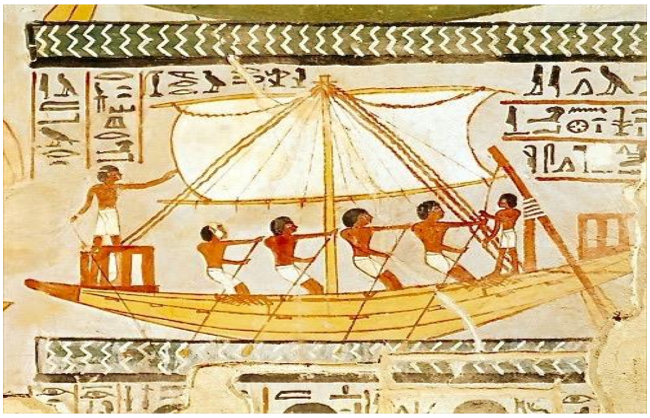


Fig.1: Ancient Egyptian ship

Fig.2: Buccaneers careened their ships for hull cleaning

He knew he was at a numerical disadvantage in fleet size - his 27 ships against 18 French and 15 Spanish vessels – so he needed an advantage. He knew a clean hull would give his fleet superior speed and agility to manoeuvre into two columns directed at right angles against the French and Spanish. Repeated broadside cannon shots resulted in the loss of 22 French and Spanish ships and not a single British loss.

What was not uppermost in the thinking then was the spread of invasive species.

**3. Invasive Species**

Charles Darwin raised the first questions about the risks in transfer of invasive species attached to ship hulls, Fig.3, when he sailed on the HMS Beagle around the Galapagos Islands in 1836. He recorded "fouling of a ship's hull could be the other means of transport of marine organisms from one location to another".

Fig.3: Ships with fouling transport marine organism from one location to another

Around the world, upwards of USD$5.7 billion is spent every year to prevent and control marine fouling and we all know now that marine biofouling is associated with the largest percentage of invasive issues, followed by ballast water.

Invasive species have been declared an environmental emergency, with the IMO calling invasive species "one of the greatest threats to the ecological and the economic well-being of the planet". These little creatures or organisms hitch a ride by clinging to the submerged areas of ships' hulls.

In its most basic form, the term "invasive species" refers to an organism being moved from its natural habitat to a new habitat, where it may have no natural predators, enabling it to take over and wipe out indigenous organisms.

**4. Coatings**

Today, commercial shipping moves 90% of the worlds trade across the oceans and seas. There are approximately 55,000 merchant ships trading worldwide at any given time and the risks of invasive species have risen dramatically.

Gone are the days of Muntz Metal lined hulls and the protective coating of choice TBT after its introduction in the 1960s (TBT brought its own highly toxic issues and was banned in 2008). We now have revolutionary biocide coatings and low energy release coatings, and the companies that produce are moving forward at a great rate of knots!

In the past, paint damage came hand in hand with hull cleaning, especially for vessels with silicone-based coatings that are damaged when inconsistent pressure is applied by the diver handling the brush-cart. The damage caused could be complex to resolve and require remedial work by the hull coating manufacturer. This issue is avoided by an ROV through the use of consistent water pressure as a cleaning medium.

**5. Associated Risks/Safety**

Hull cleaning methodology was woefully behind. Traditional cleaning – based on divers with hand-held scrubbers or driving underwater brush carts – is still carried out in many locations, and without fouling collection systems, bringing inherent risks to both the environment and human life.

With traditional methods, fouling is scrubbed off the submerged area and allowed to fall into the tidal stream. Further, the use of plastic brushes means that the brush bristles themselves add microplastic to the water column.

The hull cleaning industry has faced criticism over its health and safety record, due to the serious risk to divers' lives caused during the operation of brush-carts. An ROV significantly removes this health and safety risk.

In 2003, ROV hull cleaning became a viable option when the first Remoted Operated Vehicle (ROV) with marine fouling capture technology was introduced to commercial shipping. Whilst at first limited, today there are six known commercially viable ROV hull cleaning service providers and at least another five companies are carrying out development and testing.

Hull cleaning with marine fouling capture systems is here now. Some systems do not require divers to drive them. They are standalone ROVs that are a cost-effective and environmentally friendly option, Fig.4. In most cases, they are equipped with water jets and designed to clean up to 1500m$^2$/per hour of a hull using saltwater - a natural abrasive & lubricant - under variable pressure as the cleaning medium.

Fig.4: HullWiper ROVs

The ROV collects pollutants removed from the vessel's submerged areas for disposal in an environmentally approved and eco-friendly manner onshore. Because no divers are used, they can clean ships during bunker delivery or cargo loading/discharging cargo operations, saving valuable time for vessels. An ROV with a fouling collection system may be granted permission to clean vessels in ports where traditional cleaning is prohibited.

## 6. The Future and Legislation

Hull cleaning is seen as a necessary evil – you know you have to do it, but you leave it until the last minute.

Greater regulation is seeing more and more ports prohibiting traditional hull cleaning or restricting divers to daylight hours only. This is proactively influencing the development of alternative hull cleaning methods with fouling capture systems as a basic requirement.

State, federal and international regulators with input from the likes of BIMCO, ACT/MERC, WOC, NACE and the IMarEST will positively affect the hull cleaning industry. If more biofouling regulations are implemented and enforced, hull cleaning with biofouling capture units may become the only acceptable option.

And finally, there is the GloFouling Partnership project with its Global Alliance Initiative (GIA) launched in June 2020. It is a collaboration between the Global Environment Facility (GEF) the United Nations Development Programme (UNDP) and the International Marine Organization (IMO), focused on reducing the transfer of harmful invasive species via biofouling and contributing to global efforts to minimise GHG emissions from shipping.

This project aligns with the Ballast Water Management Convention. However, the Ballast Water Convention took the best part of 20 years to complete and has/will cost vessel owners millions to comply with. The GloFouling project is not just a cost; it also offers huge savings commercially by improving vessel efficiency and protecting our oceans with improved biofouling management and reduction of GHG.

# Underwater Cleaning in the Flemish Ports

**Jasper Cornelis**, Port of Zeebrugge, Zeebrugge/Belgium, hkd@mbz.be
**Luc Van Espen**, Port of Antwerp, Antwerp/Belgium, Luc.VanEspen@portofantwerp.com
**Karen Polfliet**, North Sea Port, Ghent/Belgium, karen.polfliet@northseaport.com

**Abstract**

*This paper describes the development of underwater cleaning policies of ship's hulls and propellers in the Flemish ports (Zeebrugge, Antwerp, North Sea Port) over the past decade. Policies have been aligned between the ports to ensure a level playing field. The policies address coating, cleaning techniques (incl. filtering techniques) and test procedures (ex situ and in situ) to proof fulfilment of acceptance criteria. Once the acceptance criteria are reached, installation-specific licences can be granted which are valid in the three Flemish ports. Since the start of the joint policy, three companies have obtained a licence for propeller polishing operations and two companies for hull cleaning operations.*

## 1. Introduction

These days, environment and sustainability are becoming ever more important, including the maritime sector, *Tamburri et al. (2020)*. The Flemish ports (Port of Antwerp, North Sea Port Flanders & Port of Zeebrugge) therefore welcome companies which develop new technologies that contribute to more environmentally friendly shipping.

Already in 2010, the Port of Antwerp set up a first framework for the cleaning of hulls, although limited to hulls with a specific environmentally friendly coating. In 2017, the Antwerp Port Authority anticipated the demand from various partners in the maritime sector for a harmonised policy on new (underwater) cleaning techniques. By fine-tuning the policy on the one hand and clarifying test procedures and acceptance criteria on the other hand, development & innovation will be stimulated. In addition, North Sea Port and Port of Zeebrugge have become partners in this project, in order to ensure a level playing field.

In the summer of 2019, a joint policy on 'underwater cleaning in the Flemish ports' was launched in the three partner ports. It concerns both hull cleaning and propeller polishing. The uniform framework ensures that market players are assessed in an equal manner in the Flemish ports, with equal requirements, like test procedures and acceptance criteria. Each test procedures consist of an 'ex situ test' (under laboratory conditions) and an 'in situ test' (on a ship in dock water) in which different criteria are tested.

## 2. Propeller polishing

Propeller polishing is used to remove deposits and fouling from the ship's propeller to ensure optimum performance and delivers significant fuel savings and emission reductions, *Schultz et al. (2011), Schultz (2007), Tamburri et al. (2020)*. However, because harmful particles could be released during such an operation, it is not allowed everywhere. The Flemish ports decided to set up a common framework to allow such operations to take place in order to achieve the benefits with regard to air quality and fuel savings, without harmful impact on the marine environment.

In the ex situ test is assessed in a standardized way whether a candidate licensee meets the acceptance criteria regarding suction and filter performance. It is crucial that the test is performed with the personnel trained for this job, the materials and associated working procedures which are specific for each installation. Fig.1 represents in a schematic way the set-up used for this purpose, and Fig.2 shows how Container 1 looks like in a real lab test.

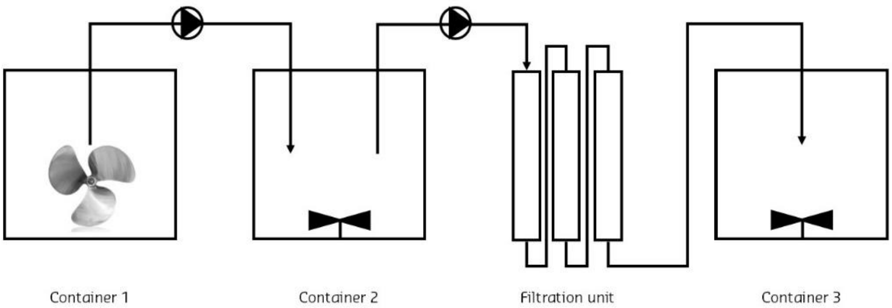



Fig.1: Schematic representation of the test set-up for the ex situ test for propeller polishing

Samples taken during the test are at least assessed on the following parameters: suspended matter, copper, aluminium, nickel, zinc and iron. On the basis of the following formulas respectively the suction and filter performance are determined:

<u>Suction performance:</u>

$$\frac{(C2 * V2) - (C0 * V2)}{((C1 * V1) - (C0 * V1)) + ((C2 * V2) - (C0 * V2))} * 100\%$$

In which:
- C0: concentration of the relevant contamination parameter in container 1 before the start of the test in mg/l (baseline measurement)
- C1: concentration of the relevant contamination parameter in container 1 after polishing in mg/l
- V1: remaining volume in container 1 after polishing in litres
- C2: concentration of the relevant contamination parameter in container 2 after polishing in mg/l
- V2: volume in container 2 after polishing in litres

<u>Filter performance:</u>

$$\frac{(C2 - C0) - (C3 - C0)}{C2 - C0} * 100\%$$

In which:
- C0: concentration of the relevant contamination parameter in container 1 before the start of the test in mg/l (baseline measurement)
- C2: concentration of the relevant contamination parameter in container 2 after polishing in mg/l
- C3: concentration of the relevant contamination parameter in container 3 after filtration in mg/l

The results of the test are checked against the acceptance criteria:
- No visual contamination of the water column;
- Suction performance is at least 90%;
- Filter performance is at least 90%;
- Total performance (= suction performance X filter performance) is at least 80%.

After successful completion of the ex situ test, an in situ test must be carried out. The emphasis lies here on the operational execution and the reproduction of the obtained results in the ex situ test. However, during the in situ test it is not possible to determine the exact suction performance -because of the infinite water mass. So during the test it is checked whether a substantial increase in concentration can be observed in the immediate vicinity of the operation. Therefore a cylindrical sampling device (or similar) is used, *VITO (2019)*. Such equipment is shown in Fig.3. As a starting point, it is stated that the concentration around the operation may increase up to 5% compared to the baseline measurements Filter performance is determined again using the formula as used in the ex situ test.

Fig.2: Polishing operation during ex situ test

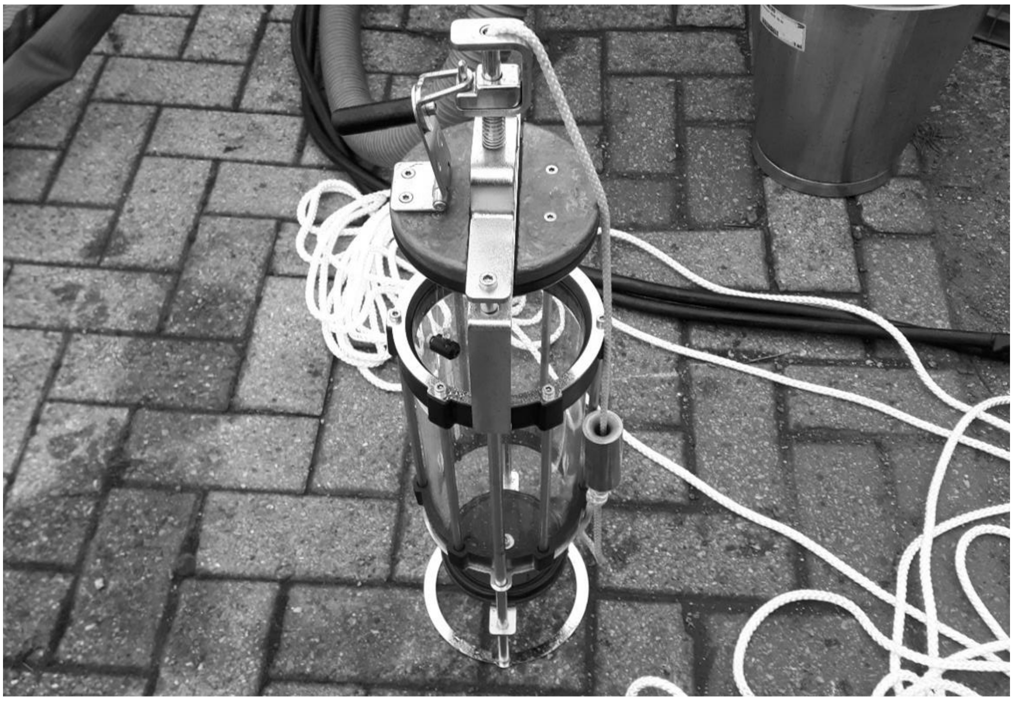


Fig.3: Example of cylindrical sampling device (Ruttner Water Sampler) used during in situ test

## 3. Hull cleaning

Hull cleaning is used to remove deposits and fouling from the ship's hull to ensure optimum performance and delivers significant fuel savings and emission reductions. However, because harmful particles (both heavy metals, biocides and alien species) are also released during such an operation, it is not allowed everywhere. The Flemish ports decided to set up a common framework to allow such operations to take place in order to achieve the benefits with regard to air quality and fuel savings, without harmful impact on the marine environment.

The authorisation process starts with the performance of an ex-situ or laboratory test. This involves testing whether the tool complies with the required acceptance criteria in terms of suction performance. This is done in two ways:

- By cleaning a metal plate which has been painted with an easily removable anti-fouling paint and which is suspended vertically in a container.
- By applying a colouring agent at three points around the device.

In contrast to the propeller polishing ex-situ test, the filter performance is not assessed in the hull cleaning ex-situ test, because a painted metal plate does not - at all - look like a fouled ship's hull. Therefore, we are afraid that performing a filter test would lead to non-representative results.

The objective of both tests is to demonstrate that the paint/colouring agent is effectively suctioned by the system and is not transmitted to the water column. During the ex-situ tests, samples are also taken and analysed by an independent authorised laboratory. The company applying for the permit will choose the independent laboratory.

If this working method is not feasible due to the size of the tool to be tested, an alternative procedure must be worked out in consultation with the Flemish ports.

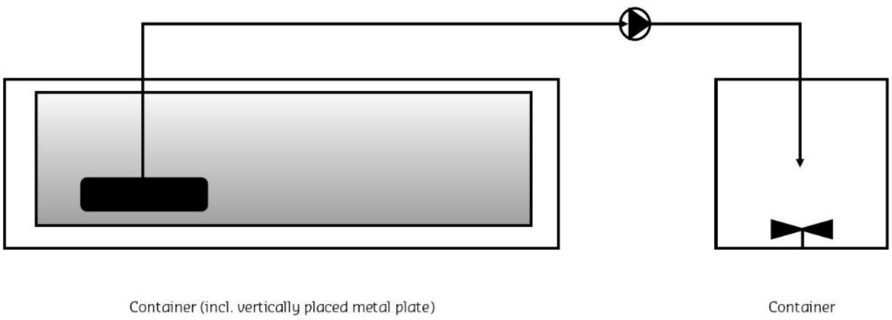



Fig.4: Schematic representation of the test set-up for the ex situ test for hull cleaning

After acceptance of the ex situ test by the Flemish ports, an in-situ test must be carried out. During the test it is checked whether a substantial increase in concentration can be observed in the immediate vicinity of the operation and whether the filtering performance meets the intended criteria.

Fig.5: Hull cleaning operation by Fleet Cleaner

Fig.6: Hull cleaning operation by ECOsubsea

As a starting point, it is stated that the concentration around the operation may increase up to 5% compared to the baseline measurements. The filter performance is determined using the same testing procedure and formula like developed for propeller polishing.

## 4. Experience so far

Since the start of the joint policy, three companies have obtained a licence for propeller polishing operations and two companies for hull cleaning operations. Several other firms are working on the licensing process. By means of illustration, 95 propeller polishing operations and 56 hull cleaning operations were carried out in the period from March 2019 to July 2020, Fig.7.

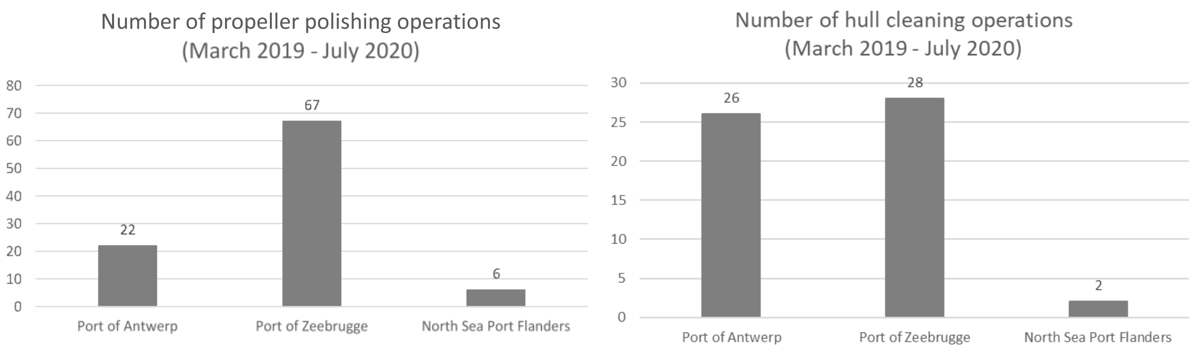


Fig.7: Propeller polishing (left) and hull cleaning (right) operations March 2019 to July 2020

## 5. Conclusion

With this project, which continues to evolve due to new insights, the Flemish ports make their contribution to a greener future, both for the climate and for the bio-marine environment. We are hoping for an international policy to convince everyone of the opportunities of these new techniques and the possible gains they will bring e.g. in terms of ships fuel consumption (up to 15% less), without compromising the marine environment in the ports where they get underwater cleaned.

## Acknowledgments

We thank Peter De Pauw (Port of Antwerp), Katrien Van Itterbeeck (Port of Antwerp), John DeConinck (North Sea Port), Paul Schroé (Port of Zeebrugge) and Yves Le Clef (Port of Zeebrugge) for their commitment and support in this project. We would also like to thank Erwin Taelens and Esmee Sanstra of Rijkswaterstaat (Ministry of Infrastructure and Water Management - NL) for sharing their expertise.

**References**

SCHULTZ, M.P.; BENDICK, J.A.; HOLM, E.R.; HERTEL, W.M. (2011), *Economic impact of biofouling on a naval surface ship*, Biofouling 27/1, pp.87-98
https://doi.org/10.1080/08927014.2010.542809

SCHULTZ, M.P. (2007), *Effects of coating roughness and biofouling on ship resistance and powering*, Biofouling 23/5, pp.331-341
https://doi.org/10.1080/08927010701461974

TAMBURRI, M.N.; DAVIDSON, I.C.; FIRST, M.R.; SCIANNI, C.; NEWCOMER, K.; INGLIS, G.J.; GEORGIADES, E.T.; BARNES, J.M.; RUIZ, G.M. (2020), *In-Water Cleaning and Capture to Remove Ship Biofouling: An Initial Evaluation of Efficacy and Environmental Safety*, Frontiers in Marine Science
https://doi.org/10.3389/fmars.2020.00437

VITO (2019), *Compendium voor de monsterneming, meting en analyse van water (WAC)*, https://emis.vito.be/nl/erkende-laboratoria/water-gop/compendium-wac

# 3D Laser Inspection of Ship Hulls

**Patrick M. Paranhos**, Kraken Robotics, Bremen/Germany, pparanhos@krakenrobotik.de

**Abstract**

*Ship hulls are susceptible to a high degree of corrosion due to continuous operation in direct contact with a corrosive environment, which may lead to critical failure. These assets typically must be brought offline for regular inspections, a costly and disruptive process. Ship hulls are also subjected to biofouling, which increases fuel consumption and threatens to introduce invasive species into a new environment. SeaVision™, manufactured by Kraken Robotics, is a self-referenced underwater laser scanner, an enabling technology for underwater ship hull digitalization. It is the author's belief that underwater 3D digitalization of the ship hull can be used for efficient monitoring of corrosion and biofouling. This paper introduces the main principles used for underwater 3D digitalization, discusses the benefits of crawler versus hovering vehicles for a digitalization campaign, and presents the results of a ship hull digitalization feasibility study deployment with SeaVision.*

## 1. Introduction

Corrosion is defined as the deterioration of material due to the conversion process which converts a base material to another more stable form. There are many types of corrosion, including:

- Globalized corrosion in which a material is degraded uniformly over the entire area of the object and localized corrosion where the effect is constrained to specific areas on the object.
- Localized corrosion can be quantified by density of corrosion pits over a given surface, and the depth and diameter of the pits. It is a persistent challenge in shipping, as most large ship hulls are made of steel plates and in constant operation in a high corrosive seawater environment.

Corrosion, if not measured and addressed, leads to compromised surface treatments, and increased maintenance costs. In extreme cases, corrosion can lead to compromised structural integrity and even structural failure if left untreated.

Biofouling is the accumulation of micro-organisms, where vegetation or natural matter attach to the ship´s hull. This can lead to an increase in the ship's drag, which will also cause an increase in fuel consumption, mechanical wear, and emission of gasses. The accumulated biofouling also poses a risk of transferring invasive marine species between geographic areas as the ship transits from one port to the next. Ship hulls require regular cleaning, and quality control reports suitable for Port Authorities are sometimes required, confirming that the hull has achieved emerging IMO standards for entering ports. 3D digitalization is the procedure used to capture the shape of a surface into a digital 3D model of the real object with high accuracy. Corrosion and biofouling can be characterized as 3D anomalies, either as a loss or addition of material with respect to the ship hull's nominal shape. The resolution of the measurement determines the threshold over which the anomalies can be detected.

Fig.1: SeaVision™ self-referenced laser scanning system

SeaVision, as seen in Fig.1, is an underwater laser-imaging scanner developed by Kraken Robotics. The sensor is able to perform 3D digitalization of submerged structures through a triangulation process. A laser line is projected onto the surface and the line is observed by the system's camera. This process is repeated continuously at a rate of 125 times per second. SeaVision is a self-referenced system, a term used to describe the breakthrough innovation of relying on the object being scanned as the reference for positioning and scaling. This enables the 3D inspection by laser scanning of floating vessels.

## 2. Underwater 3D Digitalization

The use of 3D digitalization for structural assessment is well established in the industry and common within terrestrial applications. *Grobler et al. (2017)* evaluate laser scanning technology in quantitative analysis of corrosion for structural beams. *Mukupa et al. (2018)* provide a review of laser scanning applications for change detection and deformation monitoring. In the shipping industry, it is also common to apply terrestrial laser scanners for diverse use cases such as:

- hull deflection modelling
- retrofit
- refurbishment
- renovation
- change of use
- insurance.

To date, these use cases in the shipping industry have focused on in-air 3D digitalization.

Underwater 3D digitalization is challenging due to the physical characteristics of the medium. 3D sensing technology developed for in-air applications is not directly applicable underwater. The 3D reconstruction principles can be broken down into two main classes: acoustic and optic 3D. Acoustic 3D is the most common and has many advantages compared to optic 3D approaches. As light is attenuated in water due to scattering and absorption, optic methods have limited range and are heavily affected by water conditions like turbidity. The main limitation of acoustics is the low data resolution, which is not suitable for biofouling and corrosion monitoring. *Vaganay et al. (2006)* present a result of an acoustic 3D digitalization of a ship hull propeller, Fig.2.

Fig.2: Ship hull 3D acoustics - Source: *Vaganay et al. (2006)*

The predominant approach for optic underwater 3D digitalization is sensor solutions based on passive light principles, such as photogrammetry, where the 3D scene is estimated based on the point correspondence between camera images without dependence on a controlled light source. The main principles of the technology are shown in Fig.3. Results for underwater 3D digitalization based on photogrammetry for ship hull and shipwrecks can be seen on works from *Hong et al. (2020)* and *Yamafune et al. (2017)*. The main advantage of the passive 3D approach is the ability to track the relative movement between sensor and hull. The main drawbacks are the limited range due to forward scattered light, limited depth resolution and dependence on clear target texture visibility. This technique is strongly affected by turbidity of the water and the presence of detritus in the water. Photogrammetry usually has a depth resolution of a few millimeters for inspection distances larger than 1 m from a ROV. This limitation is meaningful for ship hull monitoring, as it would not be possible to detect small corrosion pits.

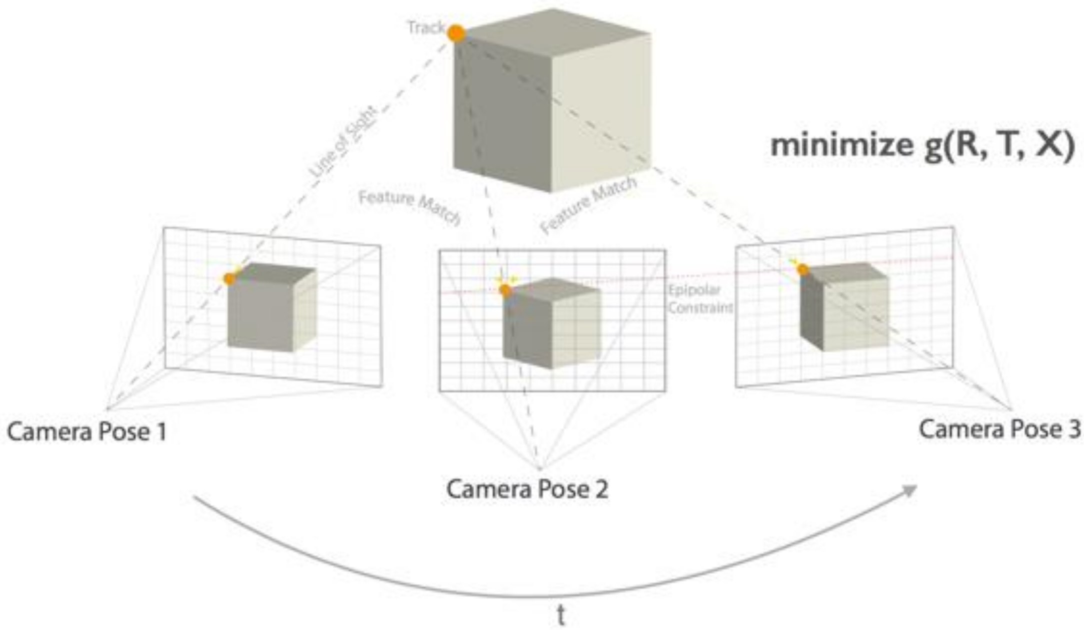



Fig.3: Photogrammetry 3D digitalization principle

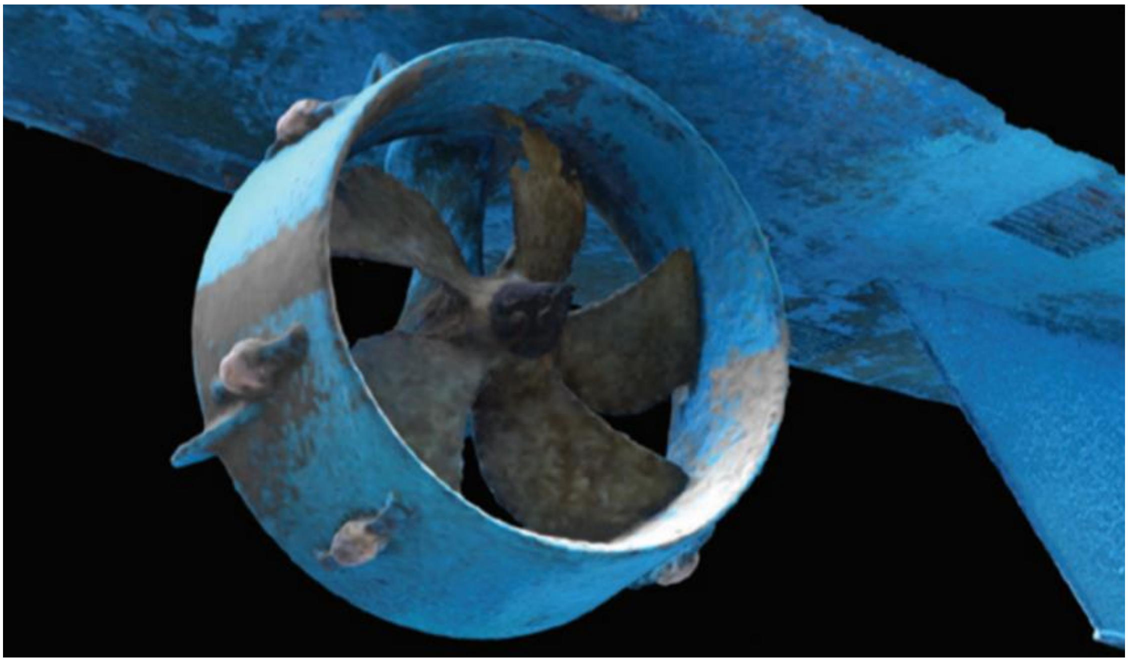


Fig.4: Photogrammetry 3D of a ship propeller. Source: https://comex.fr/

Active 3D sensors illuminate the environment with a controlled light source to perform the measurement. The main active light principle applied underwater is structured light, where the system projects a laser line onto the scene and the line is observable in the systems camera image. Through a triangulation process, the depth deformation of the laser line can be estimated. The principle of the technology is presented in Fig.5. *Castillón et al. (2019)* present a state-of-the-art review on active optical 3D scanners. The main advantages of active 3D compared to passive 3D, are the higher depth resolution, further operational range, and robustness to turbidity. *Bianco et al. (2013)* present a comparative analysis between passive and active 3D digitalization. The drawback of active 3D sensors is the need for an external positioning system to reference the measurement. As the ship is in continuous motion decoupled from the sensor motion, an external position measurement of the ship hull would not provide the needed relative position between sensor and ship.

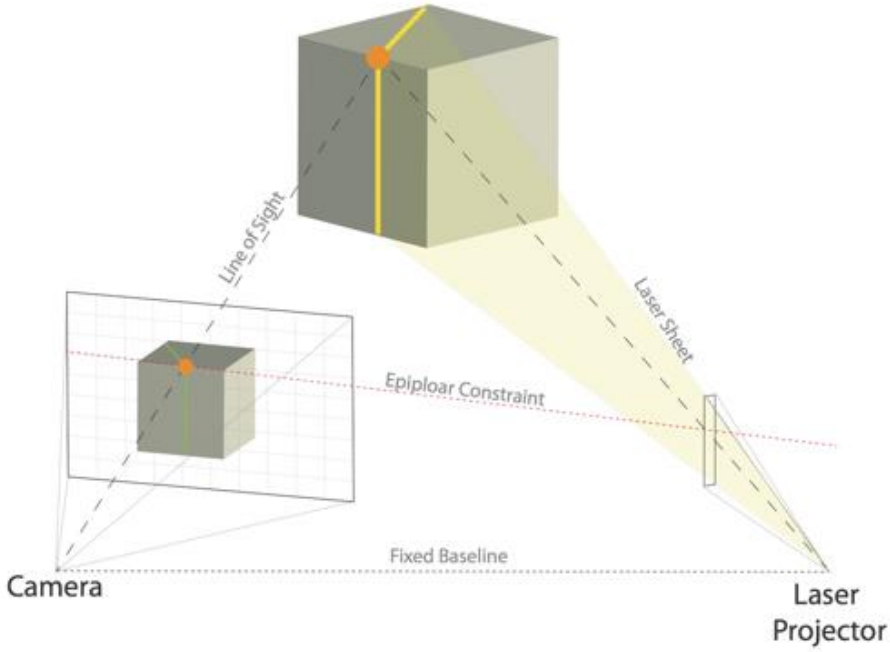



Fig.5: Structure light 3D digitalization principle

SeaVision, Kraken's sensor technology, is an underwater RGB self-referenced laser scanner system using a combination of passive and active light principles, *Duda et al. (2016)*. A self-referenced system relies on the object being scanned as the reference for positioning. This means that while scanning the hull, the laser system estimates its relative position with respect to the hull by tracking the natural features found on the target hull. The self-referenced sensor poses and positions itself relative to the hull instead of an externally fixed reference such as GPS. This method of self-referenced laser scanning has significant advantages for ship hull monitoring applications such as:

1. Accurate measurements with sub-1 mm resolution are possible under relative motion between ship and sensor at over 1 m distance from target, as seen in Fig.6.
2. Monitoring of corrosion or biofouling rates becomes possible, as the reference location is maintained across multiple port calls.
3. Inspection of a subsection or piece of the hull will maintain its reference to a fixed datum on the hull when the monitoring continues at the next port call.
4. Elimination of the need for additional equipment set-up as an LBL for positioning in the underwater domain.

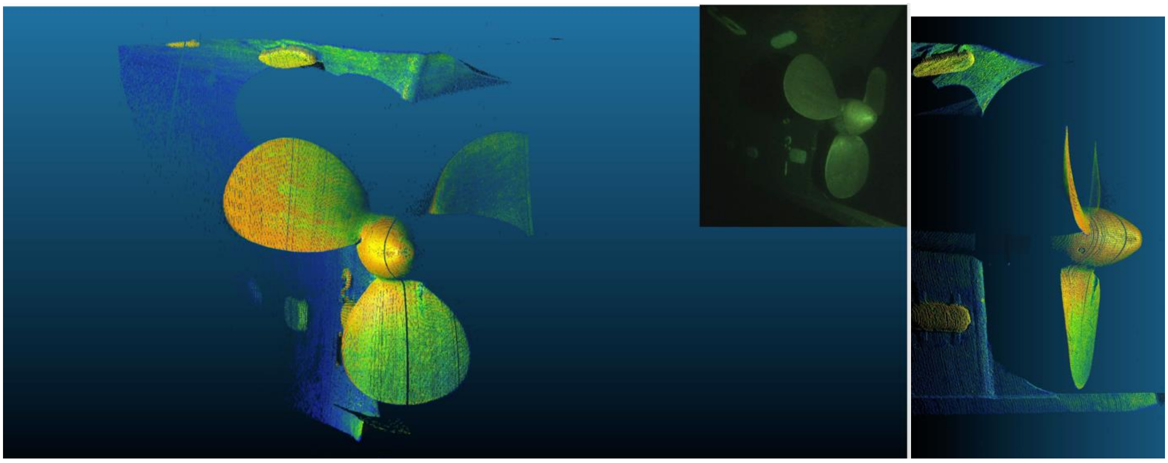


Fig.6: SeaVision self-referenced 3D scan of a propeller from a ROV. 8 s Scan at 4 m from Target

**Vehicle Type for 3D Digitalization Deployment**

Monitoring ship hull corrosion and biofouling includes not only the 3D sensor, but also the platform and method to efficiently deploy the sensor and collect the data. The requirements defined by the Royal Canadian Navy and Canadian Coast Guard are that the solution should be able to reach the vessel at anchor or at port-side and complete the survey aboard or from a support boat. The solution should be small and light enough to be flown into remote locations. These requirements were defined as part of the Innovative Solution Canada proof of concept project: "Using Enhanced Imaging and Robotic Technology to Improve Corrosion Monitoring on Naval Vessels", concluded in July 2020.

Performing ship hull inspection using a hovering remotely operated vehicle (ROV) is a practice that dates back three decades. *Lynn et al. (1999)* report the use of ROV´s since 1990 to inspect the hull of carrier, cruiser, etc. Currently, the marine industry is pushing for the use of remotely operated vehicles (ROVs) for underwater inspections in lieu of drydocking (UWILD). The standard output of an ROV survey are video images, which provide a qualitative assessment of the hull. ROV video data can be complemented with coating measurements with an ultrasound thickness gauge.

Crawler-type vehicles are a different category of underwater vehicles for ship hull inspection. Crawlers adhere to the hull surface through magnetic tracks or via suction. The main application of crawlers has traditionally been ship hull grooming, secondary use cases include camera-based inspection and thickness measurements. The incorporation of grooming into ship hull maintenance is important in the prevention of invasive species recruitment and transport, *Hunsucker et al. (2019)*. Hull grooming has a symbiotic relationship with 3D monitoring of corrosion and biofouling. The biofouling monitoring triggers the need for the grooming and the grooming is necessary for corrosion monitoring.

There is not a definitive optimal underwater vehicle type (crawlers or hovering) for ship hull applications. Each is a different tool with optimal use for a set of tasks. Hovering vehicles can reach and inspect complex regions, such as steering gear and propellers, and have a higher area coverage rate for visual and 3D inspection. Crawlers continuously maintain contact with the surface, so they can efficiently perform continuous thickness measurements and detail 3D/visual inspection without the need for continuous position and pose estimation. However, the crawlers typically have lower area coverage rates and they are limited to areas they can access.

The vehicle type and size have a direct impact on the performance of the 3D self-reference laser system. The resolution is a function of the baseline (distance between laser projector and camera) and distance between the sensor and the object being inspected (in this case, the ship hull). The graph in Fig.7 shows the achievable depth resolution versus distance and baseline.

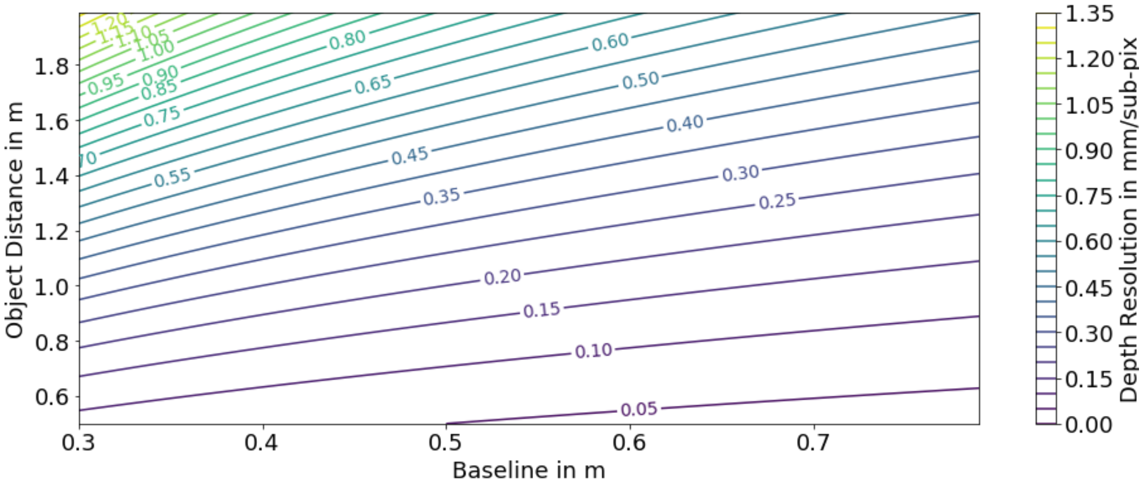



Fig.7: Depth resolution vs distance and baseline

The baseline is constrained by the vehicle size, and the operational distance is constrained by the vehicle type. A portable vehicle that can be launched from deck usually supports baselines of up to 60 cm. A hovering vehicle operates at standoff distances of ~1 m to ~4 m. A crawler operates at standoff distances of ~0.2 m to ~0.6 m. Under these conditions, the depth resolution expected is 0.5 mm for the hovering vehicle and 0.01 mm for the crawling vehicle. In crawling mode, SeaVision is ideal for monitoring roughness, coating and cracks. In hovering mode, SeaVision is ideal for monitoring pitting, anodes, deformation, biofouling and mines. For more information, see the schematic in Fig.8.

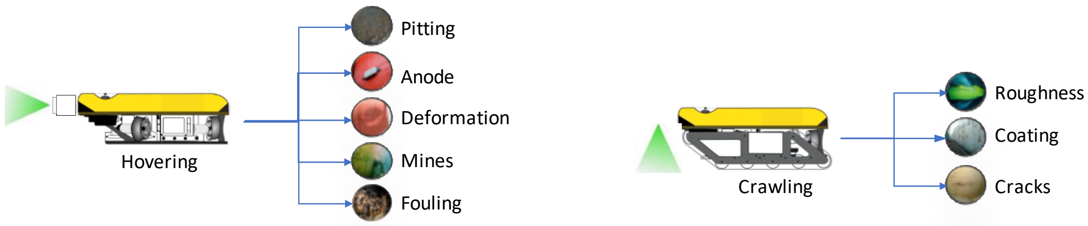



Fig.8: 3D inspection tasks per vehicle type

**Results**

SeaVision has been integrated onto both hovering and crawler-type vehicles and has been deployed for ship hull 3D inspection trials as shown in Fig.9. The hovering vehicle is a SAAB Falcon. The crawler is a VideoRay Defender with GreenSea crawler skid.

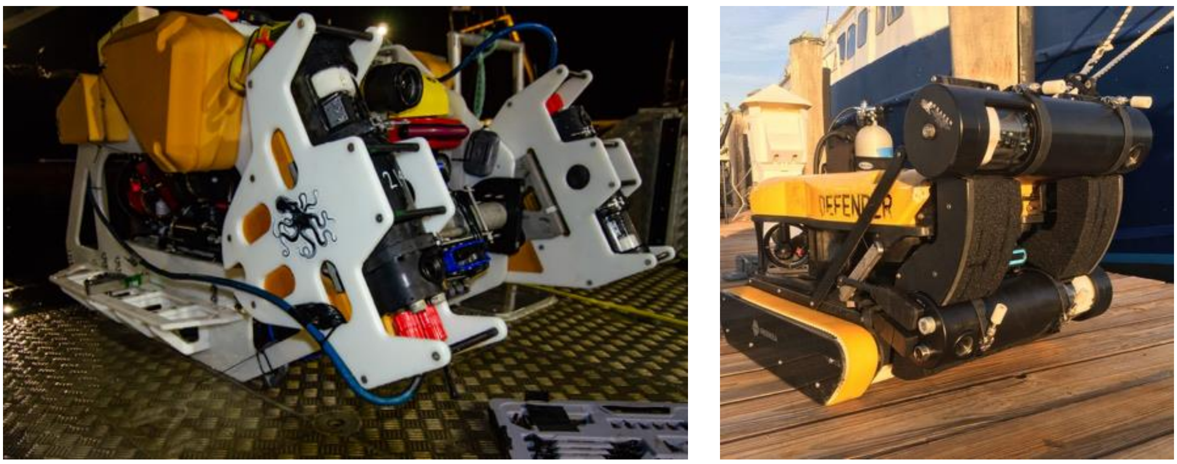
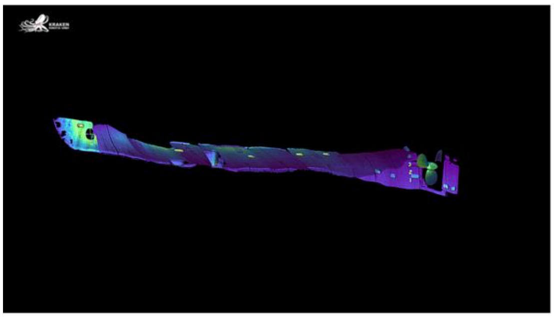
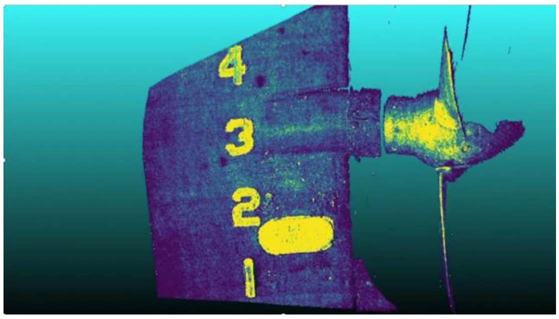
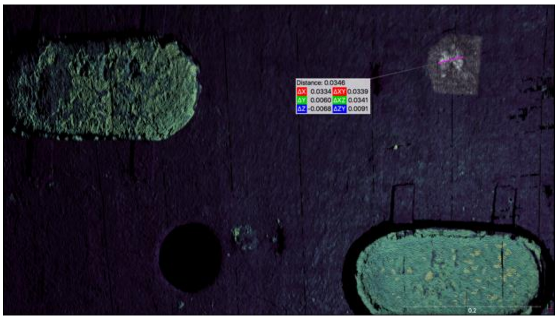


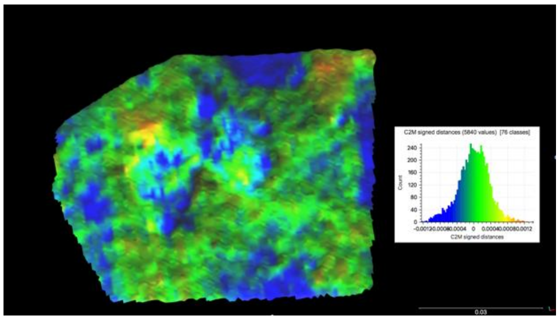
Fig.9: SeaVision integrated to hovering and crawling vehicles

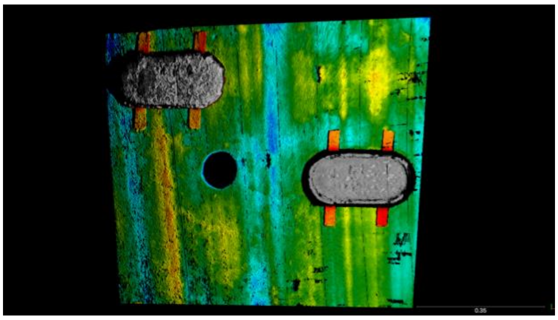
The crawler trials were performed in partnership with GreenSea Systems Inc. With the collected data set the hull was digitalized in 3D and the data analyzed for corrosion and biofouling. A "point cloud to model distance" (C2M) computational method and dimensional coloring is used to measure and highlight corrosion (light and dark blue) and biofouling (yellow and red), as shown in Fig.10. The data presented is from the hovering vehicle deployment, as the crawler data set has not yet been released for publication.

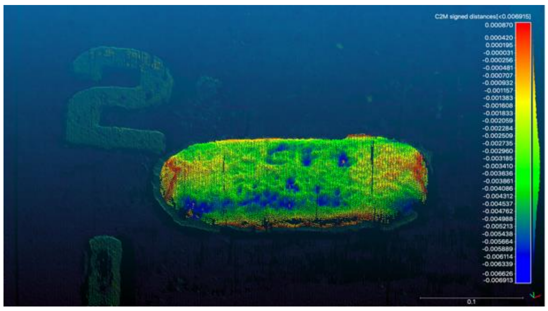

3D Reconstructed Hull


Zoom in on 3D Model


Further Zoom and Measurement of a 34 cm Pit


Further Zoom and Pit Depth Measurement of 1.2 mm


Dimensional coloring to highlight corrosion (light and dark blue) and biofouling (yellow and red) of the surface


Dimensional coloring to highlight corrosion (light and dark blue) and biofouling (yellow and red) of the anode


Zoom photography of the anode

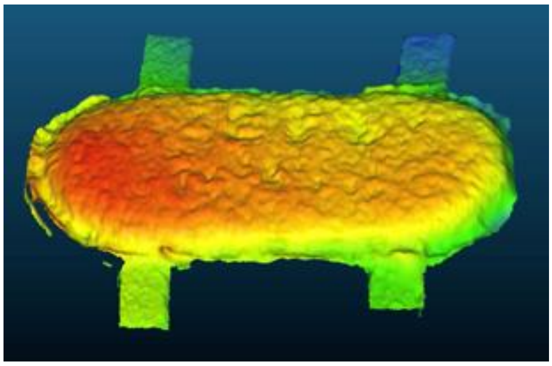

Surface mesh to estimate remaining anode volume

Fig.10: Data analytics examples of a 3D digitalized ship hull

## Conclusions

The analysis of the state-of-the-art requirements and trials led to the conclusion that a self-referenced laser system sensor on a portable autonomous underwater vehicle capable of hovering and crawling would be the ideal solution for 3D monitoring of corrosion and biofouling. SeaVision technology has been developed by Kraken over the last 4 years and is in use at the oil and gas industry for corrosion monitoring of mooring chains.

A self-referenced laser sensor is an enabling technology that estimates its position with respect to the ship hull, providing the resolution and accuracy necessary to digitalize the hull in 3D and monitor biofouling and corrosion. In crawling mode, with expected resolution of up to 0.01 mm, the system would be used for detailed 3D monitoring of hull roughness, coating condition estimate and cracks. In hovering mode, with resolution of up to 0.5 mm the system would be used for monitoring pitting, anodes, localized deformation, biofouling, and foreign objects. Preliminary tests have been performed that have validated the base sensor-system solution for the intended task.

Preliminary data analytics has been performed on the digitalized hull data through a C2M computational method. The analytics detected pits, general corrosion, and biofouling. Other computational methods exist for structural analytics of 3D reconstructed digital models that could be used in the underwater domain to fulfil shipping industry needs. In the future it could be possible to calculate the corrosion speed of the material efficiently; automatically classify types of corrosion, damages, and biofouling; and perform more complex calculations such as RLA (remaining life assessment).

It is Kraken's belief that there is a market and technology gap in sensor-system technology for underwater monitoring of corrosion and biofouling of ship hulls. It is expected that this new system will enable advanced monitoring of the ship hull corrosion and biofouling as 3D "heat" maps, with the confidence that the full area of interest has been totally covered.

Kraken is a marine technology company dedicated to the production and sale of software-centric sensors and underwater robotic systems. The company is headquartered in Mount Pearl, Newfoundland with offices in Dartmouth, Nova Scotia; Toronto, Ontario; Bremen & Rostock, Germany; and Boston, Massachusetts. Kraken is ranked as a Top 100 marine technology company by Marine Technology.

## References


BIANCO, G.; GALLO, A.; BRUNO, F.; MUZZUPAPPA, M. (2013), *A comparative analysis between active and passive techniques for underwater 3D digitalization of close-range objects,* Sensors 13, pp.11007-11031

CASTILLÓN, M.; PALOMER, A.; FOREST, J.; RIDAO, P. (2019), *State of the art of underwater active optical 3D scanners,* Sensors 19/23, pp.5161

DUDA, A.; T. KWASNITSCHKA; J. ALBIEZ; KIRCHNER, F. (2016), *Self-referenced laser system for optical 3D seafloor mapping*, OCEANS 2016, Monterey, pp. 1-6

GROBLER, H.C.I.; COMBRINK, G. (2017), *An evaluation of the efficiency of laser scanning technology in the quantitative analysis of corrosion*, South African Journal of Geomatics 6/2, pp.196-207

HONG, S.; KIM, J. (2020), *Three-dimensional visual mapping of underwater ship hull surface using piecewise-planar SLAM*, Int. J. Control, Automation and Systems 18, pp.564-574

HUNSUCKER, K.Z.; RALSTON, E.; GARDNER, H.; SWAIN, G. (2019), *Impacts of invasive species on coastal environments*, Coastal Research Library, pp.247-265

LYNN, D.C.; BOHLANDER, G.S. (1999), *Performing* Ship Hull Inspections using a Remotely Operated Vehicle, OCEANS'99, Vol. 2, pp.555-562
MUKUPA, W.; ROBERTS, G.W.; HANCOCK, C.M.; AL-MANASIR, K. (2017), *A review of the use of terrestrial laser scanning application for change detection and deformation monitoring of structures*, Survey Review 49/353, pp.99-116

VAGANAY, J.; ELKINS, M; ESPOSITO, D.; O'HALLORAN, W.; HOVER F.; KOKKO, M. (2006), *Ship hull inspection with the HAUV: US Navy and NATO demonstrations results*, OCEANS 2006

YAMAFUNE, K.; TORRES, R.; CASTRO, F. (2017*), Multi-image photogrammetry to record and reconstruct underwater shipwreck sites,* Arch. Method Theory 24, pp.703-725

# Biofouling: The Technological Mix

**Darren R. Jones**, NRG Marine Ltd (Sonihull), Coventry/UK, drj@sonihull.com

**Abstract**

*This paper focuses on how a proactive holistic approach in planning and operating in line with the direction of IMO Biofouling Guidelines and utilising next generation and greener technologies, such as Ultrasonics, can benefit, rather than hamper the industry.*

## 1. Introduction

We are a fifth of the way through the 21st Century, a century where we have recognised that mankind's activities have a global environmental impact.

The Maritime industry is not an island. Just as the rest of the world, it now has an awareness of the environmental impact it has. The industry now recognises how much $CO_2$ it produces, operators know how much $CO_2$ they create and fuel the use. And every operator now knows the same for each individual vessel.

The industry now also recognises the catastrophic effect of invasive species on the oceans eco systems.

As the world has become aware, the industry has become aware, so too have the regulators. Perceived inertia within the industry is driving regulators both internationally and unilaterally to step in.

It is unfortunate that that is the case. Regulation is only needed to rectify a market failure. The market has not, until recently, differentiated between good operators and poor operators in the arena of biofouling. The industry can choose to accelerate that or not. If it embraces change, the regulation is likely to be lighter and more effective.

The eyes of regulators are not just on the effects of fouling, but also the negative effects of some aspects of antifouling. Whether this be the effects of biocides or copper, or the introduction of microplastics through coatings and traditional abrasive in water cleaning. This creates a perfect storm.

The battle against biofouling is a global battle and a complex battle. It cannot be won by any single technology; it cannot be beaten by supply side without customer engagement. It cannot be won by vessel operators without ports supporting.

The biofouling problem can only be taken on by a technological mix and a collaborative approach.

## 2. Innovation through adversity

It is said that necessity is the mother of invention, but it is also the driver of adoption. Innovation and technology have always been affected by timing and that timing is the necessity. On the whole people, despite what they say, do not welcome change. They make excuses, they stick with the status quo and they stay in their comfort zones. Industry is run by people. Industries, no matter what sector, behave like people.

The new realisation of the environmental impact of our industry has now created the adversity to spur invention and the necessity of adoption. This is both on an ecological and financial level. Reducing $CO_2$, as now mandated, means saving fuel, the necessity of conforming to regulation brings adoption of new technology which brings cost savings in and of itself. This holds true if the technology, the innovation, is not just better than that that exists, but is also at a lower cost.

The industry is now at a point where the three factors of Environment, Cost and Technology are aligned, Fig.1, and the adoption will begin.

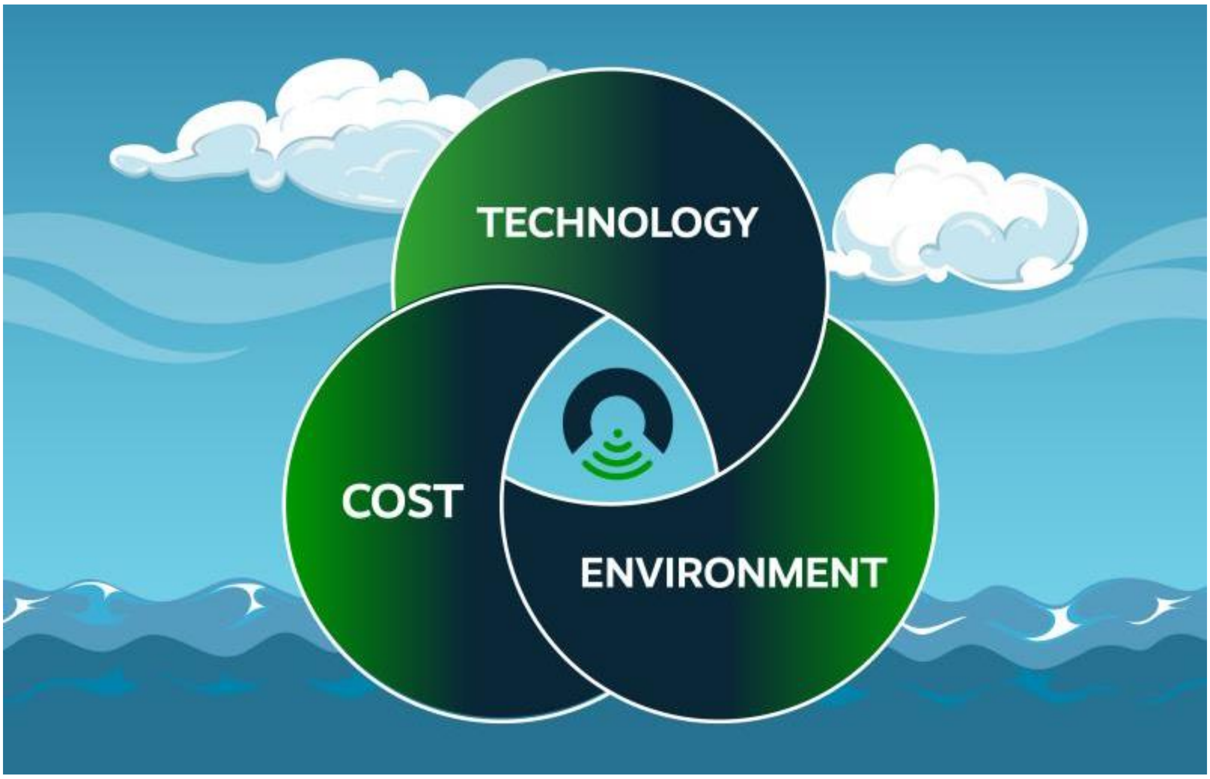



Fig.1: Technology, Cost and Environment now come together

**3. Technology**

Does the technology really exist to bring about fundamental change in the field of biofouling? Does it work? Is it proven? There will not be anyone in the area of biofouling who has not asked these questions. Depending on who they ask, they will get different answers.

So where does the truth lie? Is the technology there? The answer is yes, the technology does exist, it does work and it is proven. The answer is also no, the technology does not yet exist, it doesn't work and it isn't proven.

How can that be? The truth is that no one technology on its own is the solution. There is no device, design, coating or process that will solve the issues related to biofouling. However, a holistic approach, a joined-up approach can have an enormous impact, an impact that reduces biofouling and its associated costs.

**4. Which technologies or systems?**

There are several ways to come at biofouling in isolation. For decades we have been throwing biocides, toxins, at the problem. They have, to varying degrees, been very successful at reducing biofouling on hulls. However, the recognition of the environmental impact of putting millions of tonnes of biocides in our seas makes it inevitable that we should and will stop doing this. We will stop this of our own volition or under order of regulation.

On cooling systems, we have used sacrificial copper anodes, these have limited effect but still put thousands of tonnes of toxic metals into the oceans each year. Like biocides, copper is in the sights of the regulators.

The other standard technology is as old as shipping itself, abrasive cleaning. Often in water. This is of course often done as a reactive rather than reactive response. It is now also recognised that unless technology is adapted and adopted around this activity it can increase the transfer of invasive species and increase the introduction of microplastics into the oceans.

With these traditional methods ceasing to be as viable in their current form due to environmental ethics, efficacy and regulation where else does the industry turn.

Vessels still need coatings, ideally biocide free coatings. Coatings manufacturers are working on all sorts of solutions, industrial chemists are coming up with a multitude of formulas as they try to figure out ways of coating a vessel, protecting it from corrosion whilst also combatting biofouling.

But who are they working with? Are they talking to hull cleaners to understand where their technology is going? Are they talking to leaders in Ultrasonics to understand its effects and where it is going?

What types of coatings work best with the cleaning systems currently under development? What type of surface gets the best results with Ultrasonics? Are these questions being actively pursued?

Hull cleaning technology is developing rapidly, with robots, capture and multiple innovations. Are they being developed in conjunction with marine architects and new ship builders?

Is all this in alignment with Port authorities, regulators or operators?

The answer to these questions on cooperation, knowledge transfer and joint working is too often “no”.

This is a position that is unsustainable and will delay and deter adoption of effective systems and practices.

Developing technologies and systems in isolation will also lead to inferior technology. A unified, holistic approach will speed up development and increase efficacy in the battle against biofouling.

**5. Cooperation and competition can coexist**

Aerospace. Automotive. Electronics. All these sectors are hugely competitive but also hugely complex. No quarter is given in trying to gain market share or competitive advantage. Yet it is the very complexity of these industries that leads to technological cooperation. Whether it be OEM’s or in the supply chain, joint projects involving competitors are the norm. Whether it is Lockheed Martin with Boeing, in creating spacecraft, or Mercedes and Aston Martin creating cars and key components and systems.

The issue of biofouling is clearly a complex one. It involves as previously stated, coatings, vessel design, ultrasonics, cleaning and maintenance plans, ports. It also involves physics, marine biology, chemistry, oceanography, geography, and increasingly regulation.

It is clear that that is complex. A fundamental and material change in market and technological cooperation is required in the marine industry in order to respond to the challenges biofouling brings.

**6. Benefits of a cooperative R&D approach**

In order to alter the mindset of those involved in combating marine growth, it is necessary to highlight the benefits of working together and enhancing knowledge transfer.

Correct methodologies and formalised pilots, tests and programs enhance intellectual property rather than dilute it.

Many ideas go untried as cost and time prohibits their exploration. With a partnership approach much of the cost can be shared as can learning curves and data, reducing time and cost further.

A collaborative approach will also develop more effective solutions. A hard paint that works well with ultrasonic antifouling is best developed with both a coatings company and ultrasonics company involved. Isolation will double the costs, at least double the time and is likely to create technologies that do not align in synchronous development reducing their efficacy.

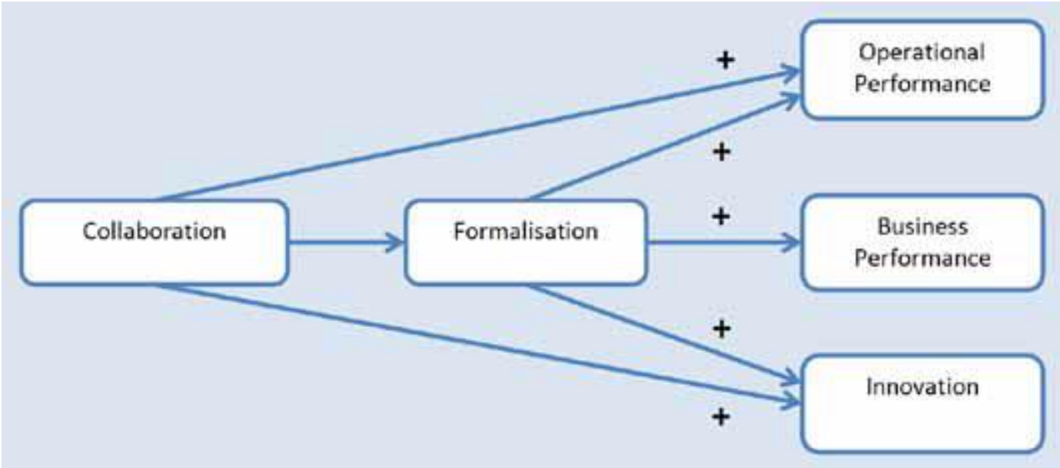



Fig.2: Relationships between collaboration, formalisation and performance outcomes, *Chakkol and Johnson (2015)*

Such an R&D project in isolation would require:

- Analysis of Ultrasonic surface effect
- Repeated and multiple test of differing coatings
- Laboratory assessment
- Test Plates experiment

It would require the resources of

- Marine Biologists
- Industrial Chemists
- Ultrasonics expert

This would all need repeating over and over again as with all experimental development, until an optimum surface is achieved. This would then likely fail to consider current or future designs of vessels that will alter the effects of ultrasonics and possibly coatings. It would not consider the effects of nascent cleaning technologies as it would use legacy data.

The benefits of a collaboration of companies and a mix of technologies brings pace, performance and future proof products. All this with lower risk and a lower price.

A collaboration of an ultrasonics company, a coatings company and a cleaning company would speed up the process and optimise. Instead of finding the perfect surface for ultrasonics, why not look at what coatings can be made with other performance parameters such as ease of application and lifespan and see which works best with ultrasonics. Combine this with the input of a hull cleaning technology provider to understand what they can and cannot cost effectively do, what the effect of their technology will be on the coating.

Bring in vessel operators to understand the optimum cleaning cycle cost compared to the preventative costs. Work with naval architects and design hulls that are easier to clean, particularly if only lightly fouled with soft fouling due to the application of ultrasonics.

Development time and cost must be reduced. Solutions must be future proof not temporary. Collaboration can achieve this.

This is of course only half the story. The Institute for Collaborative Working and Warwick Business School point out that collaboration between suppliers is ahead of that with customers and “there is still a gap between customer and supplier relationships that is not being exploited”.

## 7. The Technical Mix in Operation

With a true technical mix, operators will see reduced fouling. This will see reduced maintenance, corrosion and fuel usage. Reduced $CO_2$ emissions and faster speeds if desired. Handling will be improved as thrusters and other forms of propulsion deliver closer to their promised performance. Down time will be reduced. The risk of spreading invasive species will reduce as will the risk of falling outside of regulations, incurring fines, being denied port entry and gaining a poor environmental reputation.

The technological mix will have two starting points. Design for new build and MRO for existing fleet.

In new builds, naval architects will understand the cost and performance thresholds between different technologies. They will design areas that are easy to be cleaned by robots removing light fouling. They will utilise technologies such as ultrasonics in niche areas and have to compromise less on accessibility as they would require far fewer cleans and of softer fouling. The designs would allow for access for the necessary transducers with bulkheads and welds talking ultrasonic transmission into consideration, reducing the number of transducers required and increasing efficacy. Coatings could be specified to consider the specific area, if it is covered by ultrasonics and what the cleaning technologies effects will be. Areas that are easily, cheaply and safely cleaned could have reduced protection, reducing cost. Cooling systems could be smaller and more efficient if fouling were reduced or eliminated and a 5-year docking cycle became realistic.

Vessel Operators will plan for different hull management. It will include different cleaning cycles and different docking cycles. Technological mix will require different evidence to ports including inspection of preventative equipment. Will Ports require specific areas for cleans? Will vessels be cleaned outside of port? Will we have approved equipment to operate in every port or will each port have its own standard?

In MRO, different maintenance cycles and equipment may be required. Capacity for retrofitting new technologies will be required to meet the new regulatory pace. Heads of maintenance and fleet performance will have to evaluate the technological mix to understand what retrofitting or new technological and equipment adoption means to the bottom line while staying within the regulatory framework. Superintendents will need to evaluate the current condition and operations on their vessel and the practicality of deploying new systems. Finance directors will need to evaluate the capital investment or revenue costs of minimal change. This will be a boardroom to engine room effort.

A technological mix will see a greater balance and harmonisation between proactive and reactive biofouling maintenance.

## 8. Conclusion

The technologies to tackle the problems, operational, economic and environmental, of biofouling exist. They are here today. Like all technologies, they can be improved.

Not one of these technologies is the silver bullet. None of these technologies alone can cost effectively tackle the problem. To use just one would be either uneconomical, impractical or ineffective or all of these.

The biofouling problem is a complex problem. No one technology can work alone. As Tsinghua University concluded back in 2010, a technological mix is required. Current technologies working in harmony can dramatically reduce the problems and the costs associated with biofouling.

While making the technologies work together is a challenge, the bigger challenge is getting the various actors in the biofouling arena to work together.

The pace of change in regulation necessitates a change of systems and working practices. It necessitates a holistic approach and a mix of technology. This pace requires an industry-wide not just acceptance of change, but embracing of it.

It is imperative that operators and ports insist on cooperative working across technology providers, coatings companies, ultrasonic systems OEMs, cleaners and others. Demand side will dictate the behaviours of supply side.

Adoption of a technological mix now will give regulators pause for thought. Adoption now can help steer regulators to legislate for tomorrow not today. Regulations that will assist not hinder the industry, regulation that will only impinge on the lazy or unethical operators.

Adoption of a technological mix will reduce capital expenditure and operating costs.

Adoption of a technological mix will maintain our fleets, our ports and our oceans.

Adoption of a technological mix will make the marine industry fit for the 21st Century.

**References**

CAO, S.; WANG, J.D.; CHEN, H.S.; CHEN, D.R. (2011), *Progress of marine biofouling and antifouling technologies*, Chinese Science Bulletin 56/7, pp.598-612, https://core.ac.uk/download/pdf/186623699.pdf

CHAKKOL, M.; JOHNSON, M. (2015), *Benefits realisation from collaborative working*, Institute for Collaborative Working, Warwick Business School, https://instituteforcollaborativeworking.com/resources/Documents/collaborative_working_benefits_realisation_report.pdf

IMO (2019), *Hull scrapings and marine coatings as a source of microplastics*, Int. Maritime organisation, London, http://www.imo.org/en/OurWork/Environment/LCLP/newandemergingissues/Documents/Hull%20Scrapings%20final%20report.pdf

# In-Water Grooming of Fouling Control Coatings: From Research to Reality

**Geoffrey Swain, Melissa Tribou, Harrison Gardner, Kelli Hunsucker**,
Florida Institute of Technology, Melbourne/USA, swain@fit.edu

**Abstract**

*The proactive underwater cleaning of fouling control coatings is not new, however, advancements in underwater vehicles and robotics are enabling this technology to provide a practical solution for fouling control. The concept for ship hull grooming was first funded by the Office of Naval Research in 2005. The concept was to develop fully autonomous underwater vehicles equipped with grooming tools that could be deployed on the ship hull at a frequency that maintains the surface in a smooth and fouling free condition without creating a discharge that needs capture and treatment. The project required the design of grooming tools to match the coating and fouling pressure with minimum power consumption, a measure of the effect that grooming has on the coating and discharges to the environment, and the development of underwater vehicles with navigation and control systems to apply the grooming technology. This paper will focus on 15 years of research that investigated the requirements and the development of the grooming tool.*

## 1. Introduction

The concept of using frequent and light cleaning (grooming) to maintain fouling control coatings in a smooth and biofouling free condition is not new. Such procedures are often practiced by small boat owners whose vessels typically spend long periods of time on moorings or in marinas. The question is, can such a procedure be developed and applied to the ships of the Navy and large commercial vessels? The economic, operational and environmental drivers for developing in-water hull cleaning systems are well documented, *Townsin et al. (1981), Swain (2010), Schultz et al. (2011)*. Recent developments in underwater vehicle technologies, *Haworth and Irvine (2020), Kinnaman (2020)* in combination with new fouling control coatings, *Swain (1999), Dafforn et al. (2011), McClay et al. (2015),* may provide the opportunity to apply grooming as a practical method to better manage the outer ship hull condition.

The Office of Naval Research funded a ship hull grooming program which was developed to meet the following metrics:

- Proactive method to maintain coatings as smooth and fouling free over the open expanses of the hull surface – combat ready.
- Applied by small inexpensive fully autonomous vehicles.
- Acts synergistically with hull coatings:
    - removes silt, organics and incipient fouling
    - maintains coating function
    - does not degrade the coating
    - develop coatings that are designed to be groomed.
- Does not require capture and disposal:
    - No risk of invasive species
    - No risk from biocide free coatings
    - No increase in output of active ingredients.
- Incorporated as a part of ship operations
- Frequency to match biofouling pressure and ship's operational schedule
- Removes divers from the water
- Extended time between dry docking (8-12 years)

This paper will provide a background to the concept and summarize some of the lessons learnt over the past several years of research.

## 2. Background

The Center for Corrosion and Biofouling Control (CCBC) first looked at the interaction between fouling control coatings and in water cleaning in the mid-90s, *Wathen (1994)*, *Schumacher (1996)*. The idea was to develop underwater cleaning tools that would remove the biofouling that was found to develop on the early biocide-free silicone fouling release formulations. The idea resurfaced in 2003 when SeaRobotics submitted a proposal to the Office of Naval Research “The HullBUG, A miniature Underwater Vehicle for Cleaning Ship Hulls”. This initiated research to develop underwater cleaning technology to proactively maintain coatings in a fouling free condition (grooming), *Tribou and Swain (2010)*.

In 2012, we built a large-scale seawater test facility at Port Canaveral to evaluate the technology, provide a scientific understanding of the grooming process and to enable the development of grooming tools, Fig.1, *Hearin et al. (2015,2016)*. The research is now being transitioned through a Small Business Technology Transfer program by Greensea for the development of a fully operational semi-autonomous vehicle with grooming tool, *Kinnaman (2019)*. This paper will focus on our experience with the development of grooming technology for two US Navy qualified fouling control coatings; Interspeed BRA 640, an ablative copper antifouling coating and Intersleek 1100, a silicone-based fouling release coating that were immersed at our research site at Port Canaveral, Florida.


Fig.1: Test site location, support vessel and test panel assembly at Cape Marina

The drivers for this research were based upon the coating types and operational schedule of US Navy ships. Ninety-nine percent of the US Navy fleet’s underwater hull area (>1.1 million m2) are coated with copper ablative antifouling (AF) paint. A few ships have also been coated with silicone-based fouling release coatings. Most of these ships have a low duty cycle in that they spend 40–60% of their time pier-side which makes them vulnerable to fouling, *Martin and Ingle (2012)*. Biofouling management is presently based upon criteria presented in Chapter 8 of *NSTM (2006)*, Fig.2. For example, the criteria to trigger a full hull clean for ablative and self-polishing paints are that a fouling rating of FR-40 or greater exists over 20 percent of the hull, exclusive of docking block areas and appendages. For fouling release coatings NAVSEA Code 00C are contacted for cleaning advice when a fouling rating of FR-50 or greater is observed over 10 percent of a hull. A study that looked at the primary costs for hull fouling on the US Navy fleet of DDG-51 frigates concluded that savings as high as $12m/ship over a 15-year period could be achieved if the hull condition was maintained at a fouling rating of 10, which is described as deteriorated coating with light slime, Schultz et al. (2011). It has been shown that regular grooming of BRA640 and IS1100 is able to maintain them at a fouling rating of 0.

| Type | Fouling Rating (FR) | Description |
|---|---|---|
| Soft | 0 | A clean, foul-free surface; red and/or black AF paint or a bare metal surface. |
| Soft | 10 | Light shades of red and green (incipient slime). Bare metal and painted surfaces are visible beneath the fouling. |
| Soft | 20 | Slime as dark green patches with yellow or brown colored areas (advanced slime). Bare metal and painted surfaces may by obscured by the fouling. |
| Soft | 30 | Grass as filaments up to 3 inches (76 mm) in length, projections up to 1/4 inch (6.4 mm) in height; or a flat network of filaments, green, yellow, or brown in color; or soft non calcareous fouling such as sea cucumbers, sea grapes, or sea squirts projecting up to 1/4 inch (6.4 mm) in height. The fouling can not be easily wiped off by hand. |
| Hard | 40 | Calcareous fouling in the form of tubeworms less than ¼ inch in diameter or height. |
| Hard | 50 | Calcareous fouling in the form of barnacles less than ¼ inch in diameter or height. |
| Hard | 60 | Combination of tubeworms and barnacles, less than ¼ inch (6.4 mm) in diameter or height. |
| Hard | 70 | Combination of tubeworms and barnacles, greater than ¼ inch in diameter or height. |
| Hard | 80 | Tubeworms closely packed together and growing upright away from surface. Barnacles growing one on top of another, ¼ inch or less in height. Calcareous shells appear clean or white in color. |
| Hard | 90 | Dense growth of tubeworms with barnacles, ¼ inch or greater in height; Calcareous shells brown in color (oysters and mussels); or with slime or grass overlay. |
| Composite | 100 | All forms of fouling present, Soft and Hard, particularly soft sedentary animals without calcareous covering (tunicates) growing over various forms of hard growth. |

Fig.2: Fouling rating in order of severity Table 081-1-1 from the NSTM Ch. 8

**3. Grooming Technology**

The majority of ship hull cleaning devices have been designed to remove fouling on an as need basis with correspondingly high cleaning forces that may damage the coating and require effluent capture systems, *Curran et al. (2016), Scianni and Georgiadis (2019), Oliveira and Granhag (2020)*. The effluent may then be classified as hazardous waste. The grooming device developed by this research was designed to operate within a well-defined grooming zone, Fig.3. The grooming zone is defined as the region where small accumulations of biofilm and incipient fouling with low adhesion strength are removed by a cleaning force that does not damage the coating and create a discharge that requires capture and treatment. This will also ensure minimum wear to the brushes and a low power consumption which is a requirement for autonomy.

The grooming tools used in these trials were continually updated to reflect improvements in design, however, the basic design consisted of five 120mm diameter vertically rotating bushes each driven and controlled by a Maxon EC 22 brushless motor and GP 22HP gearhead. The brushes were rotated between 400 to 800 rpm and this created an internal vortex which attracts the brush to the surface and imparts normal forces between 12 to 48N. The brushes were mounted to articulating arms that allowed the brushes to conform to surface irregularities and they were attached to a SeaBotix vLBV remotely operated vehicle for deployment over the surface, Fig.4.

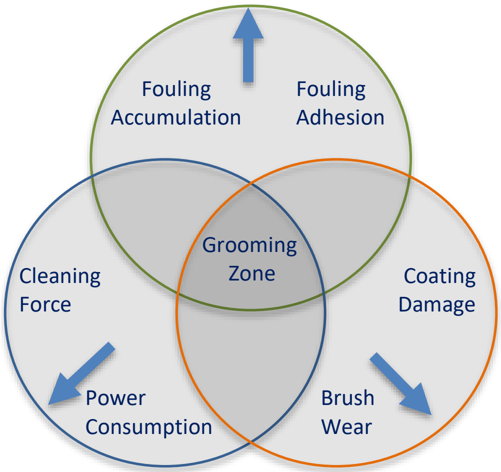



Fig.3: The grooming zone

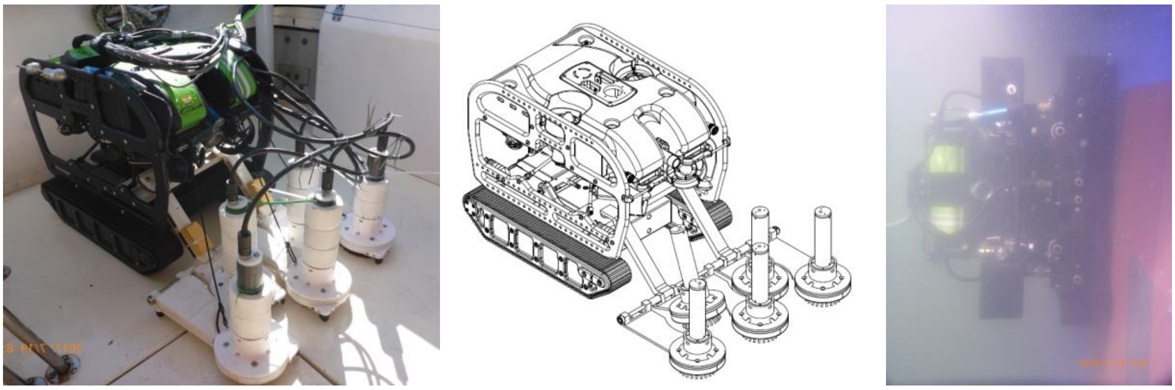


Fig.4: SeaBotix vLBV ROV plus grooming tool attachment

There was slight overlap between the brushes and width of the grooming swath was 560 mm. A typical translation rate over the surface was 0.25 m/s with a 50% overlap. This gives a grooming rate of 250m$^2$/h. Therefore, one device would take about 12 hours to groom an Arleigh Burke class destroyer (DDG-51) with a wetted surface area of ~3000 m$^2$.

**4. Methods**

The field tests were conducted at Port Canaveral, Florida, a location with high fouling activity, an average temperature of 25±4.2° C, an average salinity of 35±1.2 ppt, and water depths exceeding 4 m, Fig.5. The large-scale test facility comprises three 2.4 m x 4.57 m x 6.35 mm thick steel plates that were welded to 0.76 m diameter steel pipe for floatation. The structures were coated with Intergard epoxy anticorrosive paint and a topcoat of either Interspeed BRA 640 (BRA640) copper ablative or Intersleek 1100 (IS1100) fouling release coatings. The steel panels were orientated vertically under the steel pipe, which provided floatation. They were moored alongside a 34' Mainship trawler which acted as a support vessel for deployment and control. The fouling control coatings were subjected to regular grooming and changes in coating condition and biofouling monitored.

One panel for each coating was groomed once a week and one panel for each coating left to foul. If the fouling level reached the Naval Ships' Technical Manual definition for cleaning, then the panels were manually cleaned back by divers using handheld cleaning tools. Dry film thickness measurements were made using an Elcometer 456 separate coating thickness gauge, and coating roughness measurements were made using the TQC Hull Roughness Analyzer. DFTs and roughness were measured yearly, and when dry docked for hurricanes. At each inspection about 500 DFT measurements were taken over the whole surface using templates used to take repeat measurements in the same locations. About 400 rt50 measurements were taken over the whole surface using the TQC Hull Roughness Analyser.

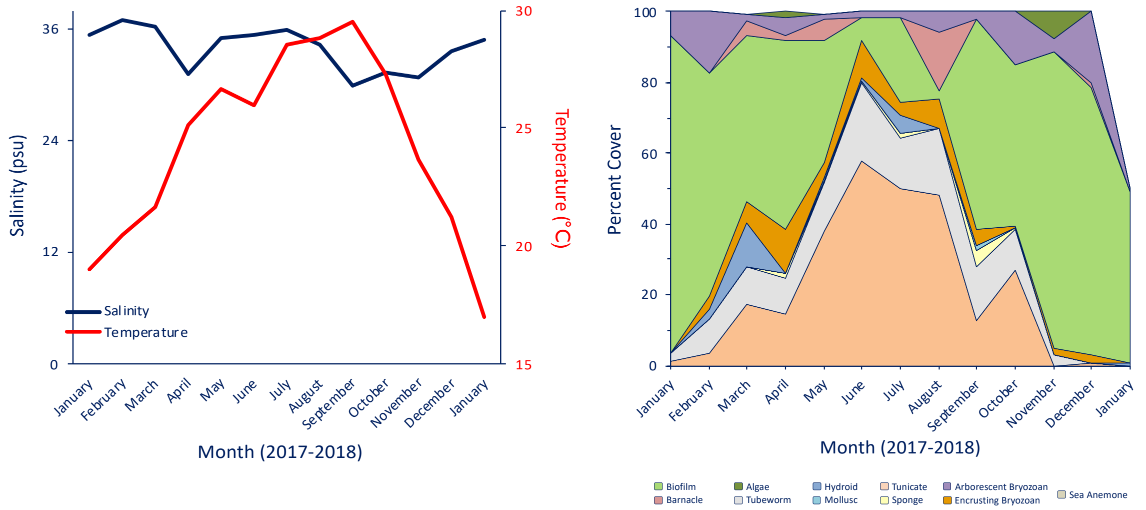



Fig.5: Temperature, salinity and biofouling data, Port Canaveral

## 5. Results

### 5.1. Intersleek 1100

The IS1100 grooming trials ran for 33 months, Fig.6. The ungroomed panel became fouled with biofilms, encrusting bryozoans and tubeworms. These required diver cleaning after 18 and 34 months. Another cleaning occurred during dry docking in October 2016 due to a hurricane. The groomed panel was maintained free of fouling throughout the immersion period except for a tenacious biofilm that sometimes became established and some encrusting bryozoans. The tenacious biofilm development has been partially solved by the development of an improved brush design which is more effective at grooming the fouling release coatings.

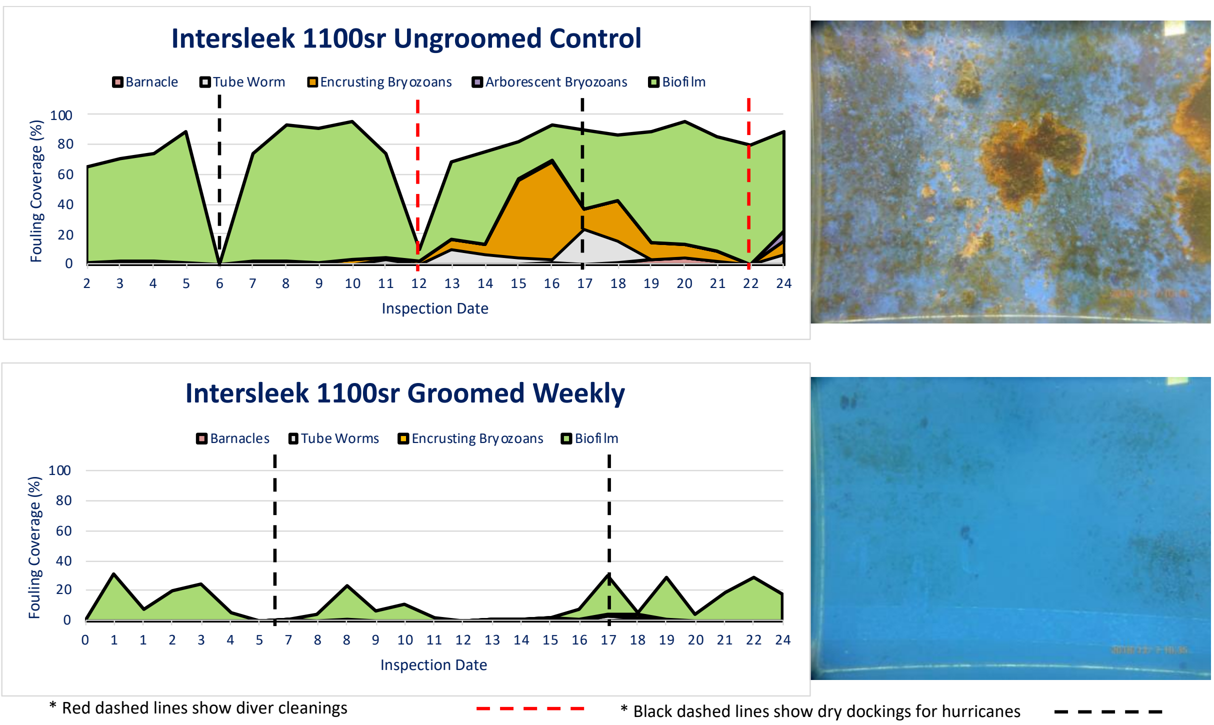



Fig.6: The fouling progression on an ungroomed and groomed IS1100 coating.

Dry film thickness and coating roughness measurements were taken after 12, 24, 33 and 35 months immersion, Fig.7. There was no significant difference in DFT during the immersion period. The average coating roughness stayed the same, however, there was an increase in the standard deviation after 24 months which can be explained by small "nicks" in the coating created by fish grazing on the surface. This was greater on the ungroomed than groomed surface.

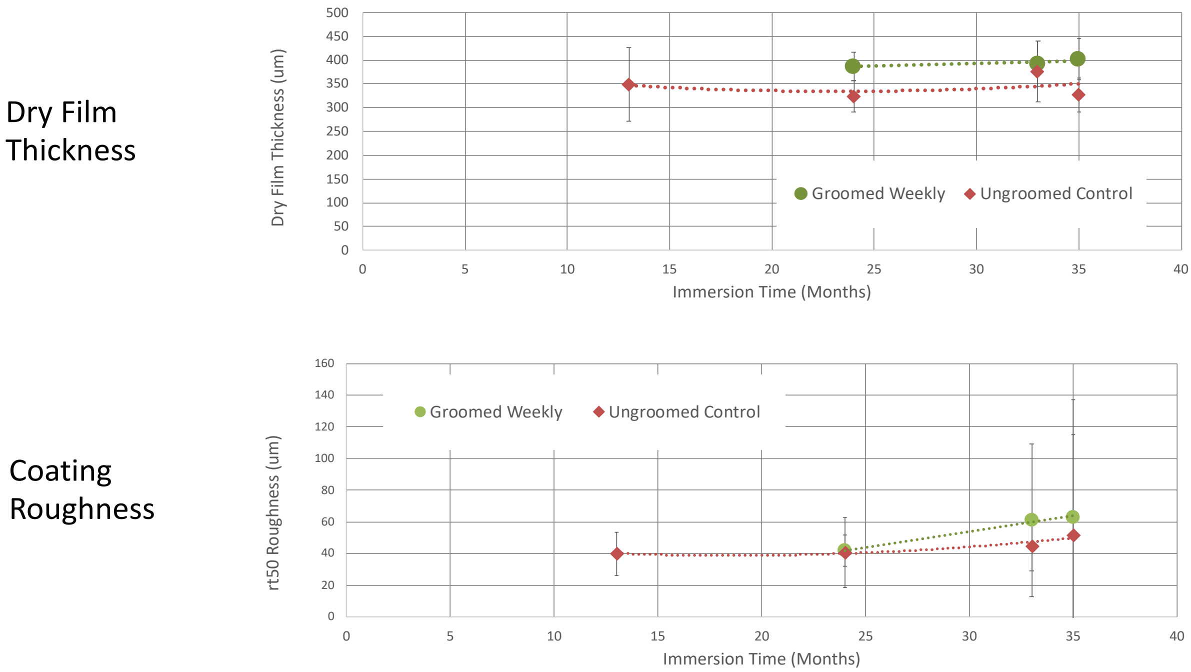



Fig.6: Dry film thickness and roughness measurements on groomed and ungroomed IS1100 coating

**5.2. Interspeed BRA640**

The BRA640 grooming trials ran for 45 months, Fig.8. The ungroomed panel became fouled with biofilms, encrusting bryozoans, arborescent bryozoans, barnacles, tubeworms and colonial tunicates. These required diver cleaning after 8, 14, 23, 30 and 47 months. Another two cleanings occurred during dry docking due to hurricanes. The groomed panel was free of fouling throughout the immersion period except for a tenacious biofilm that sometimes became established and the occasional barnacle. The tenacious biofilm development has been partially solved by the development of a hybrid brush which is more effective at grooming the BRA 640 coating.

Dry film thickness measurements and coating roughness measurements were taken after 12, 24, 33, 35 and 48 months immersion, Fig.9. There was a gradual and linear reduction in the DFT during the immersion period. This was due to the constant ablation of the coating which is designed to release copper at a level required to prevent fouling. The average copper release rate was calculated using the ISO 10890: Paints and varnishes —Modelling of biocide release rate from antifouling paints by mass-balance calculation.

M = L*a*w*p*DFT/NV

Where: M = Mass Biocide Released over lifetime of paint (micrograms/cm$^2$)
L = 100 (Percent Biocide Released During Lifetime of Paint)
a = 0.86 (mass fraction of biocide in biocidal ingredient)
w = 41.79 (% by mass content of biocide in paint)
p = 2.26 (density of paint g/cm$^3$)
DFT = ?? (dry film thickness µm)
NV = 58.03 (volume solids content of paint)

The average reduction in dry film thickness for both the groomed and ungroomed surfaces was 28 microns/year. Applying 41.79 as the % mass content of cuprous oxide; 0.86 mass fraction of biocide in biocidal ingredient; 2.26 density of paint g/cm$^3$; and 58.03 volume solids content of paint; the average copper output was calculated to be 11.0 ug copper/cm$^2$/day.

The average coating roughness for the groomed surfaces stayed the same, however, there was an increase in the roughness on the ungroomed panel caused by damage to the coating during the cleaning events.

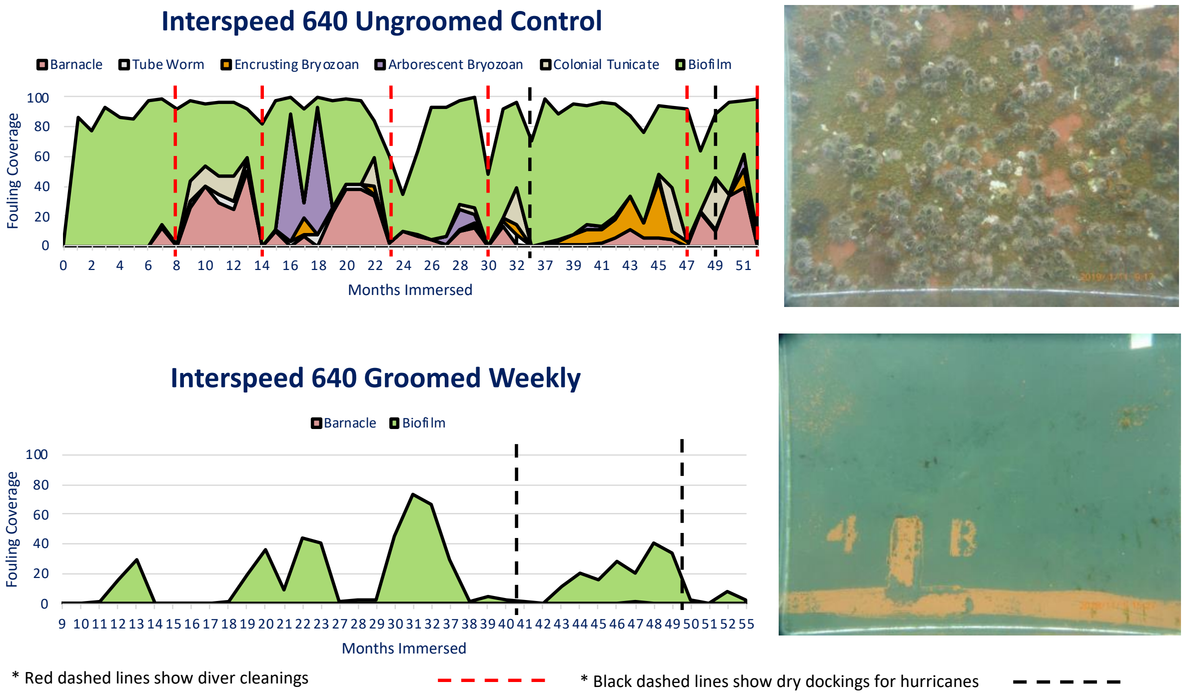



Fig.7: The fouling progression on an ungroomed and groomed BRA640 coating

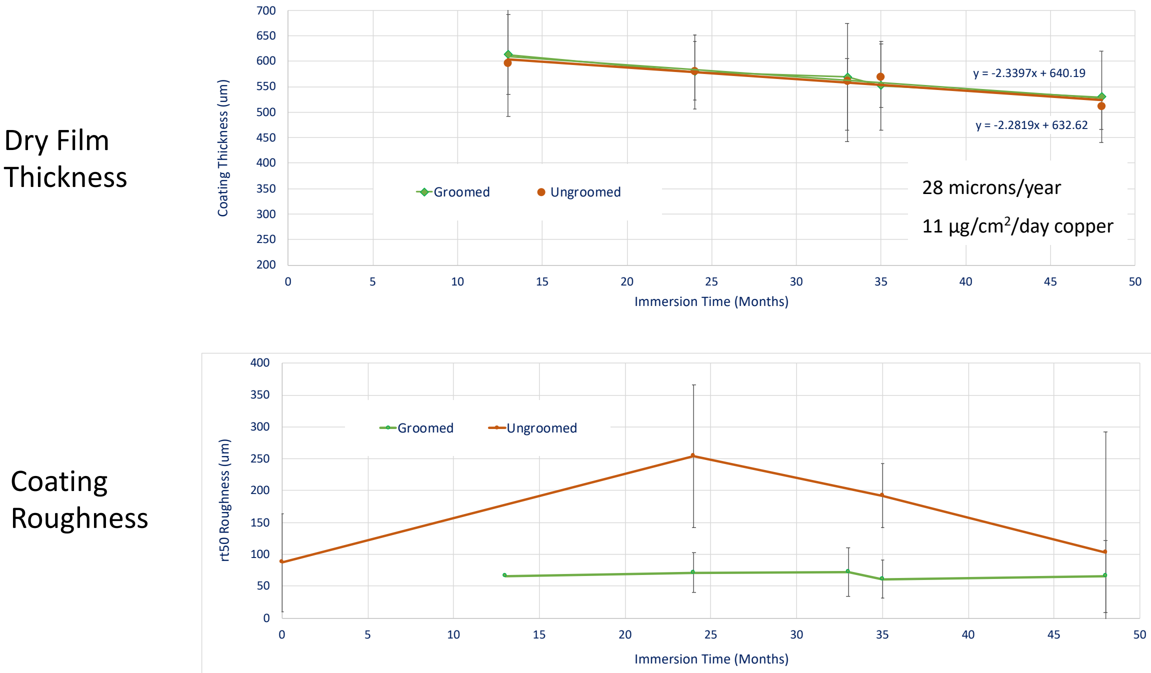



Fig.8: DFT and roughness measurements on groomed and ungroomed Interspeed BRA640

## 6. Summary

The long-term grooming trials for the Intersleek 1100 and the BRA640 at Port Canaveral have conclusively demonstrated that gentle, proactive in water cleaning of fouling control coatings which are left in a high fouling static immersed environment is able to maintain the surface in a smooth and fouling free condition without damage, excessive wear or increased chemical input into the environment.

Other questions that have and are being addressed are:

- How does location affect grooming frequency?
- How will ship schedule affect grooming?
- How will grooming work when applied to other fouling control coatings?

The answer to these questions is that the grooming brush, methods and frequency have to be designed and managed to compliment the location, ship schedule and fouling control coating. The basic understanding to optimize the grooming method for different situations is available. The technology to design and build the vehicles required to implement an autonomous or semiautonomous grooming process are being developed. This will then provide ship owners with an alternative method to better manage fouling control coatings.

**Acknowledgements**

We would like to acknowledge the support from the Office of Naval Research (N00014-10-1-0919, N00014-16-1-3050, N6833518C01471) and the program managers, Dr Stephen McElvany and Dr. Paul Armistead. Also, the many people who have been directly involved or contributed to the work. Don Darling, Ken Hollopa and Ben Lovelace (SeaRobotics); Ben Kinnaman, Karl Lander and James Truman (Greensea); Matt Naiman and Bill Hertel (NSWC); and the following students and staff from FIT: Caglar Erdogan, Michael Harper, John Hearin, J. Travis Hunsucker, Kodi Liberman, Mark Nanney, Emily Ralston, Abraham Stephens, Ann Wassick, Bruce Walker.

**References**

DAFFORN, K.; LEWIS, J.; JOHNSTON, E. (2011), *Antifouling Strategies: history and regulation, ecological impacts and mitigation*, Marine Pollution Bulletin 62, pp.453-465

HAWORTH, C.; IRVINE, G. (2020), *Subsea autonomy is moving beyond waypoints*, Hydro E-Newsletter

HEARIN, J.; HUNSUCKER, K.; SWAIN, G.; GARDNER, H.; STEPHENS, A.; LIEBERMAN, K. (2016), *Analysis of mechanical grooming at various frequencies on a large-scale test panel coated with a fouling-release coating*, Biofouling 32/5, pp.561-569

HEARIN, J.; HUNSUCKER, K.; SWAIN, G.; GARDNER, H.; STEPHENS, A.; LIEBERMAN, K.; HARPER, M. (2015), *Analysis of long-term mechanical grooming on large-scale test panels coated with an antifouling and a fouling-release coating*, Biofouling 31/8, pp.625-638

HUNSUCKER, K.; VORA, G.; TRAVIS HUNSUCKER, J.; GARDNER, H.; LEARY, D.; KIM, S.; LIN, B.; SWAIN, G. (2018), *Biofilm community structure and the associated drag penalties of a groomed fouling release ship hull coating,* Biofouling

HUNSUCKER, K.; BRAGA, C.; ERGODAN, C.; GARDNER, H.; HEARIN, J.; RALSTON, E.; SWAIN, G.; TRIBOU, M.; WASSICK, A. (2018), *The Advantages of Proactive in Water Hull Grooming from a Biologists Perspective,* HullPIC, Redworth

KINNAMAN, B. (2019), *The Future of Autonomous Robotic Hull Grooming*, Maritime Reporter and Engineering News, March

KINNAMAN B (2020), *Greensea's new ship hull crawler tech launches with VideoRay Defender*, Marine Technology News, April

MARTIN, F.; INGLE, M. (2012), *Shipboard coatings developments and emerging surface technologies*, http://www.asetsdefense.org/documents/Workshops/SustainableSurfaceEngineering2009/Agenda/Tuesday/Martin%20-%20For%20Posting.pdf

McCLAY, T.; ZABIN, C.; DAVIDSON, I.; YOUNG, R.; ELAM, D. (2015), *Vessel Biofouling Prevention and Management Options Report*, Report No. CG-D-15-15, U.S. Department of Homeland Security

NSTM (2006), *Naval Ships' Technical Manual Ch.081 – Waterborne underwater hull cleaning of Navy ships*, Publication # S9086-CQ-STM-010/CH-081 Revision 5, Naval Sea Systems Command, . Washington (DC)

OLIVEIRA, D.; GRANHAG, L. (2020), *Ship hull in-water cleaning and its effects on fouling-control coatings*, Biofouling, pp.332-350

SCHULTZ, M.; BENDICK, J.; HOLM, E.; HERTEL, W. (2011), *Economic impact of biofouling on a naval surface ship*. Biofouling 27, pp.87-98

SCHUMACHER, K. (1996), *An instrumented rotating brush device to evaluate the removal of biofouling from non-toxic antifouling coatings*, MS Thesis, Florida Institute of Technology, Melbourne

SCIANNI, C.; GEORGIADES, E. (2019), *Vessel in-water cleaning or treatment: identification of environmental risks and science needs for evidence-based decision making*, Front Mar Sci. 6, pp.1-12

SWAIN, G. (1999), *Redefining Antifouling Coatings*, J. Protective Coatings and Linings 16/9, pp.26-35

SWAIN, G. (2010), *The importance of ship hull coatings and maintenance as drivers for environmental sustainability*, RINA Conf. Ship Design and Operation for Environmental Sustainability, London

SWAIN, G.; TRIBOU, M. (2014), *Grooming an option for fouling control*, J. Ocean Technology 9/4

TOWNSIN, R.L.; BYRNE, D.; SVENSEN, T.E.; MILNE, A. (1981), *Estimating the technical and economic penalties of hull and propeller roughness*, Trans SNAME 89, pp.295-318

TRIBOU, M.; SWAIN, G. (2010), *The use of proactive in-water grooming to improve the performance of ship hull antifouling coatings*, Biofouling 26/1, pp.47-56

TRIBOU, M.; SWAIN, G. (2017), *The effects of grooming on a copper ablative coating: a six year study*, Biofouling 33/6, pp.494-504

TRIBOU, M.; SWAIN, G. (2015), *Grooming using rotating brushes as a proactive method to control fouling*, Biofouling 31/4, pp.309-319

WATHEN, T. (1994), *The design of brush technology for the evaluation of non-toxic foul release coatings*, MS Thesis, Florida Institute of Technology, Melbourne

ZARGIEL, K.; SWAIN, G. (2014), *Static vs dynamic settlement and adhesion of diatoms to ship hull coatings*, Biofouling 30, pp.115-129

# Roadmap from the Wild West to the Promised Land of Ship Cleaning

**Alex Noordstrand**, Fleet Cleaner, Delft/The Netherlands, a.noordstrand@fleetcleaner.com

**Abstract**

*Several authorities are working on environmental regulations for the underwater hull cleaning industry. There is not yet an international standard and therefore local and national authorities are crafting regulations. This paper presents Porter's Hypothesis which presents the relation between environmental regulations and innovation. If the environmental regulations for the hull cleaning industry are well crafted, more innovation will come, and the environmental impact is reduced, and the profitability of the innovating company increases. Some suggestions for regulating authorities are given which can be implemented to drive innovation and to create a sustainable industry.*

## 1. Introduction

Fouling on ship's hulls is a well-known phenomenon in the shipping industry. Fouling leads to more ship resistance and therefore higher fuel consumption. To minimize the impact of fouling, coating manufacturers tried to eliminated fouling on the hull by designing anti-fouling coatings. The most effective anti-fouling coatings use biocides as ingredients. The anti-fouling coating is designed in such a way that the biocides are gradually released onto the surface and into the water such that the hull is kept clean of fouling. Managing the biocide release of an anti-fouling coating is relatively complex and if it is not going as planned, fouling will grow on the vessels. There are many factors influencing the growth of fouling on the hull like the trade of a vessel, idle times, anti-fouling application, coating design, water conditions, etc.

When significant fouling occurs on the vessel, most ship owners and operators decide to clean the vessel to minimize the additional fuel consumption caused by fouling. In general, diver-operated tools or remotely operated vehicles (ROVs) equipped with brushes or high-pressure water jets are used to remove fouling from the ship's hull. During the processes of removing the fouling, also coating particles including biocides will be removed due to the design of the anti-fouling. Well-known cleaning locations are the anchorages of Singapore, Fujairah, Gibraltar, Algeciras, Panama, and Las Palmas. Some of these locations can be compared with the "wild west", since hardly any environmental regulations and law enforcement is in place. The service providers do not have the incentive to use fouling capturing and filtering technology. Consequently, coating and fouling particles are released into the surrounding waters resulting in contaminated water and seabed, and the risk of invasive species. This is the main reason why most authorities decided to ban hull cleaning.

Over the last decade, several incentives were launched of hull cleaning machinery equipped with fouling capturing capabilities. Some progressive ports decided to cooperate with a pilot of these technologies and make (temporary) regulations allowing hull cleaning within port. The main advantage of hull cleaning during port time is that ship owners and operators avoid downtime because the ship can be cleaned during normal cargo handling operations.

There are no international regulations for fouling capturing and filtering during hull cleaning. So far, each local or national authority makes its own regulations. Consequently, the invented fouling capturing and filtering systems used by hull cleaning service providers vary from place to place in effectiveness. In some places the local environment is contaminated more than in other places. In this paper we will apply Porter's hypothesis about the relation between environmental regulations and innovation to in-port cleaning. Porter's hypothesis is often used by authorities to increase the effectiveness of new environmental regulations. In this paper we provide corresponding suggestions to create a hull cleaning industry with less environmental impact.

## 2. Porter's Hypothesis

Michael Porter from the Harvard Business School directed scientific attention towards the relation between regulations and environmental innovation, *Porter (1991)*. Until that time, the traditional view of virtually all economists was that more environmental regulations resulted in a profit reduction for firms. Their idea was that requiring firms to reduce an externality like pollution, will restrict their options and thus by definition will reduce their profits. After all, if profitable opportunities existed to reduce pollution, profit-maximizing firms would already be taking advantage of them. Porter showed that well designed environmental regulations result in innovations that not only reduced the environmental impact but also result in a cost saving for the firm and in the long run a head start for the innovative firm on its competitors. Porter's message is that there seems to be no trade-off between economic growth and environmental protection but a win-win situation instead.

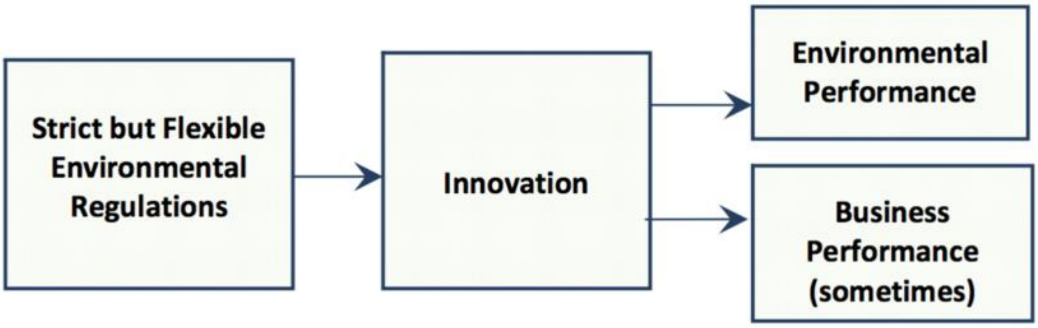



Fig.1: Porter's hypothesis

*Porter and van der Linde (1995)* explain that there are at least five reasons that properly crafted regulations may lead to these outcomes:

1. Regulations signal likely resource inefficiencies and potential technological improvements.
2. Regulations focused on information gathering raise corporate awareness.
3. Regulations reduce the uncertainty whether investments to address the environment will be valuable.
4. Regulations create pressure that motivates innovation and progress
5. Regulations level the transitional playing field

The general validness of the Porter's hypothesis is widely accepted but two versions of the hypothesis are developed, a weak and strong version. The 'weak' version is: "strict environmental regulations result in more innovation". This version is backed by empirical research and is generally accepted. The 'strong' version of the hypothesis is: "strict environmental regulations improve the competitive advantage of a company". Empirical evidence for this model is less evident, *Ambec et al. (2013)*. According to Porter's model, if authorities want to minimize the environmental impact of hull cleaning companies, they should implement well-crafted regulations for hull cleaning providers. With well-crafted regulations businesses will innovate such that more environmentally friendly technologies and processes will be implemented.

## 3. What is a well-crafted environmental regulation?

Porter's model is only valid for well-crafted environmental regulations. Not all environmental regulations result in radical innovation. If environmental standards are to foster the innovation offset that arise from new technologies and approaches, they should adhere to three principles:

1. Environmental regulations should be made such that there is maximum opportunity for innovation, leaving approach to innovation to the industry and not to the standard-setting authority.

2. Environmental regulations should foster continuous improvement, rather than locking in any technology or status quo.
3. The regulatory process should leave as little room as possible for uncertainty at every stage.

## 4. Suggestions to create a hull cleaning industry with minimal environmental impact

In this final chapter, we will give suggestions how the above-mentioned theory can be used by regulating authorities to create environmental regulations for the hull cleaning industry. Well-crafted regulations ensure that more radical innovations will be introduced into the market and that the environmental impact of the hull cleaning industry is minimized.

- Maximize opportunity for innovation
  - In regulating, authorities could specify the maximum environmental impact of the cleaning operation. The maximum release at the cleaning apparatus and of the filtered wastewater should be limited; practical examples are to set a limit of particle size and quantity of metals and fouling in filtered water. Corresponding with the Sustainable Development Goals the environmental impact of hull cleaning may even be set to zero by 2030. Companies will innovate and come up with various fouling capture systems and waste water filter or treatment systems to comply with the regulations and maximize efficiency.

- Foster continuous improvement
  - It is difficult to use the captured waste as a residual product because the waste is seen as light chemical waste mainly due to the biocides in anti-fouling. Therefore, the captured waste should be processed by certified waste handling companies incurring additional cost to the cleaning company. In the current market, there is no financial incentive to capture more waste. If more waste is captured, more costs are incurred to the cleaning company resulting in lower profits. A financial incentive could be introduced by the port authority to the cleaning provider. The cleaning company should be rewarded for the capturing waste. In several ports seagoing ships are obligated to pay a waste charge for the collection and processing of ship-generated waste. This waste charge ensures that the polluter, the ship itself, pays for the generated waste. In addition, the waste charge gives an incentive to the waste processing company to collect the waste. A “fouling charge” for ships could be introduced by port authorities to ensure that the ship owners pays for the captured waste. The port authority could allocate a part of the fouling charge to the hull cleaning company when waste is delivered to a waste collector. If the income from the fouling charge is more than the cost of the innovative capturing and filter system, the cleaning company could increase its business performance.
  - Regulators could make the regulation such that they become stricter over time to drive to ensure that companies know they continuous must innovate their product and process to comply with future regulations. An example is to increase quality requirements of filtered wastewater over time.
  - Implement a waste registration system for hull cleaning companies to ensure that the captured waste per vessel is measured and registered. This should be published to the authorities; collecting this information will result in an increased awareness within companies and authorities. The authorities could use this information to benchmark cleaning companies and to push cleaning companies to increase innovation. If a cleaning company consistently captures less fouling compared to other companies, the authorities could push the underperforming company to innovate or to exit the market.

- Minimize uncertainty
  - Ensure that the market uncertainty is reduced by implementing strict environmental regulations for a long period. This is important to ensure that the investments made by companies to comply with the environmental regulations can be earned back. Authorities could

provide an environmental permit to the hull cleaning company for a temporary duration during the pilot stage. This temporary permit gives a lot of uncertainty to earn the investments back. An intention of the authorities to prolong the permit if the innovation results in the desired outcome could reduce the uncertainty.

- Environmental regulations without proper law enforcement result in uncertainty for companies to earn their investment back because not complying with the regulation creates a competitive advantage. Companies that do not make the investments to comply with environmental regulations have a competitive advantage. If competing companies cut the corners by not complying with the regulations, an unequal playing field arises if they are not controlled and penalized. As a result, innovation in the industry stops because companies cannot earn their investments back.

## 5. Recommendations

The current hull cleaning industry is fragmented with several local cleaning providers competing on a global market. Radical innovations for fouling capturing and filtering technology are needed to ensure that the environmental impact of the hull cleaning industry is reduced. We recommend local authorities to work together and craft strict but flexible environmental regulations to create a level playing field between cleaning locations. A level playing field is essential for innovative companies to make sure that they can earn their investment back.

## References

AMBEC, S.; COHENY, A.A.; ELGIEZ, S.; LANOIE, P. (2013), *The Porter Hypothesis at 20: Can Environmental Regulation Enhance Innovation and Competitiveness?*, Review of Environmental Economics and Policy, Association of Environmental and Resource Economists 7/1, https://people.unica.it/carlamassidda/files/2012/04/Ambec-et-al2013_Can-Environmental-Regulation-Enhance-Innovation-and-Competitiveness.pdf

PORTER, M.E.; VAN DER LINDE, C. (1995), *Toward a New Conception of the Environment-Competitiveness Relationship*, J. Economic Perspectives 9/4, pp.97-118, https://pubs.aeaweb.org/doi/pdfplus/10.1257/jep.9.4.97

# Quality Assurance for Underwater Cleaning Work

**Gunnar Pihl,** Pihl Expert GmbH, Hamburg/Germany, gunnarpihl@pihl-expert.de


### Abstract

*This paper describes concepts and strategies for Quality Assurance for Cleaning Works Underwater*

- *Specification of underwater cleaning work*
- *Quality criteria for cleaning work results, cleaned surface, emission to surrounding water*
- *Cleaning work methods, tools / pressure / speed / volume flow of cleaning water e.g.*
- *Standards for degrees of surface cleanness*
- *Measurement / control of above mentioned criteria*
- *Measurement / control accuracy check*


### 1. Introduction to Quality Assurance for Cleaning Works Underwater

The following aspects need to be addressed:

- Specification of cleaning work

  Any work order needs a clear specification to enable contracting parties to check the work result. The specification should include the work method, the work result and the influence on the surrounding. The work results need to be defined with repeatable measurable criteria, preferably according to industry accepted standards.

- Quality criteria for cleaning work results, cleaned surface, emission to surrounding water

  Quality criteria are substantial for a work specification, for each of the above-mentioned aspects, and needs to be defined in a verifiable way. The influence on the surrounding needs to be specified with measurable / checkable quality criteria.

- Cleaning work methods, tools / pressure / speed / volume flow of cleaning water, etc.

  The work method is often a topic of a work specification and needs to be defined properly.

- Standards for degree of surface cleanness

  The degree of surface cleanness is the main point of the specification and quality criteria. On air, a lot of industry recognized standards about surface cleanness are available. It needs to be checked which criteria defining standards can and should be used underwater.

- Measurement / control of above-mentioned criteria

  To check work results against quality criteria, measurements are often used. Measurement can also be performed by visual comparison with comparative pattern. Industry-recognized measurement standards are available. It needs to be checked which of these can be used underwater.

- Measurement / control accuracy check

  To enable repeatable measurements, measurement accuracy needs to be known, defined and checked. Therefore, the measurement accuracy needs to be checked before any measurement. Especially underwater with changing conditions like water temperature, salt, turbidity, currents, the actual accuracy needs special attention.

# In-Transit Cleaning of Hulls

**Rune Freyer**, Shipshave AS, Stavanger/Norway, rune.freyer@shipshave.no
**Eirik Eide**, Shipshave AS, Stavanger/Norway, eirik.eide@shipshave.no

**Abstract**

*A new method allows In-Transit Cleaning of Hulls (ITCH) by "grooming". ITCH at commercial speeds avoids the need of idling vessels in harbor for cleaning operations. The effluents from the cleaning operations with ITCH are disposed in deep waters offshore, with an objective of avoiding costal pest invasions. The ITCH method has been successfully tested on vessels with speed of between 9 and 14.5 knots at sea. The paper will discuss the learnings from the initial tests. The overall objectives of the ITCH are to clean the hull while maintaining the vessel schedule, to have very low costs per hull cleaning and to avoid damages to the hull paint.*

## 1. Introduction to In-Transit Cleaning of Hulls

The commercial motivation for cleaning vessel hulls under water is to reduce the fuel consumption related costs, which is a large part of the total operating costs of commercial vessels. The hydrodynamic surface roughness caused by biofouling is reduced, and the viscous resistance is lowered. The environmental motivations are to avoid transport of invasive species and reduce greenhouse gas emissions due to a lower fuel consumption.

The cleaning methods has traditionally involved divers or dry docking, but underwater cleaning techniques are nowadays much more common due to the lower cost and shorter off-hire durations. Some challenges with the methods are:

- Off-hire time of vessel because
  - travel to port with cleaning facilities or to a cleaning location
  - waiting for cleaning and the cleaning operation
- Disruption of the schedule of the vessel causing cleaning to be deferred
- Rough methods degrade the antifouling paint, increasing marine growth for the future
- Low-cost In-Port Hull Cleaning treatments disperse waste such as invasive species and antifouling residue

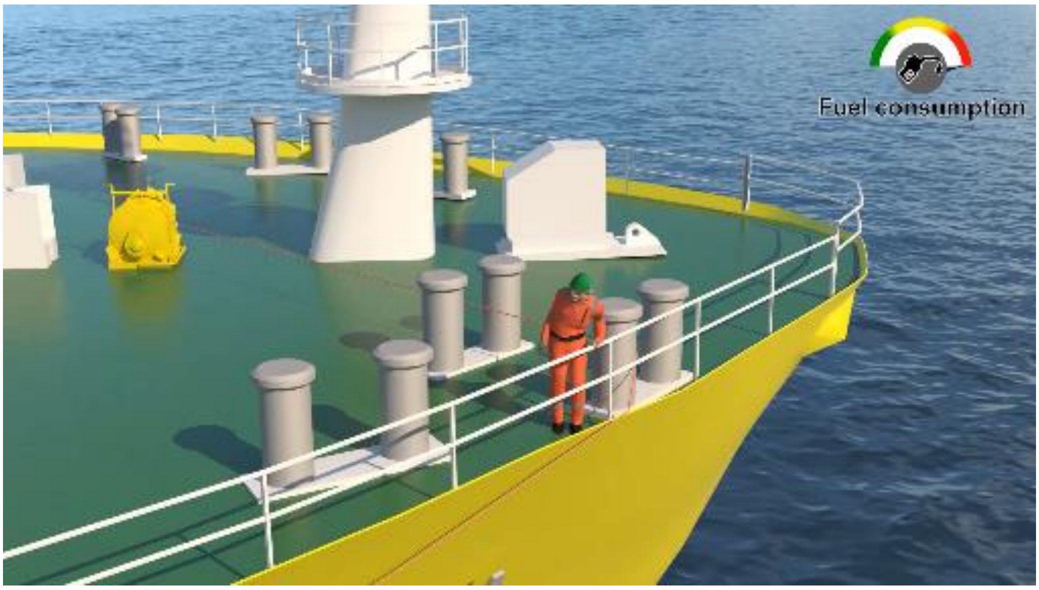



Fig.1: Winch on forecastle deck with rope via fairlead

As an alternative to in-port cleaning, frequent brushing with low forces were attempted (grooming), *Hunsucker et al. (2019)*. Grooming provides a superior surface, however, limited commercial popularity may be caused by the logistics of frequent treatments. To overcome these challenges, the ITCH system was developed.

## 2. In-Transit Cleaning of Hulls

Except for port calls for cargo operations and fueling, a ship is an independent unit. Crews takes pride in maintaining and running the ship uninterrupted and in shipshape. Traditional hull cleaning does not allow the crew to maintain the underwater hull. It has been performed by third-party specialists.

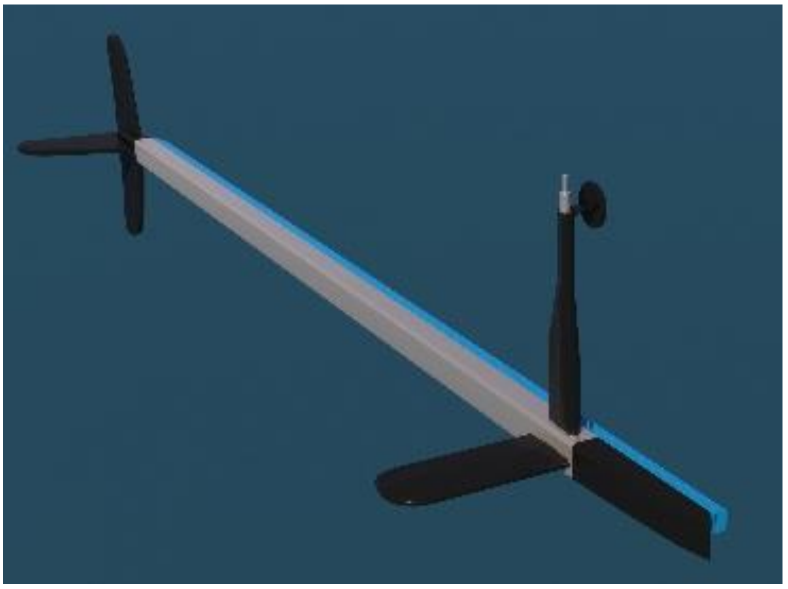


Fig.2: ITCH robot

The ITCH solution shall enable the crew to gain control over hull performance. The equipment required to be installed onboard is a winch on the forecastle deck. The robotic ITCH unit has a low mass and is hydrodynamically efficient designed, enabling easy manual deployment. The rope is led out via one of the foremost fairleads together with a robotic ITCH unit. The robotic ITCH unit has a rudder to maneuver and use the energy of the waterflow around the vessel to clean the hull. The robot automatically senses its position and conducts a vertical movement up and down on the hull sides while soft brushes are forced against the hull. The number of sweeps on each location can be defined through the combined settings of the winch and the settings on the ITCH Robot software.

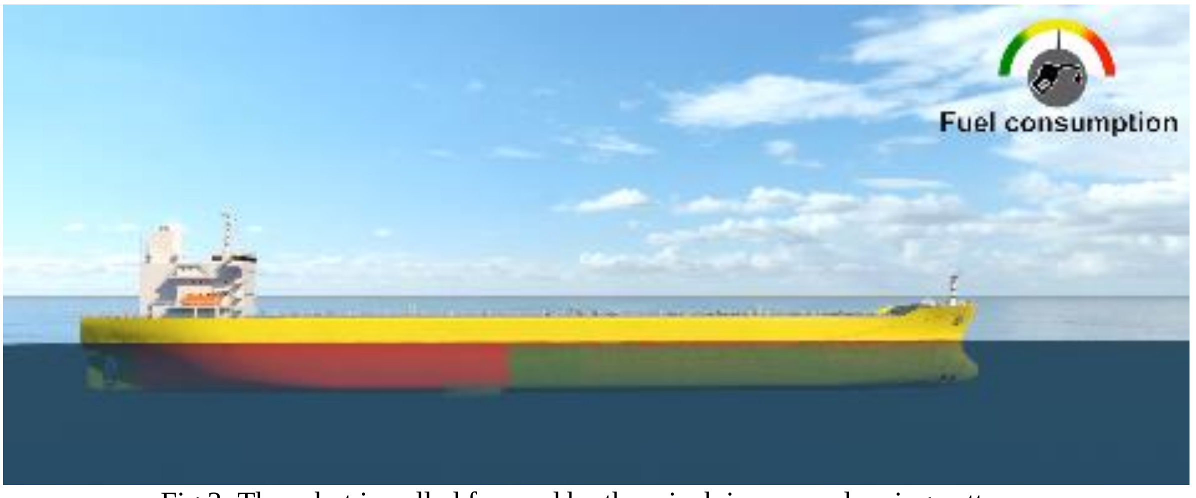



Fig.3: The robot is pulled forward by the winch in an overlapping pattern

The method uses non-rotating, soft brushes in a swiping motion with controlled hydraulic forces and a controlled number of strokes. A camera is attached to the ITCH Robot and can visually display videos with the effects of cleaning and the condition of the hull.

**3. Hull performance measurement**

The ITCH method is performed within a few hours at the same voyage. The ship has the same cargo condition and trim and usually similar weather and sea state. Measurements of fuel efficiency before and after cleaning on the same voyage will be unaffected by difference in loading and trim. The measurements will marginally be affected by currents and weather.

Hull performance depends on numerous variables and is difficult to measure and allocate to each individual source accurately. Hull paint roughness, fouling on hull and propeller, cargo loading, trim, sea temperature, current, wind, waves and speed through water all affects the apparent hull performance. Analyzing the data scatter accurately before and after hull cleaning requires advanced sensors and capable engineers to compensate for data noise. Hence the width of the data scatter may often be larger than the performance improvement.

The most accurate measurement of fuel efficiency improvement gained by a cleaning treatment will therefore be performed when cargo, wind, current, water temperature is the same and without delay. The simplest measurement with high accuracy of the hull performance effect of cleaning is made before and after an infinitely short treatment during a voyage. Cleaning in-transit can therefore negate the traditional long time series to get reliable estimates for fuel efficiency improvements.

**4. Hull condition inspection**

Many researchers advocate visual monitoring of hulls before cleaning to minimize paint wear and cleaning cost. The hull may be inspected by divers or ROVs to determine the need for an in-port cleaning operation. Qualitative information can be had, but quantitative is hard to get accurate as it depends on light, diver training, and other factors. The ITCH system may exhibit a cleaning cost for a hull that is lower than the survey cost. The soft brushes will likely eliminate paint cleaning damage. With a low-cost, neglectable damage cleaning method, inspections with high relative cost may provide less value.

Furthermore, the ITCH system has a video camera showing the cleaned surface before, during and after cleaning on the same screen picture. Because of the rapid flow during transit, released biofouling plumes may be seen, but the vision is unimpaired. One does not only get a regular hull cleaning, but also a regular hull inspection.

**5. Invasive species and antifouling disposal**

Hull fouling leads to the transportation of invasive species. Cleaning in port, dock or slipways contributes to such pests when ships are cleaned without complete capture and destruction of effluent. The antifouling polymeric components and its included biocides may also be released to accumulate in harbor sediments. IMO and others target to develop global regulations to avoid geographic variations to protect near shore aquatic environments. Researchers also point to the technical complexity of full effluent capture of in-port cleaning systems. From an environmental perspective, hull cleanings should be performed at locations where pollution and pest cannot spread, such as well controlled dry docks or the open ocean.

**6. Cleaning frequency**

Cleanings today are performed during scheduled dry docking and may be cleaned with in-water cleaning in between dry docks.

Vessel hulls are typically cleaned, and spot blasted when being Dry Docked. Depending on the established Hull Performance management procedures within a company the vessel is then cleaned several times underwater within the next years by divers. The fuel efficiency penalty for not cleaning in between dry-docking cycles can be a higher double-digit percentage figure. Both for financial savings and for achieving IMO fuel efficiency goals more frequent cleaning will be required in the future for vessels that are trading in areas prone to high fouling pressure. The ITCH project targets:

- Unrestricted trading availability of vessel
- Avoid logistics of third parties and harbour infrastructure
- Very low treatment cost
- No surface damage to sensitive antifouling paints

As the financial gain through fuel consumption reductions can be significant, cleaning frequency may increase if these goals are reached.

Most in water cleaning today is initiated when satisfactory fuel efficiency or contractual speed is no longer is obtainable. The methods used during such reactive cleaning abrades in the most cases the hull paint surface and is therefore increasing the viscous resistance. Lately researchers have argued for hull grooming with softer brushes to maintain the hull surface like new.

It is hard to measure the fuel efficiency effects of an ordinary underwater hull cleaning accurately. The results of the treatments can be shown in scatter plots where the variability often exceeds the gains of the cleaning. In common hull cleaning operations, fuel efficiency is measured before the vessel enters the unloading harbor. The vessel is cleaned and then departs. Weather, trim, draft and currents are normally different for before and after measurements. Beside this many shipping companies relies on noon reports.

**7. Cost-benefit analysis**

To determine the most economical frequency of cleaning the hulls a simple hull cleaning calculator was developed. The key assumption is according to, *Hunsucker et al. (2019)*, and anticipates no paint surface damage for soft brushing. An example shows yearly cleaning with In-Port cleaning compared to in-transit cleaning every 4 weeks. On average, the proposed case delivered a 7.7% decline in average consumption during a 5-year docking sequence. The purpose of the simulation is just to exemplify the process, not to make quantifiable statements about benefits in fuel efficiency.

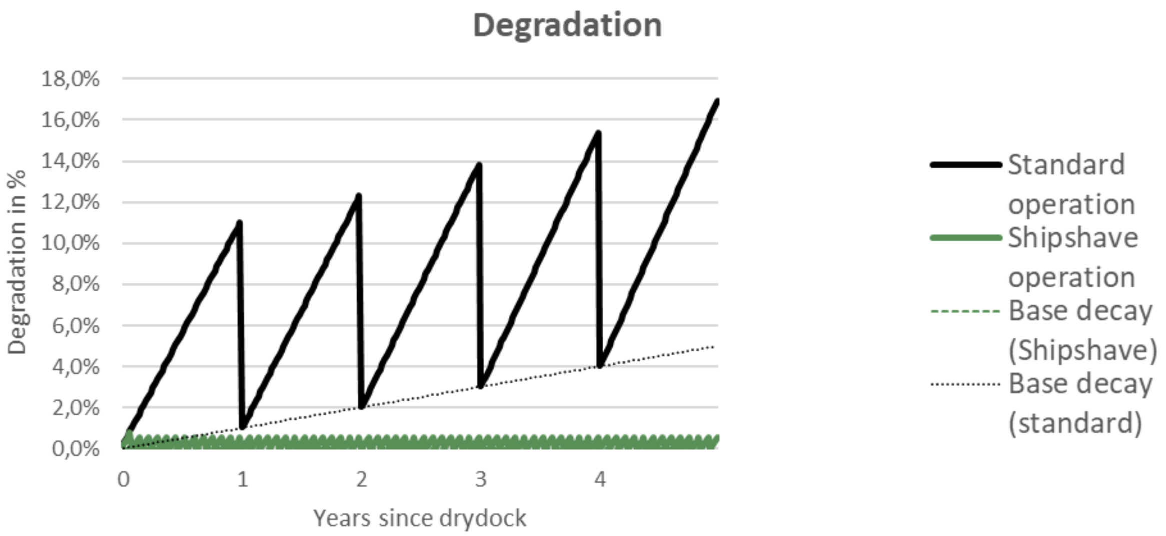



Fig.4: Hull degradation / cleaning time histories for different approaches

## 8. Hull cleaning cost

The variable cost components of ITCH hull cleanings are estimated to:

| Cost element | |
|---|---|
| Idling of vessel and crew | No cost |
| Crew hours | Less than one shift |
| Disruption of trading schedule | No cost |
| Service crew and equipment rental | No cost |
| Scheduling and management | No Cost |
| Added fuel | Cost of drag during operation |
| Consumables | Less than 500 USD per clean |

The hull cleaning tests that was performed with the ITCH system indicates that these assumptions are correct.

## 9. Testing

Testing has successfully been performed on numerous vessels with lengths from 60-200 m at speeds from 9-14.5 knots. The purpose with the testing has been to verify initial results, ensure that all product items work in concert and document cleaning results.

Fig.5: 3 years' fouling on an OSV

The tool was tested on a vessel at 9.2 knots. The hull had been in the water for 30 months without cleaning, predominantly in a shallow port more than 95% of the time. After the test, the boat was pulled up on a railed slipway and inspected. The findings were that almost all algae and soft fouling was removed by the brushing. Damages to the paint were not observed.

Another test was performed on an 8-year old Offshore Supply Ship of 5000 DWT, Fig.5. The ship had heavy algae fouling from 3 years of intermittent operation in temperate waters entirely covering the hull surface. The hull was shifting between black and green. The ITCH tool was used from bow to stern. The functionality was proven and the range of swipe velocity was confirmed. Where the ITCH had been operated repeatedly it fully cleaned the hull. A key learning was that developed fouling requires a larger number of swipes than simply grooming.

A method for removing calcareous fouling using the ITCH tool, but with a different removal mechanism was trialed on a ship on a slipway. The objective of removing barnacle cones without paint damage was achieved. The method works as projected, but piloting in the sea remains, because of lack of local vessels.

## 10. Further work

The method and tools are new, and the information presented is “hot off the press”. The testing till date verifies tool functionality. It does not quantify benefits over full operation cycles so far. Further qualifications may be required for applications such as high or low speed, high seas, different antifouling systems and calcareous fouling.

## References

HUNSUCKER, K.; RALSTON, E.; GARDNER, H.; SWAIN, G. (2019) *Specialized Grooming as a Mechanical Method to Prevent Marine Invasive Species Recruitment and Transport on Ship Hulls*, Impacts of Invasive Species on Coastal Environments, pp.247-265

# Cloud-based Vessel Biosecurity Management to Mitigate the Transfer of Harmful Non-indigenous Species

**Con Strydom**, DHI Water & Environment Pty Ltd, Surfers Paradise/Australia, cjs@dhigroup.com
**Alex Robertson**, DHI Water & Environment Pty Ltd, Surfers Paradise/Australia, alro@dhigroup.com
**Michael J. Andersen**, DHI A/S, Hørsholm/Denmark, mja@dhigroup.com

**Abstract**

*We describe a global vessel risk assessment decision support portal "Vessel-Check" to aid the maritime industry and governments in identifying actions that can as low as reasonably practicable mitigate the risk of vessels transferring non-indigenous species (NIS) across the world's oceans. Focusing on a vessel's biofouling management practices, the portal rapidly and consistently assesses a vessel's biofouling management to examine if they are sufficient to mitigate the introduction of NIS to as low as reasonably practicable (ALARP). The early detection of vessel mediated biofouling risks through Vessel-Check allows for more effective pre-border risk management options for both vessel operators and regulatory agencies. Vessel-Check creates a consistent and level playing field across the spectrum of vessel operators and regulatory agencies, by providing a cost-effective solution for those that have limited capacity to effectively manage NIS risks, as well as enhancing existing practices. Further, increased consistency between biofouling regulators provides certainty and increased understanding of biofouling risk factors within the maritime industry. Vessel-Check provides the global solution to NIS risk mitigation via shipping; will make direct contributions to the targets set out in the United Nations Sustainable Development Goals (SDG)(e.g. SDG 13, 14 & 15), and will contribute to the Convention on Biological Diversity and its Aichi Biodiversity Targets (e.g. Strategic Goal B, and Aichi Target 9).*

## 1. Introduction

Non-indigenous species invade marine habitats via numerous pathways. Using detailed inventories of marine invasions from different sources, *Molnar et al. (2008)* and *Davidson et al. (2018)* identified international shipping as the main human-assisted pathway for the introduction of non-indigenous species (NIS). It is also a trade pathway that has been growing substantially over the last decade and will continue to do so into the future, *UNCTAD (2019), Ojaveer et al. (2018)*.

Ballast water and vessel hull biofouling are key potential modes of introduction (MoI) contributing to the risk of spreading NIS along the shipping pathway. A clear commitment to minimising the transfer of non-indigenous species through ships' ballast water has been achieved through the adoption of the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 (BWM Convention). However, biofouling is now widely recognised as one of the most significant MoI for NIS that can cause severe social, environmental and economic impacts, *IMO (2012), Hewitt and Campbell (2010), Williams et al. (2013), Davidson et al. (2009).*

The accumulation of aquatic organisms like microorganisms, plants and animals on vessel hulls, immersed surfaces and structures exposed to the aquatic environment is known as biofouling, *IMO (2012)*, which NIS can be part of. NIS on vessels can be transported from source locations and subsequently establish at new locations, *Schimanski et al. (2017)*. The potential environmental, social and economic impacts of NIS are varied, and can include changes in biodiversity of marine habitats, erosion and alteration of physical habitat structures and of marine food webs (e.g. Microcosmus squamiger); through to impacts on fisheries and aquaculture systems (e.g. Hydroides elegans), as well as causing substantial maintenance costs associated with marine/coastal infrastructure (e.g. Amphibalanus improvises), *Fofonoff et al. (2018), Katsanevakis et al. (2014).*

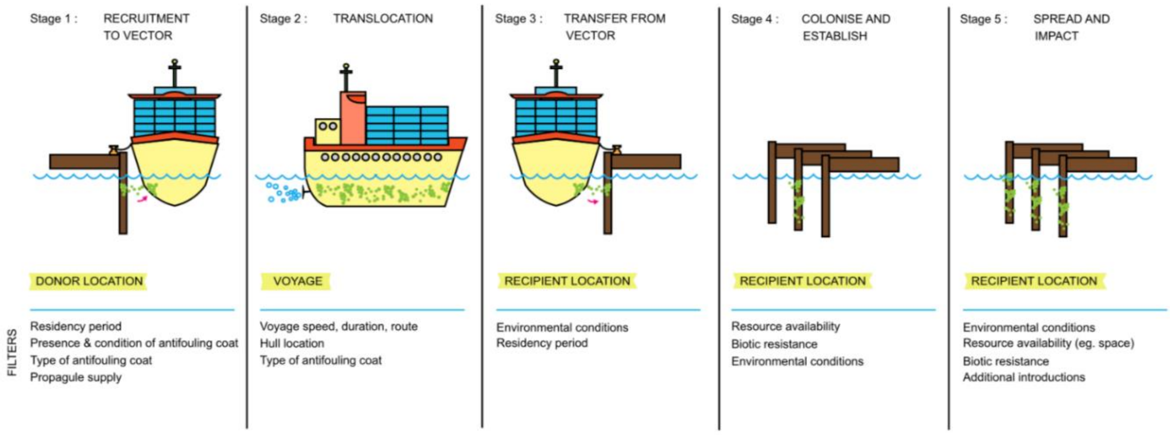



Fig.1: Stages of introduction of non-indigenous species by vessel biofouling, *Schimanski et al. (2017)*

Internationally, New Zealand and California have developed regulations to minimise the risk of transferring non-indigenous species through the vessel biofouling MoI. New Zealand's 'Craft Risk Management Standard: Biofouling on Vessels Arriving to New Zealand' (CRM) came into force in November 2018. The CRM defines a "clean hull' and prescribes thresholds for long-stay and short-stay vessels. California's State Lands Commission has enforced biofouling management regulations to minimise the transfer of nonindigenous species from vessels arriving at California ports since 2017. Australia is moving to implement regulation with the recent release of the Australian Commonwealth Governments Biofouling Management regulatory impact statement for consultation in 2019, however, Australian jurisdictions have already implemented requirements for the management of vessel biofouling (e.g. Western Australia and Northern Territory)

The regulations being set globally are generally aligned between jurisdictions, and consistent with voluntary guidelines published by IMO's Marine Environment Protection Committee (MEPC) for best-practise management of biofouling, *IMO (2012)*. The MEPC's guidelines for the control and management of ships' biofouling stipulate that vessel owners should have a biofouling management plan for each vessel and keep a biofouling record book for documenting all inspections and biofouling management activities related to that vessel, *IMO (2012)*.

Here we describe a cloud-based solution to aid in the mitigation of transferring non-indigenous species through biofouling, which focusses on two key areas:

1. The ability to rapidly and consistently assess the risk associated with a vessel's biofouling on the basis of the vessel's biofouling management practices; and,
2. Effective pre-border communication and awareness with industry stakeholders outlining indicative risk profiles, and how the biosecurity risk can be managed appropriately to as low as reasonably practicable.

The Vessel-Check portal has been developed through strong collaboration with biosecurity regulatory agencies. It is designed for vessel owners/operators providing information to biosecurity management agencies, with extensive vessel user testing and feedback. The portal does not rely on any specific questions – it effectively seeks what vessel biofouling management is being undertaken for a vessel and assesses whether the outlined management is sufficient to mitigate the transfer of non-indigenous species (NIS) to as low as reasonably practicable (ALARP). The indicative risk provided by the Vessel-Check portal indicates the likely efficacy to mitigate the transfer based on the management practices being employed on a vessel.

The portal simplifies the process for vessels to provide information to biosecurity regulators (relating to biofouling management); brings in a level of automation through the use of AIS data, and improves storage and transfer of information both in a historical sense as well as across jurisdictional borders.

**2. Portal Methodology**

The portal provides an indicative risk assessment for a vessel, based on its indicated management practices to mitigate the transfer of a NIS. It follows the best practice set out by the IMO's guidelines for the management of ships biofouling, *IMO (2012)*.

In brief, the portal achieves this by allowing a vessel (Owner, operator and/or vessel agent of a vessel) to register on the portal (free to register and use). Associated users for a vessel (vessel company representative, vessel agent, appointed consultant or vessel master/officer) supplies the requisite vessel biofouling management information and any associated documentation (i.e. copy of vessel's biofouling management plan, etc.). The required information, is outlined in the IMO biofouling management guidelines and covers:

- biofouling management practices employed for a vessel
- characteristics of the vessel
- operational details of the vessel.

The profile for a vessel is only created once, minimising the ongoing burden for vessels when moving between jurisdictions. A vessel only needs to provide updates (as needed/available) to any information (e.g. implementation of management actions in the portals record book section) to ensure the vessels profile is up-to-date, and their indicative risk is accordingly current.


Fig.2: Vessel-Check metrics (orange text) used to assess the management practices employed by a vessel to mitigate the transfer of non-indigenous species to as low as reasonably practicable. Additional operational indicators (green text) are also calculated by Vessel-Check to further assist regulatory authorities, but do not form part of the overall risk assessment for a vessel. Note: BMP = Biofouling Management Plan, AFC = Antifoulant Coating, IMS = Introduced Marine Species

The Vessel-Check Portal (based on supplied information in vessel's profile) calculates an indicative risk associated with the vessel based on seven (7) metrics covering the vessels management practices and the implementation of its management practices, Fig.2. The overall indicative risk assessment for a vessel is the average of the individual metrics for a vessel. The metrics considered by the Vessel-Check portal examine the proactive and reactive biofouling management actions planned by a vessel, and the implementation of planned actions to mitigate the transfer of NIS. Thresholds used within the risk metric calculations are determined by the jurisdiction relative to their legislative requirements providing a clear avenue for vessel operators to quickly understand the expectations of the jurisdiction they intend to visit.

To further assist regulatory authorities, operational indicators, Fig.2, are also calculated but do not contribute to the vessel's risk assessment. The operational indicators provide further information to assist in the proactive management of an unacceptable risk. For example, if a vessel's overall indicative risk is 'High', the regulatory authority can quickly understand what the likely source/sink environmental compatibility is to guide their understanding of the survival likelihood for NIS that may be present.

As part of the utility of the Vessel-Check portal to further increase efficiencies for regulatory authorities, data source and data validation cross-checking is applied to calculate an assurance measure for the supplied documentation associated with a vessel biofouling management profile.

The indicative biofouling management risk for a vessel is calculated automatically (based on the information contained vessels profile) once the vessel designates in its onboard Automatic Identification System (AIS) system that it intends to enter a jurisdictions port, *Molnar et al. (2008)*. (For ports monitored by the jurisdiction. If a port has not been designated by the jurisdiction for monitoring within the portal, the nomination will not be captured and an indicative risk calculation is not possible for the vessels proposed port entry.) The indicative risk score is updated automatically daily up to 24 h from the vessel's expected arrival into the intended jurisdiction. After which, the indicative risk can be re-calculated by the jurisdiction which oversees the intended destination port of the vessel. To maintain the most up-to-date indicative risk profile for a vessel, the vessel operator need only update the record book information associated with the vessel's profile to demonstrate the continued implementation of the vessel's biofouling management practices.

A manual nomination process is available for a vessel, to designate its last port of call (LPoC), its destination port and the expected arrival date/time. The indicative risk assessment is calculated automatically on the submission of the manual nomination, however, this risk assessment is not updated daily and requires any re-calculation to be undertaken by the jurisdiction which oversees the intended destination port of the vessel.

From a vessel operators perspective beyond the efficiencies afforded by the portal in communicating their biofouling management practices, the Vessel-Check portal has additional features (planned for release in 2020) to aid in the vessel's biosecurity management and operations, such as Ballast Water exchange/Treatment management, Biofouling Predictor (Fuel Penalty Estimate) and Metocean Forecasting.

## 3. Discussion

There is an increased international focus on the need for management of vessel biofouling to mitigate the transfer of non-indigenous species, such as the International Maritime Organisation biofouling management guidance and legislation managing vessel biofouling risks (e.g. New Zealand's Craft Risk Management Standard, California's Biofouling Regulations and the proposed Australia Government Biofouling Regulations). To assist and encourage vessels in determining how best to mitigate their likelihood of transferring a non-indigenous species, a decision support tool 'Vessel-Check' has been developed.

The Vessel-Check portal improves a vessels proactive management of biofouling risks by allowing a vessel the ability to self-assess and undertake proactive management of biofouling risk when transiting between international jurisdictions and/or domestically between jurisdictions within a country (e.g. Australia). Moreover, the Vessel-Check portal creates an even playing field where not only larger operators with dedicated biosecurity personnel but small vessel owner/operators with limited resources can achieve "best-practice" in aquatic biosecurity across various jurisdictional requirements, Fig.3.

From a regulatory perspective, the Vessel-Check portal improves efficiency in service delivery to industry and an ability to prioritise resources according to risk. Smaller regulatory agencies/port authorities with developing biosecurity management can now achieve awareness and oversight of biofouling risk management issues for international and domestic (interstate and intrastate) vessel arrivals comparable to that of larger or more developed jurisdictions/ports, creating a truly global solution to the impacts of transferring non-indigenous species, Fig.3.

Early detection of biofouling risk management issues for international and domestic vessel arrivals will allow for more effective risk management options by regulatory authorities ensuring a jurisdictions biosecurity while minimising impacts to industry and economic development.

The utility of the Vessel-Check portal will be further enhanced in 2020 with the release of additional features including the incorporation of the Ballast Water Management (BWM) module and also the Biofouling Predictor (BP) module. For example, the BP module will aid jurisdictions in estimating potential vessel biofouling risks even for vessels which have not created a biofouling management profile. That is where biofouling management is only voluntary and not yet regulated.

Synergistically, implementing management of a vessel's biofouling through the Vessel-Check portal can also lead to benefits in a vessel's performance, as hull fouling leads to significant increases in vessel resistance through the water, *Townsin (2003)*. It is well known that vessel fouling has a large impact on the vessel's performance, consumption and thus operational cost, *Bressy and Lejars (2014)*. Additionally, influences the emissions of air pollutants and greenhouse gases generated by the vessel. Therefore, biofouling management through the Vessel-Check portal can be an effective tool in enhancing energy efficiency and reducing air emissions for ships, Fig.3. This has significant benefits for both vessel owner/operators in ensuring compliance with GHG emission requirements, as well as jurisdictions by contributing to global sustainable development goals.

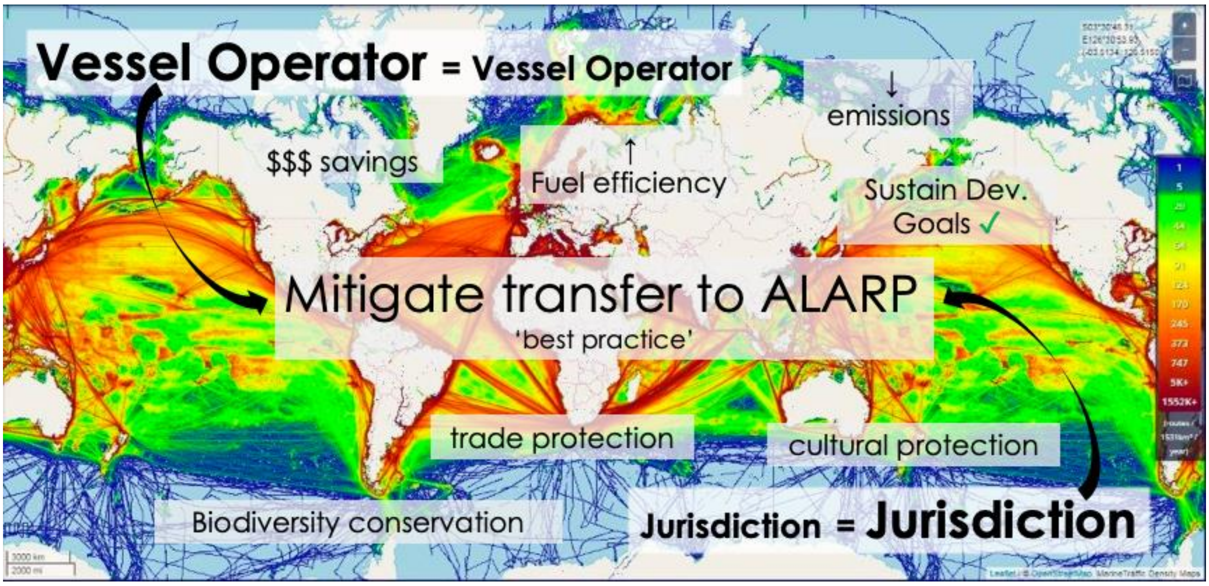



Fig.3: Benefits of implementing next-generation vessel biofouling management practices through the use of the Vessel-Check portal. Small operators/jurisdictions can achieve 'best practice' outcomes of larger operators/jurisdictions with greater capacity/resources.

The 2020 release of additional Vessel-Check feature modules (such as BP and BWM) provides a vessel operator further opportunities to maximise efficiencies in their operations. For example, the BP module allows vessel operator's to plan appropriate biofouling management according to their existing operational schedule to avoid unnecessary impacts while maximising their biosecurity management/fuel efficiency.

## References


BRESSY, C.; LEJARS, M. (2014), *Marine fouling: An overview*, The Journal of Ocean Technology 9(4), pp.19-28

DAVIDSON, I.C.; BROWN, C.W.; SYTSMA, M.D.; RUIZ, G.M. (2009), *The role of container ships as transfer mechanisms of marine biofouling species*, Biofouling 25, pp.645-655

DAVIDSON, I.C.; SCIANNI, C.; MINTON, M.S.; RUIZ, G.M. (2018), *A history of ship specialization and consequences for marine invasions, management and policy*, J. Applied Ecology 55(4), pp.1799-1811

FOFONOFF, P.W.; RUIZ, G.M.; STEVES, B.; SIMKANIN, C.; CARLTON, J.T. (2018), National Exotic Marine and Estuarine Species Information System. http://invasions.si.edu/nemesis/

HEWITT, C.L.; CAMPBELL, M.L. (2010), *The relative contribution of vectors to the introduction and translocation of non-indigenous species*, Commissioned by The Department of Agriculture, Fisheries and Forestry (DAFF), Canberra. 56pp

IMO (2012), *Guidelines for the control and management of ships' biofouling to minimize the transfer of non-indigenous species (Biofouling Guidelines)*, Res. MEPC.207(62)), Int. Maritime Organisation, London

KATSANEVAKIS, S.; WALLENTINUS, I.; ZENETOS, A.; LEPPÄKOSKI, E.; ÇINAR, M.E.; OZTÜRK, B.; GRABOWSKI, M.; GOLANI, D.; CARDOSO, A.C. (2014), *Impacts of invasive alien marine species on ecosystem services and biodiversity: a pan-European review*, Aquatic Invasions 9(4), pp.391-423

MOLNAR, J.L.; GAMBOA, R.L.; REVENGA, C.; SPALDING, M.D. (2008), *Assessing the global threat of invasive species to marine biodiversity*, Frontiers in Ecology and the Environment 6(9), pp.485-492

OJAVEER, H.; GALIL, B.S.; CARLTON, J.T.; ALLEWAY, H.; GOULLETQUER, P.; LEHTINIEMI, M.; MARCHINI, A.; MILLER, W.; OCCHIPINTI-AMBROGI, A.; PEHARDA, M.; RUIZ, G.M.; WILLIAMS, S.L.; ZAIKO, A. (2018) *Historical baselines in marine bioinvasions: Implications for policy and management*, PLOS ONE 13(8): e0202383

UNCTAD (2019), *Review of Maritime Transport 2019 - Sustainable Shipping*, United Nations Convention on Trade and Development

SCHIMANSKI, K.B.; GOLDSTIEN, S.; HOPKINS, G.A.; ATALAH, J.; FLOERL, O. (2017), *Life history stage and vessel voyage profile can influence shipping-mediated propagule pressure of non-indigenous biofouling species*, Biological Invasions 19, pp.2089-2099

TOWNSIN, R.L. (2003), *The ship hull fouling penalty*, Biofouling, 19(S1), pp.9-15

WILLIAMS, S.L.; DAVIDSON, I.C.; PASARI, J.R.; ASHTON, G.V.; CARLTON, J.T.; CRAFTON, R.E.; FONTANA, R.E.; GROSHOLZ, E.D.; MILLER, A.W.; RUIZ, G.M.; ZABIN, C.J. (2013), *Managing multiple vectors for marine invasions in an increasingly connected world*, BioScience 63(12), pp.952-966

# Remote Vessel Inspections with an ROV using Livestreaming

**Michael Stein**, Stein Maritime Consulting, Hamburg/Germany, stein@stein-maritim.de
**Henri Parviainen**, Blueye Robotics, Trondheim/Norway, henri.parviainen@blueye.no

**Abstract**

*This paper describes the possibility of conducting in-water surveys with ROV (remotely operated vehicles) as part of a risk management approach for maritime and port operations. The risk management approach will be evaluated using a qualitative mixed-method analysis of literature analysis, a well-accepted risk management model being the Swiss Cheese Model and a connected Bow Tie Analysis. Furthermore, the practicability of commercially available small-size ROV is being displayed in this paper based on operational examples and frameworks. This paper furthermore introduces the concept of remote streaming as part of an unmanned inspection to enhance operational qualities through remotely adding competencies to the operation.*

## 1. Introduction of small-size ROV (remotely operated vehicles)

Remotely operated vehicles have been in operation for decades, mainly in deep-sea and offshore operations. Over the past years, technology evolved and a number of small-size ROV (remotely operated vehicles) systems have entered the commercial market. The comparable low price of small-size ROV of about 15.000 € compared to former ROV prices of several hundred thousand € as well as the technological abilities of this new ROV class have caused a shift in ROV operability. Affordable prices and operational technology have shifted ROV operation from offshore to the ports and allow for a whole new dimension of unmanned inspection as part of risk management. With affordable and reliable technology at hand, port operators, authorities as well as ship owner and -charterer are able to conduct inspection of underwater structures at almost any time without expensive diver operations.

Increasing demand on efficiency of global transportation results in increasingly complex supply chains for producers of goods, retailers and transportation service provider. This leads to firms becoming extremely vulnerable to the consequences of a disruption in the transportations system, *Hecker (2002), Flynn (2006)*. In the context of maritime operations this factor is crucial because ports and ship operating services are very price sensitive and are confronted by national and international competition. Any mean to uphold legal requirements in terms of inspection or other danger prevention and/or to even enhance service quality while reducing operation costs at the same time are perceived as highly welcome in the maritime business both from academia and from business operations. This paper argues that enhancing service quality while reducing costs can to a large part be achieved through innovative technology where ROV are seen as such a mean. The main areas of service are seen to be on the safety and the security side or maritime operations.

On the safety side, ROV represent an innovative technology assisting and or replacing conventional diving operations that are often expensive and not without danger for the diver. Sone ports don't even allow manned diving operations, while evidence rises, that unmanned diving operations are not affected by these safety regulations. The argument of providing safe inspection services can even be integrated in the concept of corporate social responsibility (CSR) where it is shown, that "responsible firms are better positioned to grow in terms of reputation and revenues", *Drobetz et al. (2014)*.

From a security side, ROV provide advantages in preventions of smuggling of contraband and other illegal substances through ports. After the 9/11 attacks in the US, maritime operation security is legally regulated by the ISPS code (International Ship and Port Facility Security). *Stein (2018)* introduced the concept of ROVs to assist ISPS operations in ports. Studies already revealed a connection between transport service security and customer satisfaction (see for example *Hu and Lee (2011), Chang and Thai (2016)*. It is inevitably agreed that security is to be embedded into daily operations processes, *Frittelli (2003)*, and in collaboration among different stakeholders, *Bichou (2005)*, in order to be successful. Costs of security, however, are crucial with regard to competition.

This paper follows the ROV classification scheme by *Capocci et al. (2017)* displayed in Fig.1. According to them, micro or handheld inspection ROVs weigh between 3 kg and 20 kg and can be deployed and recovered using manpower alone. They state that “a significant aim in using micro ROVs is to reduce operational costs and system complexity, allowing the user to complete the job in an efficient manner”. The depth rating of this ROV category is generally less than 300 m.

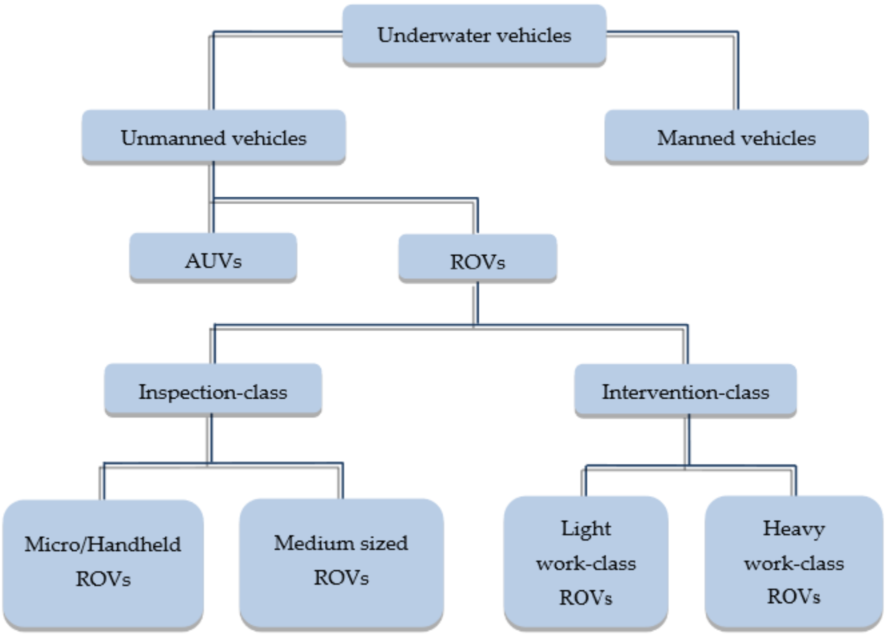



Fig.1: Outline of underwater vehicles, *Capocci et al. (2017)*

## 2. Methodology

This paper introduces the concept of ROV based vessel inspection using livestreaming technology. Livestreaming is particularly suitable because it allows for different stakeholders to join and spectate the inspection remotely. This paper argues that the availability of small-size ROV brings significant advantages to underwater inspection operations as part of a general risk management. After introducing the concept of ROV and underwater inspections in form of a literature analysis, the paper introduces the concept of ROV based under inspection based on well accepted risk-management frameworks. Furthermore, the concept and advantages of livestreaming are being introduced in this context and finally results and evaluations are being discussed towards the end of this contribution.

This paper choses a qualitative mixed-method analysis of qualitative evaluations and a case study analysis. The literature review follows a systematic approach as presented in *Tranfield et al. (2003), Denyer and Tranfield (2009)*. The risk management analysis follows well-accepted frameworks of the Swiss Cheese Modelling, *Reason (1990), Reason et al. (2006),* and the Bow Tie Analysis, *Nielsen (1971)*. The combination of qualitative methods is regarded to be particular suitable for innovation research in transport logistics. *Voss et al. (2002)* state that “case research reflects one of the most powerful research methods in operations management, particularly in the development of new theory”. In line with this argument, *Näslund (2002)* also states the importance of qualitative research to enhance logistics research quality. Studies already addressed the importance of structured frameworks as a basis for future research for academic areas with limited existing literature, *Miles and Hubermann (1994), Shields and Rangarajan (2013)*. Academic contributions on ROV operations are indeed limited to this time, with leads to the conclusion that the above introduced methods appear very suitable for this paper’s innovation research.

## 2.1 ROV literature analysis

Following the classification of *Capocci et al. (2017)*, this paper focusses on the Micro or handheld ROVs of the inspection class as displayed in Fig.1. While the amount of literature in the context of deep-sea ROV operations of medium sized ROV systems and above given, contributions of micro-sized ROV operations are limited. This can nonetheless be explained by the relatively novelty of this ROV class entering the industrial markets less than a decade ago. Furthermore, the aspect of remote and unmanned inspection using drones, also called UAS (unmanned aerial systems) or UAV (unmanned aerial vehicles) is well evaluated while underwater remote inspections is a novelty within the literature to the best of the authors' knowledge. Following the explained structured literature approaches, two main areas of micro ROV studies were identified among the literature being ROV development and ROV operation. While quite some contributions focus on developmental systems and introductory tests, the operational contributions of industrially available case studies remain scarce.

The development of micro-class or "low-cost" ROV systems is covered by the literature to some extent, however, its contribution to science remains questionable as many developments lack behind already industrially produced ROV at the time of research.

*Battle et al. (2003)* have experimented with a low-cost ROV system called URIS based on a Pentium III system. They can be referenced among the pioneers of experimenting with low-cost micro-class ROV systems prior to the widespread availability of sophisticated micro-processors and industrially constructed ROVs or its spare parts. Over a decade later several research designed ROV studies were introduced but apart from their new design form, their operational ability was already behind market standard of low-cost micro ROVs commercially available. *Zain et al. (2016)* describes a 4-thruster torpedo form ROV based on the open source platform open ROV using an ATMega2560 microcontroller. The innovation of this design lies in its streamline form that makes it potentially suitable for long distance operations with minimum power demand. *Vukšić et al. (2017)* developed a ROV based on an already existing Blue Robotics system rebuild in steel using single board microcomputers (2549Q–AVR–02/2014). Apart from the increased robustness using steel instead of plastics, depth of 150m were not exceeded so that the prototype is not exceeding any comparable industrially produced ROVs from that time. *Wiryadinata et al. (2017)* designed a 3 degrees of freedom ROV system in 4-inch PVC pipe form using an AVR microcontroller (ATMega32). *Kungwani and Misal (2017)* used a PVC pipe form with a PIC16F877A microcontroller that in line with *Wiryadinata et al. (2017)* provide 3 degrees of freedom and no significant advantage to market ready ROV systems at that time. At the same time, *Osen et al. (2017)* developed a PE plastic and Plexiglas ROV for Aquaculture inspection based on Raspberry Pi and Arduino microcontroller and were able to provide a prototype for an investment of 1.500 € that is basically 1/10 of the market price of comparable cow-cost ROV systems at that time. *Hartono et al. (2020)* introduce a research design ROV using an Arduino microcontroller, however, despite making reference to an industrially produced ROV system in one figure (a Deep Trekker DTG-2) the prototype offers no advantage compared to current ROV systems already widely available on the market. *Siregar et al. (2020)* introduces a Fitoplankton SAS ROV with 3 degrees of freedom based on a Raspberry Pi type B+ microcomputer and a PIXHAWK flight controller, both state-of-the-art technologies that are also operated in industrially produced ROVs such as the BlueROV-2. The advantage of this micro class ROV is provided by the ability to maintain depth with a single camera using the triangle similarity algorithm

On the operations side only few contributions provide case study analysis and even fewer using industrially produced ROV systems. *Pacunski et al. (2008)* used an industrial ROV (DOE Phantom HD2+2) to collect quantitative data for analyzing marine communities of fish. The ROV of the study ranged around 100.000$ which was a low-cost investment at that time. *Alotta et al. (2012)* introduce Nemo, a metal frame ROV that conducted inspections at the wreck of the Costa Concordia Ship off the coast of Tuscany. The ROV, however, is only a prototype and no market ready low-cost system. *D'Alessando et al. (2016)*, *Heisinger et al. (2017)* as well as *Costa et al. (2018)* operated a self-assembled open source ROV first generation that was later in 2018 succeed by the second generation ROV called Trident. The cost of this self-assembled ROV kit ranged around 1.000$ and is based on

Beaglebone Black and Arduino MEGA microprocessors. *Teague et al. (2018)* operated a BlueROV2 (company Blue Robotics) of about 10.000€ exploring hydrothermal venting using photogrammetric analysis. *Lund-Hansen et al. (2018)* operated a low-cost ROV of 15.000 € as blend of polycarbonate and aluminum parts being tested for maneuvering under ice covered waters. The paper provides novel insights as it is the first contribution operating a low-cost ROV under technical challenges of working in the Arctic at water and air temperatures well below 0 °C. *Buscher et al. (2020)* operated an industrially manufactured second generation open ROR trident system (company Sofar Ocean) of about $2.000 to asses ecological baselines of an indigenous seascape.

**2.2 Risk management analysis introduction on underwater inspections**

*Stein (2020)* introduced the concept of risk management of unmanned inspection among maritime infrastructures, which is also the basis for this paper's qualitative analysis. The evaluation and recognition of accidents as a chain of subsequent events has a history in risk management theory. Over time and as a reaction to major disasters, risk analysis focused more on the organization and their internal factors of inabilities to prevent accidents. Theory claims that organizations tend to a certain degree of uncertainty, leading to "ill-defined or competing preferences, ambiguous goals, unclear technology and fluid patterns of stakeholders' involvement in the decision-making process", *Moura et al. (2017).*

The aspect of different subsequent effects in environments of rising complexity was evaluated by *Reason (1990)* and his "Swiss cheese model" (SCM) that shaped risk management orientation for many years. Its orientation based on mayor disasters in the late 1970s and 1980s including Flixborough, Challenger, Three Mile Island, Bhopal, Chernobyl, the Herald of Free Enterprise and the King's Cross Underground fire, *Reason et al. (2006)*. Since maritime disasters were regarded among complex system failures in the SMC, this model is particularly suitable for this paper's research. *Reason et al. (2006)* later described the model as "explanatory device for communicating the interactions that occur when a complex well-defended system suffers a catastrophic breakdown". The defense within a system and their associated inadequacies are graphically represented by layers of and holes in Swiss cheese. When the 'holes' in a system's defense align, an accident trajectory can pass through the defensive layers and result in a hazard causing harm to people, assets and the environment, *Reason (1990)*.

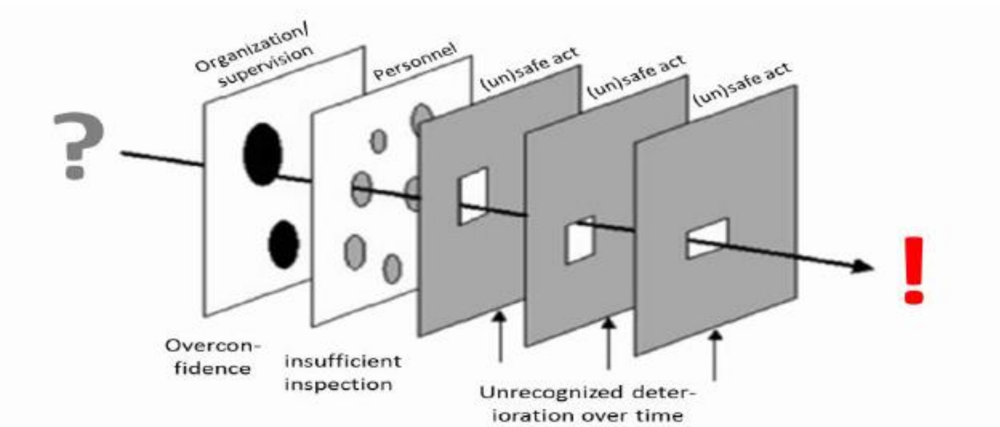



Fig.2: The Swiss cheese model, *Stein (2020)* based on *Reason (1990)* and *Reason et al. (2006)*

The initial Swiss Cheese Model (SCM) based on *Reason (1990)* differentiated accident causation among one of four domains, being organizational influences, supervision, preconditions, and specific acts. With regard to port inspection as basis for risk management, the model exhibits a certain necessity for modification with regard to the underlying accident domains as displayed in Fig.2. Basically, every accident caused by deterioration is based on the absence of information mainly of structural damages caused by long-term corrosion. The barriers preventing such an accident are three-fold starting with the organization, over personnel and finally to the act itself. The basic decision to prevent breakdowns due to material fatigue is the decision of the organization to invest into inspection mechanisms such as industrial climbers, divers, drone operators, etc. Supervision for the sake of this argument is included into this barrier because one can only surveil, if means to do so are integrated in the organization. Main reasons for port facilities and ship operators to fail this preventative barrier are cost savings due to the already stated competition and price sensitivity of the maritime domain. Risk management literature describes organizational failure associated with a status of overconfidence in the own risk management, *Årstad and Aven (2017)*. Such overconfidence in risk management often ends at the edge of regulatory compliance compared with a failure to learn from prior major accidents. The personnel level of accident prevention is then faced with insufficient inspection means as a consequence of the organization's overconfidence. From a model perspective, the unknown deterioration is then (worst case) brought to the operational level of (un)safe acts. Unlike in other regards of the SCM such as the airline industry, a personnel and organizational failure is no guarantee for an unsafe act, although it increases the chance of an accident to occur. The act itself is the handling of port operations such as loading of containers using gantry cranes, or the berth of a ship at a quay facility or other daily maritime transport operations. Such acts per se are not unsafe even if structures are deteriorated. Over time, however, and under the absence of knowledge that reveals structural damages, a former safe act becomes unsafe because structures cannot withstand the force caused by such operation, which then leads to the accident. In order to address general criticism on the SCM, e.g. *Hollnagel et al. (2012)*, for oversimplification, this paper addresses the specific hole in the model using bow tie analysis (BTA).

Among the most reliable structured approaches to identify accident causations is the bow tie analysis (BTA), which was developed by connecting an event tree and a fault tree analysis connected to an unwanted event (e.g. accident) by *Nielsen (1971)*. The method visualizes of the relationships between the causes of undesired events, the escalation of such events, the controls preventing such event from occurring and the measures in place to limit the impact. BTA has been extensively used in safety critical domains such as the petrochemical and chemical industry and mining industry, which makes it particularly suitable for application in complex maritime settings. The technique does not only assist in effective analysis of incidents and risks but can also be utilized as an effective tool for communicating safety issues, *Stemn et al. (2018)*. The structure of the bow tie focusses on the undesired event in the centre, as a knot point, that leads to a certain hazard in the operation. A hazard often refers to a safety incident where, loss of control of the hazard directly gives rise to the unwanted event e.g. the accident. Threats are located on the left side of the model that passes preventive barriers of preventative control measurements before leading to the knot point. The right side of the model reflects the consequences of an undesired event that are often associated with loss/damage of people, material or operations. From the centre to the consequences, the severity of an event can be controlled by mitigation barriers that reduce or hinder the consequence after an event.

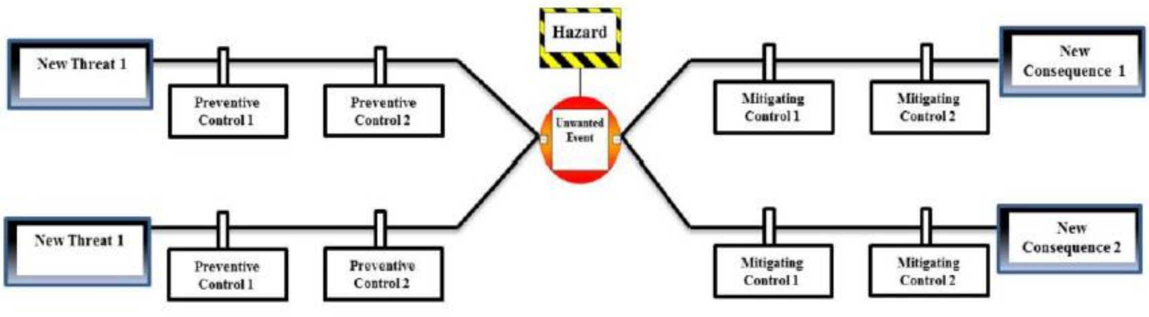



Fig.3: The bow-tie model, *Stein (2020)* based on *Nielsen (1971)*

In order to learn from accidents, one must understand the effects that lead to the accident and the consequences these effects have hand on the overall severity of the accident. *Stemn et al. (2018)* contributed to this area by connecting BTA to learning effects. Risk analysis models such as the SCM and the BTA provide powerful methods to simplify complex structures in order to communicate them properly in organizations.

### 2.3 Applying BTA analysis to underwater inspections

The BTA application on ROV inspections on underwater structures bases on the aspect that unrecognized material fatigue will over time lead to a breakdown of the structure. The breakdown represents a tremendous safety incident in a port or ship structure with immediate short- and long term effects. Threats arise in forms of insufficient inspection routines or limited inspection capabilities such as the absence of divers and other underwater inspection mechanisms like ROVs.

Preventive barriers account for the human factor and the quality of the inspection and the speed and quality of an incident report may be influenced by preventative measurements such as awareness, error handling strategies and code of conducts. Inspection quality can be raised through the use new and diversified technology (such as ROVs), procedural improvements or tighter inspection periods and two factor report checks. Using the remote streaming option of this paper's case study, the quality of the inspection can also be enhanced because more spectators with different competencies can join and comment on the very same operation that without online streaming would be limited to physically attending personnel only. Physical protection measurements can to some extent prevent damages in marine port structures as for example introduced by *Liu et al. (2007)*. Such structures, however, come at high costs and orient towards flood protection of the hinterland rather than reducing deterioration of port structures in practice.

The consequences of a breakdown range from immediate shore and possible ship damage, environmental damage (in case dangerous material from containers is exposed to the sea), economic damage (due to operational stops) to human casualties and severe long-term economic damages. The economic and environmental damages can be condemned through existing resilience strategies. The likelihood of human damage and casualties can be reduced through operational safety procedures. Long-term economic damage in form of lost customer trust or service quality can be reduced by a company's willingness to learn as well as customer management.

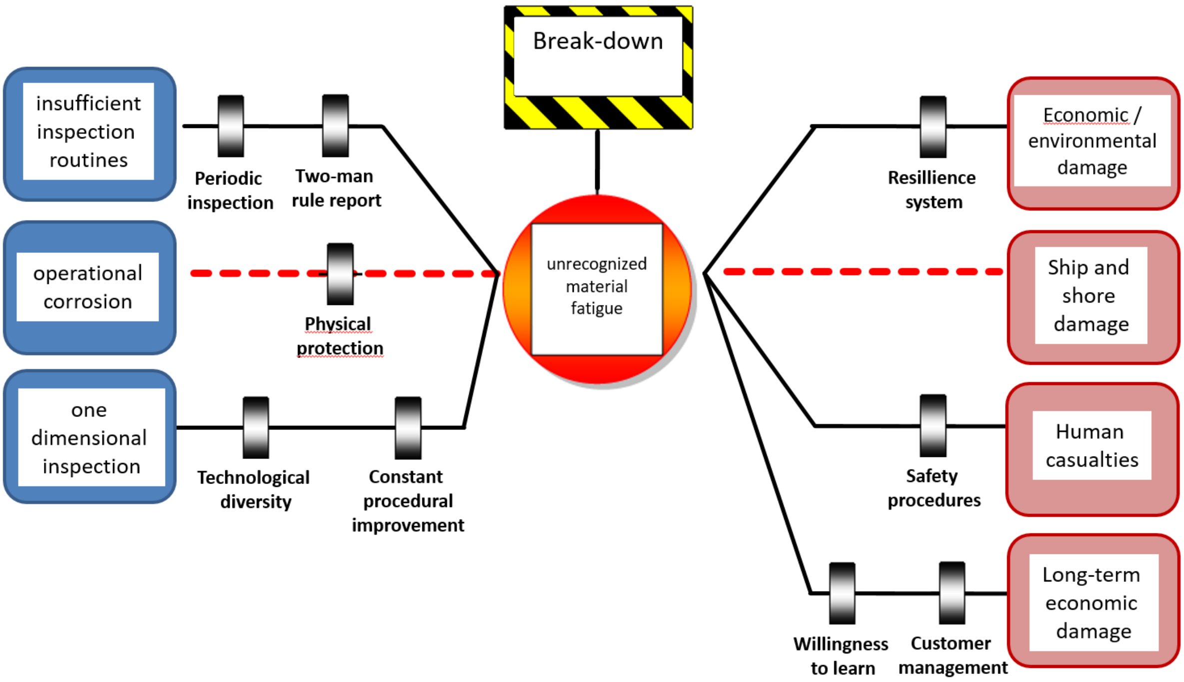



Fig.4: Applying BTA to unrecognized underwater material fatigue

## 3. The ROV System

The system operated in this study is a Blueye Pro ROV of the company Blueye Robotics A/S from Trondheim, Norway. The measurements of the ROV are 485x257x354 mm (LxWxH) and the system weights 8.6 kg and consists of a ABS and Aluminum enclosure with Polycarbonate windows. The maximum depth rate is 305 m thus exceeding the definition by *Capocci et al. (2017)* and being the most robust and deep-sea operative low-cost ROV system at the market (at the time of this study). The system consists of an Exmor R CMOS, 1/2.8 inch with maximal image size of 1920 x 1080 and full HD video resolution of 1920 x 1080 25/30 Fp. The integrated LED provides a maximum of 3.300 lumen and can be dimmed. The IMU consists of a 3-axis gyro/accelerometer/magnetometer with depth sensor resolution of 0.2 bar and maximum operating range of 30 bar.


Fig.5: The Blueye Pro ROV system

### 3.1 Introducing livestreaming to underwater inspections

Introducing the concept of Livestreaming of an unmanned ROV inspection is a novelty among academic contributions. The literature analysis of this paper revealed past and recent studies on low-cost ROV systems with a focus on hardware. This case study goes further by evaluating also the software aspect of ROV inspections introducing remote spectating via livestreaming as shown in figure 6. In this case study setting, the ROV is connected via tether with a surface unit that transmits video and control signals over Wi-Fi to a controlling unit with smartphone. A mobile app specifically designed by the ROV manufacture allows to stream the diving operation over Wi-Fi to additional devices in the vicinity of the operation or to stream it globally over the internet. A web application allows for streaming on conventional computers with latency times of less than one second from the ROV to the spectator.

Fig.6: ROV operation framework including streaming via Wi-Fi or internet

### 3.2 The Case Study

The case study was conducted in May 2020 using a Blueye Pro ROV in the port of Trondheim, Norway. The aim of the operation was to inspect a damaged part of a steel reinforced concrete dock front, where sediments below were suspected to flow away over time. The structure belongs to a former WW2 submarine base that is partially damaged and requires an increased demand of inspection and monitoring. Fig.7 displays the area of operation as well as the remote streaming of the inspection.

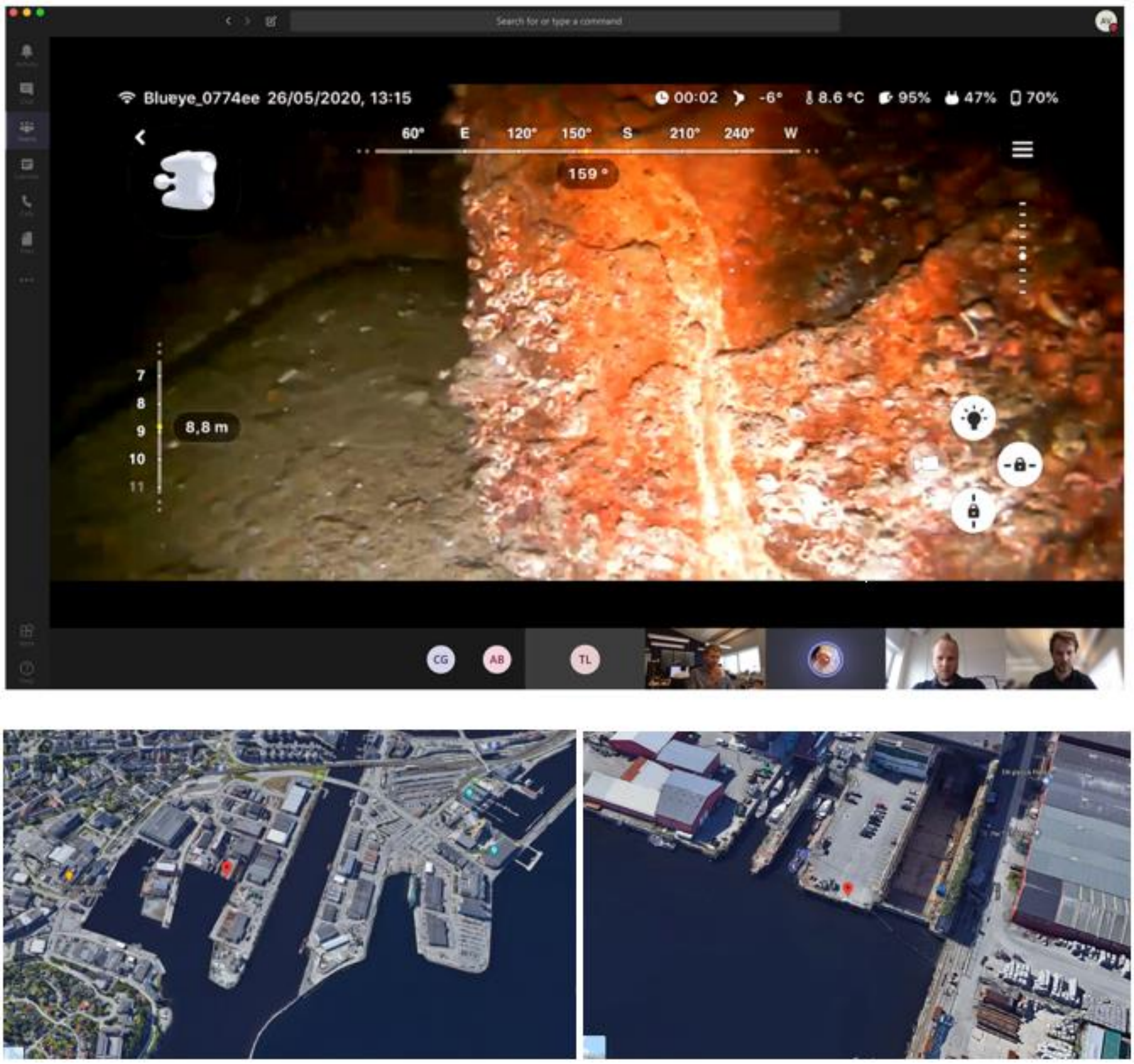



Fig.7: Case Study operation

Fig.7 reveals that apart from the ROV pilot at the port, two service technicians and five spectators followed the operation using Microsoft Teams video capture function. As mentioned, the ability to remotely follow and spectate the operations allows for enhancing the inspection competency because several spectators with additional knowledget can now be part of the very same operation. This aspect represents a new milestone in unmanned inspections using low-costs ROV systems and further enhances inspection quality for ports and shipping companies.

Fig.8 reveals that sediments were indeed floating away as a result of structural damages in the concrete structure of the harbor front. In total, the diving operation took 10 Minutes preparation, 8 minutes diving time and additional 5 minutes to pack up, while stakeholder and other inspection personnel was able to follow the operation remotely and discuss the findings and plan future repair operations.

Fig.8: Inspection Pictures from the operation

## 4. Conclusion

Micro or handheld ROV systems according to the definition of *Capocci et al. (2017)* provide significant advantages for underwater inspections. Formerly expensive deep-sea hardware evolved to small systems of a few kg and with investments of less than 15.000 € making this technology available to a wide range of user. The applied risk analysis of this paper argues that inspection quality and procedural improvements of inspection operations are to a large extent accountable for structural information qualities to counteract unrecognized material fatigue of underwater structures. The structured literature analysis of this contribution revealed fragmented experiments on ROV designs that often lack behind already existing industrial systems thus providing limited novelty. Operations of low-cost micro ROV among the literature is scars but grew among the past years as a result of widespread availabilities of cheap ROV and computer hardware.

This study is the first of its kind to introduce a case study using a Blueye Pro system and also introducing the aspect of remote surveillance using software streaming. The aspect of remotely collaboration and adding of competent personnel to a diving operation increases the inspection quality while reducing costs in form of man hours, travelling etc. at the same time. The introduced case study revealed operational results for a remote audience of inspection stakeholders in less than 30 minutes and is far more attractive to operators of any marine infrastructure than conventional diving operations.

## References

ALLOTTA, B.; BRANDANI, L.; CASAGLI, N.; COSTANZI, R.; MUGNAI, F.; MONNI, N.; NATALINI, M. (2015), *Development of Nemo ROV for the Inspection of the Costa Concordia Wreck*, J. Engineering for the Maritime Environment 231/1, pp.3-18

ÅRSTAD, I.; AVEN, T. (2017), *Managing major accident risk: concerns about complacency and complexity in practice*, Safe. Sc. 91, pp.114-121

BATTLE, J.; NICOSEVICI, T.; GARCIA, R.; CARRERAS, M. (2003), *ROV-aided dam inspection: Practical results*, IFAC Proc. Vol. 36(21), pp.271-274

BICHOU, K. (2005), *Maritime security: framework, methods and applications*, Report to UNCTAD, Geneva

BUSCHER, E.; MATHEWS, D.L.; BRYCE, C.; BRYCE, K.; JOSEPH, D.; BAN, N.C. (2020), *Applying a Low Cost, Mini Remotely Operated Vehicle (ROV) to Assess an Ecological Baseline of an Indigenous Seascape in Canada*, Frontiers in Marine Science 7, https://www.frontiersin.org/articles/10.3389/fmars.2020.00669/full

CAPOCCI, R.; DOOLY, G.; OMERDIĆ, E.; COLEMAN, J.; NEWE, T.; TOAL, D. (2017), *Inspection-class remotely operated vehicles - A review*, J. Marine Science and Engineering 5(1), p.13

CHANG, C.H.; THAI, V.V. (2016), *Do port security quality and service quality influence customer satisfaction and loyalty?*, Maritime Policy & Management 43(6), pp.720-736

COSTA, E.; GUERRA, F.; VERNIER, P. (2018), *Self-assembled ROV and photogrammetric surveys with low cost techniques*, Int. Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences 42(2)

D'ALESSANDRO, A.; BOTTARI, C.; BUCALO, F.; CAPIZZI, P.; COCCHI, L.; COLTELLI, M.; COSTANZA, A.; D'ANNA, G.; D'ANNA, R.; FAGIOLINI, A.; FERTITTA, G.; R. MARTORANA, R.; PASSAFIUME, G.; SPECIALE, S.; VITALE, G. (2016), *A Low Cost Customizable Micro-ROV for Environmental Research-Applications, Advances and Challenges*, Near Surface Geoscience 2016-2nd Applied Shallow Marine Geophysics Conf. Vol. 1, pp.1-5

DENYER, D.; TRANFIELD, D. (2009), *Producing a Systematic Review*, The Sage Handbook of Organizational Research Methods, Sage

DROBETZ, W.; MERIKAS, A.; MRIKA, A.; TSIONAS, M.G. (2014), *Corporate Social Responsibility Disclosure: The Case of International Shipping*, Transportation Research Part E, Vol. 71, pp.18-44

FLYNN, S.E. (2006), *Port security is still a house of cards,* Far Eastern Economic Review 169(1), pp.5-11

FRITTELLI, J.F. (2003), *Port and maritime security: background and issues for Congress*, Congressional Research Service, Report RL 31733

HARTONO, M.T.; BUDIYANTO, M.A.; DHELIKA, R. (2020), *Micro class underwater ROV (remotely operated vehicle) as a ship hull inspector: Development of an initial prototype*, AIP Conf. Vol. 2227/1, p. 020025, AIP Publ.

HECKER, J.Z. (2002), *Port security: nation faces formidable challenges in making new initiatives successful*, U.S. General Accounting Office

HEISINGER, B.E.; HOLM, W.; FULLER, C.; QUIGG, G.F. (2017), *The Hester Lake B-24 Crash: A Case Study for Small, Low-Cost ROVs*, 50th Annual Society for Historical Archaeology Conf., Forth Worth

HU, K.C.; LEE, P.T. (2011), *Developing a New Technique for evaluating service quality of container ports*, Current Issues in Shipping, Port and Logistics

KUNGWANI, B.; MISAL, N. (2017), *Design and fabrication of a low cost submersible ROV for survey of lakes*, Int. Research J. Engineering and Technology (IRJET) e-ISSN 2395-0056

LIU, L.M.; QIU, W.M.; LIU, G.; WANG, Y. (2007), *A Discussion on the Damage Mechanism and Reinforcement of the Concrete Board Shore Protection*, Disaster and Control Engineering 2

LUND-HANSEN, L.C.; JUUL, T.; ESKILDSEN, T.D.; HAWES, I.; SORRELL, B.; MELVAD, C.; HANCKE, K. (2018), *A low-cost remotely operated vehicle (ROV) with an optical positioning system for under-ice measurements and sampling*, Cold Regions Science and Technology 151, pp.148-155

MILES, M.B.; HUBERMAN, A.M.; HUBERMAN, M.A.; HUBERMAN, M. (1994), *Qualitative data analysis: An expanded sourcebook,* Sage

MOURA, R.; BEER, M.; PATELLI, E.; LEWIS, J.; KNOLL, F. (2017), *Learning from accidents: interactions between human factors, technology and organisations as a central element to validate risk* *studies*, Safety Science 99, pp.196-214

NÄSLUND, D. (2002), *Logistics needs qualitative research–especially action research*, Int. J. Physical Distribution & Logistics Management 32(5), pp.321-338

NIELSEN, D. (1971), *The cause/consequence diagram method as a basis for quantitative accident analysis*, Report Risø-M-1374 of the Danish Atomic Energy Commission, Risø

OSEN, O.L.; SANDVIK, R.I.; ROGNE, V.; ZHANG, H. (2017), *A novel low cost ROV for aquaculture application*, OCEANS 2017, Anchorage, pp.1-7

PACUNSKI, R.E.; PALSSON, W.A.; GREENE, H.G.; GUNDERSON, D. (2008), *Conducting visual surveys with a small ROV in shallow water*, Marine habitat mapping technology for Alaska, pp.109-128

REASON, J. (1990), *Human error*, Cambridge Univ. Press

REASON, J.; HOLLNAGEL, E.; PARIES, J. (2006), *Revisiting the Swiss cheese model of accidents*, J. Clinical Engin., 27(4), pp.110-115

SHIELDS, P.M.; RANGARAJAN, N. (2013), *A playbook for research methods: Integrating conceptual frameworks and project management*, New Forums Press

SIREGAR, S.; SANI, M.I.; SILALAHI, S.T.P. (2020), *Single camera depth control in micro class ROV*, Telkomnika 18(3)

STEIN, M. (2018), *Integrating unmanned vehicles in port security operations: An introductory analysis and first applicable frameworks*, Ocean Yearbook Online 32(1), pp.556-583

STEIN, M. (2020), *Unmanned maritime infrastructure inspection–a mixed method risk management approach from German port facilities*, Proc. Transport Research Arena (TRA), Helsinki

STEMN, E.; BOFINGER, C.; CLIFF, D.; HASSALL, M.E. (2018), *Failure to learn from safety incidents: status, challenges and opportunities*, Safety science 101, pp.313-325

TEAGUE, J.; MILES, J.; CONNOR, D.; PRIEST, E.; SCOTT, T.; NADEN, J.; NOMIKOU, P.V. (2017), *Exploring Offshore Hydrothermal Venting Using Low-Cost ROV and Photogrammetric Techniques: A Case Study from Milos Island, Greece*, Preprints, https://www.preprints.org/manuscript/201710.0014/v1

TRANFIELD, D.; DENYER, D.; SMART, P. (2003), *Towards a methodology for developing evidence-informed management knowledge by means of systematic review*, Br. J. Manag. 14, pp.207-222

VOSS, C.; TSIKRIKTSIS, N.; FROHLICH, M. (2002), *Case research in operations management*, Int. J. Operations & Production Management 22(2), pp.195-219

VUKŠIĆ, M.; JOSIPOVIĆ, S.; ČORIĆ, A.; KRALJEVIĆ, A. (2017), *Underwater ROV as inspection and development platform*, Trans. Maritime Science 6(01), pp.48-54

WIRYADINATA, R.; NURLIANY, A.S.; MUTTAKIN, I.; FIRMANSYAH, T. (2017), *Design of a Low Cost Remotely Operated Vehicle with 3 Dof Navigation*, Bulletin of Electrical Engineering and Informatics 6(1), pp.13-23

ZAIN, Z.M.; NOH, M.M.; AB RAHIM, K.A.; HARUN, N. (2016), *Design and development of an X4-ROV*, 2016 IEE

# Proactive Cleaning and the Jotun Hull Skating Solution

**Geir Axel Oftedahl**, Jotun A/S, Sandefjord/Norway, geir.axel.oftedahl@jotun.no
**Alexander Enström**, Jotun A/S, Hamburg/Germany, geir.axel.oftedahl@jotun.no

**Abstract**

*The paper describes Jotun's Hull Skating Solutions (HSS) for proactive hull cleaning. The solution combines high-performance antifouling, proactive condition monitoring, inspection and proactive cleaning, remote operation from shore as well as, performance and service level guarantees. The paper describes the background for the development of HSS, how it works, its benefits and the partners involved on its' development. A guideline for proactive cleaning in ports and at anchorages, developed in collaboration with representatives from relevant stakeholders, is attached as Annex 1.*

## 1. Background

The accumulation of fouling over time leads to a significant drop in performance and an increase in the vessel's fuel consumption and environmental footprint. To counter this, ship operators use hull coatings with anti-fouling properties. However, these coatings will not always deliver optimal anti-fouling protection due to changing operational profiles or the operation being so challenging that fouling pressures exceeding coating tolerance.

Many vessels spend time in challenging and complex environments, or are deployed in difficult operational profiles, where hull fouling can have a marked impact on efficiency and raise fuel costs. Various circumstances can prove challenging from a hull performance point of view and require proper attention since the current solutions on the market struggle to address these problems. Also, operational profile factors outside coating tolerance such as speed, activity and temperature can be encountered for a variety of reasons.

Bulk carriers, tankers and general cargo ships can spend long periods in ports being loaded and unloaded. Some of them may also be prevented from berthing for long periods due to neap tides. In such cases, shallow water and temperate environments can lead to accelerated fouling. Many shipowners must deal with these challenging operations on a regular basis.

According to the IMOs 4th GHG emissions study. *IMO (2020)*, International shipping emitted around 919m tons of CO2 and 21m tons of other GHGs in 2018 (incl. methane, NOx, SOx). According to the same study, 9% of consumption and emissions were caused by biofouling, resulting in a total annual reductions potential of around 83m tons of CO2 and around 2m tones of other GHGs. The share of consumption and emissions caused by biofouling corresponds with findings from earlier studies including Clean Shipping Coalition submission to the 63rd IMO Marine Environment Protection Committee meeting, *CSC (2015)*.

For the ships the greatest biofouling challenge, the share of fuel consumption caused by biofouling is likely to greatly exceed the 9% average for all ships. The improvement potential is therefore considerable.

Most shipowners and operators accept that anti-fouling coatings and operational measures combine to affect efficiency and they will make choices mostly based on their own experience of different products. There are many solutions in the market today, offering different types of anti-fouling coatings that use different types of technology to ensure that fouling will not settle on the ship's hull. One area, however, where today's solutions for anti-fouling have not fully succeeded is challenging operations, forcing owners and operators to spend a lot of money and effort on inspections and cleaning.

Aside from cleaning or replacing the antifouling during dry-dockings, hulls and propellers may be cleaned occasionally in water while in service. This is normally done on the so-called reactive cleaning basis, which usually takes place during the dry-docking or when heavy fouling is evident. Today, performance monitoring software tools make it possible to detect varying degrees of fouling based upon the ship's performance and fuel consumption data and allow for cleaning to be arranged. However, at this stage fouling is already a major problem.

Traditionally cleaning would be done manually by teams of divers. This is still a method that is in common use, but which is increasingly coming under scrutiny. Diving teams may be good at clearing the fouling from the hull but there are problems. Firstly, it is a labor intensive and costly process. If there are insufficient divers available, the time needed can be difficult for ship operators to fit into schedules and may lead to off hire time for chartered ships.

Moreover, manual cleaning often leads to the coating becoming damaged and potentially creating an even worse problem in a very short time. The effect on the environment is also an issue as the cleaning process may result in aquatic invasive species and/or eroded coating materials being deposited into the water column. This can have a detrimental effect on local ecosystems and is something that authorities are not keen on permitting.

Finally, and perhaps most importantly, in some situations manual cleaning with divers place the divers at risk. Injuries and deaths are reported each year.

Consequently, manual cleaning by divers is no longer permitted in a number of ports. Many others are considering banning such activities. That does make following the International Maritime Organisation's (IMO) biofouling guidelines difficult and is something that will need to be addressed if controls become mandatory.

Robotic cleaning (with remotely or diver operated equipment) is another way to clean hulls and there are a range of solutions of varying maturity emerging. Some of these solutions even allow for the capture of some or all of the biofouling waste and eroded coating materials removed during the cleaning.

However, the common denominator for all cleaning technologies in use today is that they are used reactively – they are designed for and applied when the fouling has already become a problem.

**2. Proactive cleaning and the Jotun Hull Skating Solution**

To combat fouling and help address the challenges faced by owners and operators of ships in the most challenging operations, Jotun introduces proactive cleaning through its Hull Skating Solution, a groundbreaking approach engineered to keep the hull free of fouling at all times.

When the biofouling pressure exceeds the antifouling or fouling release capabilities in the coating used, biofouling will begin to settle on the hull. Biofouling progresses in several stages:

Stage 1 (USN FR 0 to 10): Settlement of individual bacteria (within minutes)
Stage 2 (USN FR 20): Biofilm / slime (within 1 day)
Stage 3 (USN FR 30): Algae and single-cell organisms (within 1 week)
Stage 4 (USN FR 40 and up): Macro-fouling (tubeworms, barnacles, etc.) (within 2-3 weeks)

USN FR refers to the US Navy Fouling Rating scale, *US Navy (2006)*.

In the Guideline for Proactive Cleaning of Hull Areas in Port & at Anchorage, Annex 1, proactive cleaning is defined as the proactive removal of fouling at Stage 1 and early in Stage 2 - before it reaches Stage 3. Proactive cleaning is achieved by cleaning the hull regularly before fouling takes hold. Fouling is therefore removed before it affects hull performance and before there is biofouling waste to be captured. When fouling is removed at such an early stage, the force needed to remove the fouling is also very limited, with the result that the fouling can be removed without damage to or erosion of the coating.

Put simply, Jotun Hull Skating Solutions keeps ship's hull clean to minimize performance loss with no debris or waste, giving an unmatched environmental footprint and full operational flexibility.

### 2.1. Solution elements

The solution combines five elements to deliver an always clean hull:


Fig.1: The 5 elements in the Hull Skating Solution

- High performance coatings
  Jotun's 'SeaQuantum Skate' coating has been developed specifically to optimize performance in combination with the HullSkater technology. The new coating builds upon the excellent performance of the SeaQuantum brand, which is the result of over 20 years research and development in silyl acrylate technologies. SeaQuantum Skate is the only coating tailored for Hull Skating.

- Proactive condition monitoring
  This is an essential component of predictive hull maintenance. Jotun's in-house analysts make fouling predictions based on big data trends, algorithms and analyses, and advise customers on when to carry out hull maintenance. This also includes oceanographic assessment for fouling prediction and enabling the Skate Operator to perfectly time the deployment of the system.

- Inspection and proactive cleaning
  The HullSkater is the first robotic device that has been purposed designed for proactive cleaning. It has high inspection and cleaning capacity and removes fouling without damaging the anti-fouling coating. The HullSkater is always kept onboard in a portable station with launch and recovery ramp. This means that it is always available and can be used when the ship is in harbour or at anchor.

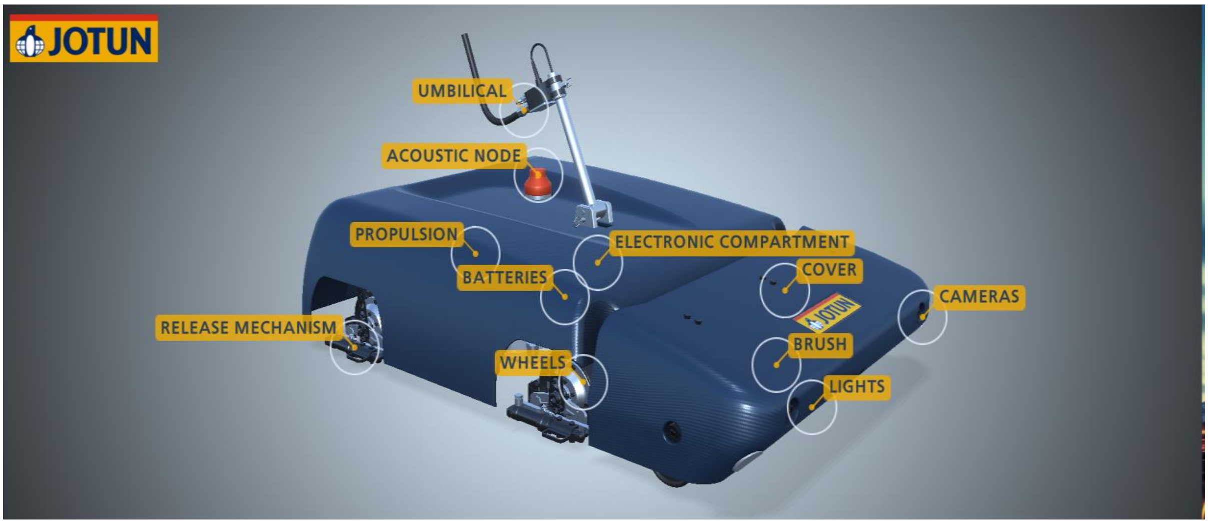



Fig.2: The Hull Skater

- High-end technical service
  The solution includes highly skilled coating advisors who ensure high performance coating application, including a comprehensive regime for measuring and documenting the quality of the application process. Also, every delivery of this solution is supported by a certified project manager, overseeing the application process and ensuring smooth instalment and set-up of the robotics. The HullSkater is remotely operated by Skate Operators working in our "follow the sun" operating hubs, enabling 24/7 support.

- Performance and service level guarantees
  Our confidence in Jotun's Hull Skating Solutions allows us to offer performance and service level guarantees fitting the needs of the most challenging operations.

## 2.2. How it works

Jotun Hull Skating Solutions is installed on the vessel at the new build or dry dock yard and remains on board and in operation all through the drydocking cycle.

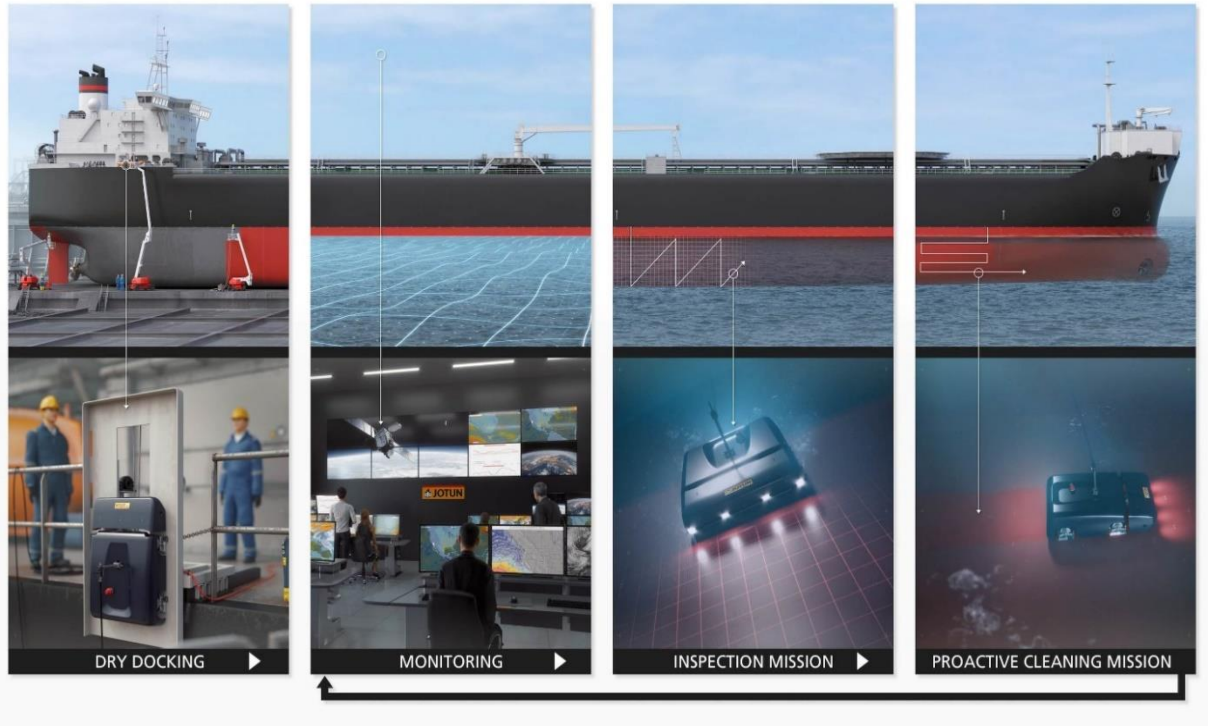



Fig.3: How it works

- Drydocking
  During drydocking the painting process is supervised by a certified Jotun Project Manager, who also is responsible for the installation of the Jotun HullSkater and the Skate Station.

- Monitoring
  In Jotun Hull Skating Solutions, big data and advanced algorithms are used to predict the probability of fouling, and to identify when the Skater needs to be deployed for an inspection and potentially proactive cleaning mission.

- Inspection Mission
  When alerted by the fouling prediction algorithm, the Jotun Skate Operator contacts the ship to schedule an inspection mission. The Jotun HullSkater can be operated in port or at anchor, as long as there is sufficient 4G coverage for communication.

- Proactive Cleaning Mission
During the inspection mission, if light fouling is detected, the Skate Operator initiates proactive cleaning. If time does not allow for a proactive cleaning mission, then the Jotun Skate Operator agrees with the ship when the next opportunity will be.

## 3. Benefits of proactive cleaning with the Jotun Hull Skating Solutions

Proactive cleaning with Jotun Hull Skating Solutions (HSS) provides market leading hull performance by combining advanced coating systems with proactive, efficient, safe and environmentally friendly inspections and cleaning.

- Full operational flexibility and unlimited idle days
HSS gives the vessel full operational flexibility with unlimited idle days. This is achieved by combining fouling prediction with the onboard capability to inspect and proactively clean before hard growth takes hold and prior to changing geographical bio-environments. This reduces downtime for unplanned, reactive, inspections and cleaning.

- Reduced fuel costs
The ability to engage in cleaning the hull proactively allows the hull to be maintained at peak performance, thereby reducing emissions whilst saving fuel costs as compared to market average.

- Reduced environmental footprint
A continuously clean hull improves fuel consumption resulting in lower greenhouse gas (GHG) emissions.

- Reduced risk of spreading invasive species
The IMO has published Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species. The timely removal of light hull biofouling at its geographical origin reduces the risk of spreading invasive species in the oceans and coastal waters.

- Verification capabilities
Many incidents at sea trigger the need for underwater hull inspection. HullSkater onboard enables the hull to be inspected at any time, 24/7. HSS also provides documentary evidence of hull cleaning for Port Authorities prior to arrival.

## 4. Partnerships

The marine business environment is growing increasingly complex and challenging, requiring development of new solutions through partnerships. Developing Jotun Hull Skating Solutions had not been possible without world-class partners, Fig.4.


Fig.4: Jotun Hull Skating Solution partners

## References


CSC (2015), *A transparent and reliable hull and propeller performance standard*, Clean Shipping Coalition (2015*)* submission to IMO MEPC 63.

IMO (2020), *4$^{th}$ IMO GHG Study – Final Report*, IMO MEPC 75

US NAVY (2006), *Naval Ships' Technical Manual Chapter 081 Waterborne Underwater Hull Cleaning Of Navy Ships*, https://maritime.org/doc/nstm/ch081.pdf

## Annex 1: Guideline for Proactive Cleaning of Hull Areas in Port & at Anchorage

HSS | Hull Skating Solutions

JOTUN
Jotun Protects Property

### Guideline for Proactive Cleaning of Hull Areas in Port & at Anchorage

**Rev 16, 27.08.2020 - placed in public domain as per Creative Commons CC BY-SA**

#### Executive Summary

*The intent of this guideline is to provide input to ports and other jurisdictions facing requests for proactive in-water cleaning of ships' underwater hull areas while in port or at anchorage. It addresses key points to consider, such as requirements and how delivery on these requirements is to be documented.*

#### Table of contents



Contact for further information: Geir Axel Oftedahl
Jotun A/S, Hystadveien 167, 3209 Sandefjord, Norway
geir.axel.oftedahl@jotun.no

## 1. Introduction

### 1.1. Purpose

The intent of this guideline is to provide input to ports and other jurisdictions facing requests for proactive in-water cleaning of ships' underwater hull areas while in port or at anchorage. It is intended to support the accelerated implementation of (ecologically and economically sound) proactive in-water cleaning procedures in port and at anchorage.

### 1.2. Background

Biofouling on the hull of a ship is an important vector for the spread of aquatic invasive species. Biofouling also increases ship hull resistance and decreases propeller efficiency; both leading to higher fuel consumption and associated emissions to air ($CO_2$, SOx, NOx, etc.). The increase in fuel consumption (or saving potential) may be significant. It is estimated that approximately10 % of the fuel consumed by the world's fleet could be saved by better management of hull and propeller surfaces, *IMO (2011a)*.

Measures to combat biofouling, collectively termed 'antifouling measures', are, therefore, an environmental and economic necessity for shipping. The most commonly used approach is based on antifouling coatings. These coatings contain one or more biocides, embedded in a slowly dissolving or eroding matrix. Another common antifouling approach is fouling release coatings. These have surface properties that make fouling adhesion difficult. Fouling release coatings typically require higher speeds to be self-cleaning.

When the biofouling pressure exceeds the antifouling or fouling release capabilities in the coating used, biofouling will begin to settle on the hull. Biofouling progresses in several stages:

- Stage 1 (USN FR 0 to 10): Settlement of individual bacteria (within minutes)
- Stage 2 (USN FR 20): Biofilm / slime (within 1 day)
- Stage 3 (USN FR 30): Algae and single-cell organisms (within 1 week)
- Stage 4 (USN FR 40 and up): Macro-fouling (tubeworms, barnacles, etc.) (within 2-3 weeks)

USN FR refers to the US Navy Fouling Rating scale (US Navy, 2006) also included as Annex 1.

Cleaning of the first two stages can be done using minimal force and is often referred to as soft cleaning. Cleaning of the last two stages of fouling will require more force.

An inherent risk when cleaning antifouling and fouling release coatings with too much force, is that the coatings are eroded or damaged. This may result in excessive amounts of biocides or coatings particles being released into the local environment. It will typically also result in a deterioration in antifouling or foul release capabilities and therefore an increased risk of the biofouling problem reemerging.

It is generally held that biofouling in the two first stages is of no concern in terms of aquatic invasive species. An inherent risk when cleaning biofouling at stage is that the cleaning may result in the release of aquatic invasive species into the local environment, however.

Proactive cleaning means to remove the biofouling during the first two stages and before it has progressed to stage 3. If done correctly, biofouling can therefore be removed without causing erosion of or damage to the coating and without risk of transfer of aquatic invasive species.

Proactive cleaning in port or at anchorage may be done using divers or remotely operated vehicles (ROVs). Divers and operators of ROVs are both exposed to health and safety risk and may represent a risk to other marine traffic. There may also be privacy and security concerns related to cameras and other sensors used.

Key concerns of ports and jurisdictions related to in-water cleaning are:

- Release of aquatic invasive species
- Release of biocides and other paint components
- Health, safety and (other) environmental concerns
- Privacy & security

These concerns of ports and other jurisdictions must be addressed appropriately by any proactive cleaning procedure before a port or other jurisdiction can grant permission for such a procedure to be used.

### 1.3. Who should read this guideline?

Ports and other jurisdictions who may want to grant permission to undertake proactive cleaning in a port or at an anchorage, ship operators or service providers who may want to apply for such permission (hereinafter the "Applicant"), as well as other representatives from ports, jurisdictions, ship operators, service providers, other regulatory authorities and associations of the above.

## 2. Requirements for proactive cleaning of ships' underwater hull areas

The key concerns of ports and other jurisdictions translate into corresponding requirements for any proactive cleaning procedure. In the following subchapters, such requirements are listed. It is also suggested how these requirements can be addressed and how acceptable fulfillment of requirements might be proven.

### 2.1. Basic documentation

Any procedure must be documented with an account of its working principle and operational requirements, including:

- Equipment to be used with specific manufacturers/models
- On what parts of the ship's underwater hull area the equipment can be used and what areas are excluded (e.g. specific hull features, extreme curvature, etc.)
- Other requirements or limitations (e.g. wind, waves, temperature, daylight, etc.)

### 2.2. No release of aquatic invasive species

While the procedure needs to facilitate the effective inspection and proactive cleaning of a hull, its execution shall not lead to the release of aquatic invasive species. For proactive cleaning this is achieved by restricting cleaning to areas of the hull with biofouling at stage 1 or 2. As long as proactive cleaning is only done on areas that are already clean by this standard, there will be no significant risk that the cleaning results in a release of aquatic invasive species.

In order to ensure proactive cleaning will only be done on areas that are already clean, the Applicant must document that procedures are in place to:

- Identify areas with biofouling at stage 3 and above as per the US Navy Fouling Rating scale (US Navy, 2006) included as Annex 1.

- Avoid these areas during the proactive cleaning

The Applicant must also document that the procedures in place are adequate. This can be documented by inclusion of a risk assessment by a competent third party.

In order for a port or other jurisdiction to be able to verify that proactive cleaning has only done on areas that are already clean, the Applicant must agree to:

- Capture, store and make available to the port or other jurisdiction video of the full proactive cleaning operation, where video must be of sufficient quality to allow determining if the areas proactively cleaned were already clean or not.
- If in dispute, refer final decision to a competent third party agreed upon upfront and cover half the cost of such verification. The Applicant may nominate a competent third party, and vouch for a maximum cost of verification, as a part of the application.

Areas that are found to be fouled with biofouling in Stage 3 or beyond should be recorded. Such areas may undergo conventional/reactive cleaning in a port where such conventional/reactive cleaning services are allowed.

### 2.3. No unacceptable release of biocides and other chemicals

The cleaning should remove fouling effectively but must not be abrasive to the paint. The Applicant must therefore document that:

- The cleaning equipment to be used can be operated on the same type of paint system in a similar condition (including age and remaining dry film thickness) and on the same type of fouling without significant risk of erosion or damage to the paint.
- In biocide-containing paints, there should be no visible sign of the cleaning resulting in erosion to the intact antifouling paint beneath the leached layer.

This can be documented by inclusion of a risk assessment by a competent third party.

### 2.4. Respecting other stakeholders

#### *2.4.1. Non-interference with normal port operations*

It should not be possible to use the cleaning equipment to collect photographic or other information about other ships in ports. Also, the use of the cleaning equipment must not interfere with normal port operations. It therefore needs to be documented that:

- sensors (including cameras) are not able to reach near-by ships
- the use of the cleaning equipment will not interfere with normal port operations

This can be documented by inclusion of a risk assessment by a competent third party.

#### *2.4.2. Respecting health & safety requirements*

Health and safety aspects may be addressed in various forms, usually using a combination of design of equipment, training and instructions. The details will depend on the procedure chosen.

The Applicant must document that

- The procedure does not pose any unusual risks for human health or the environment during the complete phase of operation including launching, operation, retrieval and stowage of equipment.

This can be documented by inclusion of a risk assessment by a competent third party certifying that the procedure yields acceptable safety level.

## 3. Training & instructions for proper operation

It should be ensured that operators of cleaning equipment meet defined competence requirements which are accepted by the industry and concerned authorities. Suitable training should address the competence criteria, covering all work processes and all roles involved in cleaning operations.

It should be demonstrated that

- Training and/or instructions for operators are in place
- The success of training is assessed, and a record is kept (electronic format suffices)

This can be documented by inclusion of a risk assessment by a competent third party certifying that the training yields an acceptable safety level.

## 4. Documentation

The Applicant must document compliance with these guidelines. If not included as a part of the original documentation, the port or jurisdiction may require that a competent third party issue a statement of compliance.

Documentation requested from a potential supplier by the port or jurisdiction may be submitted via a portal (e.g. Vessel Check Portal), email or in paper version. A submission via a portal is recommended as the facilitates the review by all stakeholders.

In general, all quality management measures in place should be documented and stated when applying for in-principle permission to clean with a given procedure or technology in port or at anchorage.

## 5. References

CSC (2011). *A transparent and reliable hull and propeller performance standard,* Submission by Clean Shipping Coalition to MEPC.63-4-8, Int. Maritime Org., London, https://jotunimages.azureedge.net/images/images/mepc-63-4-8_tcm214-10265.pdf

IMO (2011). *2011 Guidelines for the Control And Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species,* Resolution MEPC.207(62), Int. Maritime Org., London, http://www.imo.org/en/OurWork/Environment/Biofouling/Documents/RESOLUTION%20MEPC.207[62].pdf

US Navy (2006). *Naval Ships' Technical Manual Chapter 081 - Waterborne Underwater Hull Cleaning of Navy Ships*, US Navy, https://www.hnsa.org/wp-content/uploads/2014/07/ch081.pdf

## 6. Change log

| Revision | Changes made from last revision | Comments |
|---|---|---|
| 15 | • Placed on Jotun template and in the public domain as per Creative Commons CC BY-SA | |
| 16 | • Changed reference to be used for identifying fouling as Stage 3 or beyond in Clause 2.2. from MPI 2018 to US Navy 2006 and removed MPI 2018 from Annexes.<br>• Added change log | Change has been made to simplify and clarify distinction between proactive and reactive cleaning. Note that this change also serves to further tighten requirements somewhat. |
| | | |
| | | |
| | | |
| | | |
| | | |

**Annex 1: US Navy Fouling Rating Scale (*US Navy,* 2006).**

S9086-CQ-STM-010

**Table 081-1-1** FOULING RATINGS (FR) IN ORDER OF INCREASING SEVERITY

| Type | Fouling Rating (FR) | Description |
|---|---|---|
| Soft | 0 | A clean, foul-free surface; red and/or black AF paint or a bare metal surface. |
| Soft | 10 | Light shades of red and green (incipient slime). Bare metal and painted surfaces are visible beneath the fouling. |
| Soft | 20 | Slime as dark green patches with yellow or brown colored areas (advanced slime). Bare metal and painted surfaces may by obscured by the fouling. |
| Soft | 30 | Grass as filaments up to 3 inches (76 mm) in length, projections up to 1/4 inch (6.4 mm) in height; or a flat network of filaments, green, yellow, or brown in color; or soft non calcareous fouling such as sea cucumbers, sea grapes, or sea squirts projecting up to 1/4 inch (6.4 mm) in height. The fouling can not be easily wiped off by hand. |
| Hard | 40 | Calcareous fouling in the form of tubeworms less than ¼ inch in diameter or height. |
| Hard | 50 | Calcareous fouling in the form of barnacles less than ¼ inch in diameter or height. |
| Hard | 60 | Combination of tubeworms and barnacles, less than ¼ inch (6.4 mm) in diameter or height. |
| Hard | 70 | Combination of tubeworms and barnacles, greater than ¼ inch in diameter or height. |
| Hard | 80 | Tubeworms closely packed together and growing upright away from surface. Barnacles growing one on top of another, ¼ inch or less in height. Calcareous shells appear clean or white in color. |
| Hard | 90 | Dense growth of tubeworms with barnacles, ¼ inch or greater in height; Calcareous shells brown in color (oysters and mussels); or with slime or grass overlay. |
| Composite | 100 | All forms of fouling present, Soft and Hard, particularly soft sedentary animals without calcareous covering (tunicates) growing over various forms of hard growth. |

# Industry Standard for In-water Cleaning with Capture

**Aron Frank Sørensen**, BIMCO, Bagsvaerd/Denmark, afs@bimco.org

**Abstract**

*This paper describes the development of an industry standard for in-water cleaning with capture initiated in recognition of the decline in the number of ports around the world allowing cleaning and the level of variance in the performance of in-water cleaning companies . The industry standard on in-water cleaning with capture shall help ensure that: (1) the cleaning process is planned, safe and effective; (2) the environmental impact is controlled, and properties of anti-fouling systems are preserved; (3) approval of in-water cleaners is internationally accepted. A BIMCO led working group consisting of shipowners, cleaning companies, ports, paint manufacturers and international organizations have worked on the standard since 2018. This paper will show the result of the group's work to date.*

## 1. Introduction

In-water cleaning is only allowed in a few locations around the world and there is an increasing tendency for coastal and port states to have rules, which at best allow in-water cleaning under certain circumstances and at worst prohibits it. In 2018, BIMCO therefore initiated the development of a standard that should be acceptable to relevant stakeholders and help improve the quality and safety of in-water cleaning.

The industry standard consists of three separate documents that outline performance-based requirements for the in-water cleaning of a ship's hull and niche areas with the capture of the materials that are removed during the process:

- Approval procedure for in-water cleaning companies
- Industry standard on in-water cleaning with capture
- Explanatory notes to the industry standard on in-water cleaning with capture

In the documents, the stakeholders are ships, cleaning companies, paint manufacturers, ports and other local authorities. The set- up is as follows:

1. The cleaning system and the working procedures are tested and approved by an independent approval body in accordance with the Approval procedure for in-water cleaning companies.
2. After approval, the quality systems of the cleaning company will be subject to internal audits and external audits carried out by the approval body.
3. Ships, paint manufacturers and cleaning companies will use the requirements outlined in the industry standard on in-water cleaning for planning, conducting, and reporting on the cleaning.
4. For an approved cleaning company to operate in any given location, the port and other relevant authorities must issue a local permission.

The standard helps to ensure that the in-water cleaning with capture of a ship's hull and niche areas including propeller, can be carried out safely, efficiently and in an environmentally sustainable way.

## 2. Approval of In-water Cleaners

It has been necessary to divide niche areas into different categories because the same piece of equipment cannot be used to clean all of them:

a. Niche areas present on the vertical side or the bottom of the ship that can be readily cleaned without using special equipment. On such areas, the equipment used is designed to clean large flat areas fast, which includes remotely operated vehicles (ROV's) and divers
b. Propellers
c. Niche areas that for example are built into the hull and/or have bends or corners have to be cleaned with special equipment and therefore are non-comparable to (a) and (b).

A cleaning company can be approved for one or more of the categories. The approval process involves a test of the equipment and the certificate will specify which category or categories; the cleaning company is approved to perform.

This procedure contains the minimum requirements and test protocols for demonstrating compliance with the industry standard on in-water cleaning with capture and the approval process for cleaning companies.

**3. Testing**

In-water cleaning companies will be tested for three different performance criteria based on their individual performance/manufacturers claims. The verification testing will take place on actual ship surfaces (submerged hull and/or niche areas) and anti-fouling coating system (AFC) (non-biocidal and/or biocidal) depending on cleaning company's claims. Manufacturer's and cleaning company's specifications should include the following as a minimum:

- biofouling type and extent
- AFC type(s)
- categories of areas (hull, niche areas and/or propeller)
- visibility and operational limits.

The performance criteria include:

1. Limits to the type and extent of biofouling that the system is able to clean from ship surfaces (e.g., a height of hard calcareous fouling, fouling ratings, percentage of surface area covered with soft macro fouling and hard fouling, total amount of material that can be handled, etc.),
2. Capture and removal of material produced collected during in-water cleaning (e.g. largest size and percentage reduction of particulate matter in effluent water);
3. Impact to local water quality (e.g., levels of total suspended solids and/or AFC associate bio-cides) as a result of in-water cleaning.

**4. Inspections and planning of in-water cleaning**

The *IMO (2011)* guidelines recommend the use of a biofouling management plan and biofouling record book (Resolution MEPC.207(62), 2011 Guidelines for the Control and management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species). The information in the IMO guidelines has formed the basis of the practical part of the in-water cleaning standard.

The biofouling management plan must specify under which conditions in-water inspections should be conducted. Some inspections are prescheduled in accordance with the ship's planned maintenance system (PMS) while others are planned in accordance with the operational profile of the ship, including after extended idle periods.

The decision to conduct an in-water inspection should be based on, but not limited to the following:

1. Risk assessment of biofouling growth
2. Assessment of the propulsion power and fuel consumption over a specified period (hull performance monitoring)

3. Statutory and class IWS (in-water survey) between dry docks
4. Availability of services provided by divers e.g. regular propeller polishing or cleaning or underwater repair
5. Idle periods or specific lay ups for example as stipulated in a charter party or in contracts with the AFS manufacturer
6. Mandatory inspection requirements according to relevant regulatory regimes before proceeding to an arrival port or waters of a coastal state
7. Requests by the charterer due to failure of the AFS
8. Inspections carried out at planned intervals in accordance with the PMS
9. Inspections requested by the AFS manufacturer.

This industry standard introduces reference areas, which will serve as datum areas that are used for inspection and to measure the efficacy of the cleaning.

During every inspection, attention should be paid to the reference areas and ensure information is being recorded accurately. The condition of reference areas will give an indication of biofouling growth, therefore, accurate inspection and recording of details will be of upmost importance. It may not be possible to inspect all reference areas during one single inspection, so every new inspection should select different reference areas in order to represent the entire underwater area.

The industry standard includes detailed procedures for the planning and execution of in-water cleaning. The cleaning should be seen as a part of the whole biofouling management process. This is the backbone of the standard that ensures that a cleaning is carried out safely.

Fig.1 provides an overview of the communication flow between the various parties using this industry standard when conducting hull inspection and/or cleaning.

**Acknowledgement**

The industry standard has been written by an industry working group consisting of paint manufacturers, in-water cleaners, shipowners, ports, international organisations and authorities. The following were represented in the work: Akzo Nobel, BIMCO, C-Leanship, CMA Ships, DG Diving Group, Dutch Ministry of Infrastructure and Water Management, Fleet Cleaner, Hapag-Lloyd, Hempel, HullWiper, International Association of Classification Societies, International Chamber of Shipping, Minerva Shipping, Portland Port (UK), Port of Rotterdam, Alliance for Coastal Technologies (ACT), PPG Coatings, and Maritime Environmental Resource Center (MERC) and the broad international ACT/ MERC collaboration on independent testing of in-water cleaning systems.

**References**

TAMBURRI, M.N.; DAVIDSON, I.C.; FIRST, M.R.; SCIANNI, C.; NEWCOMER, K.; INGLIS, G.J.; GEORGIADES, E.T.; BARNES, J.M.; RUIZ, G.M. (2020), *In-Water Cleaning and Capture to Remove Ship Biofouling: An Initial Evaluation of Efficacy and Environmental Safety*, Front. Mar. Sci. 7, https://www.frontiersin.org/articles/10.3389/fmars.2020.00437/full

IMO (2011), *Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species,* International Maritime Organization, London

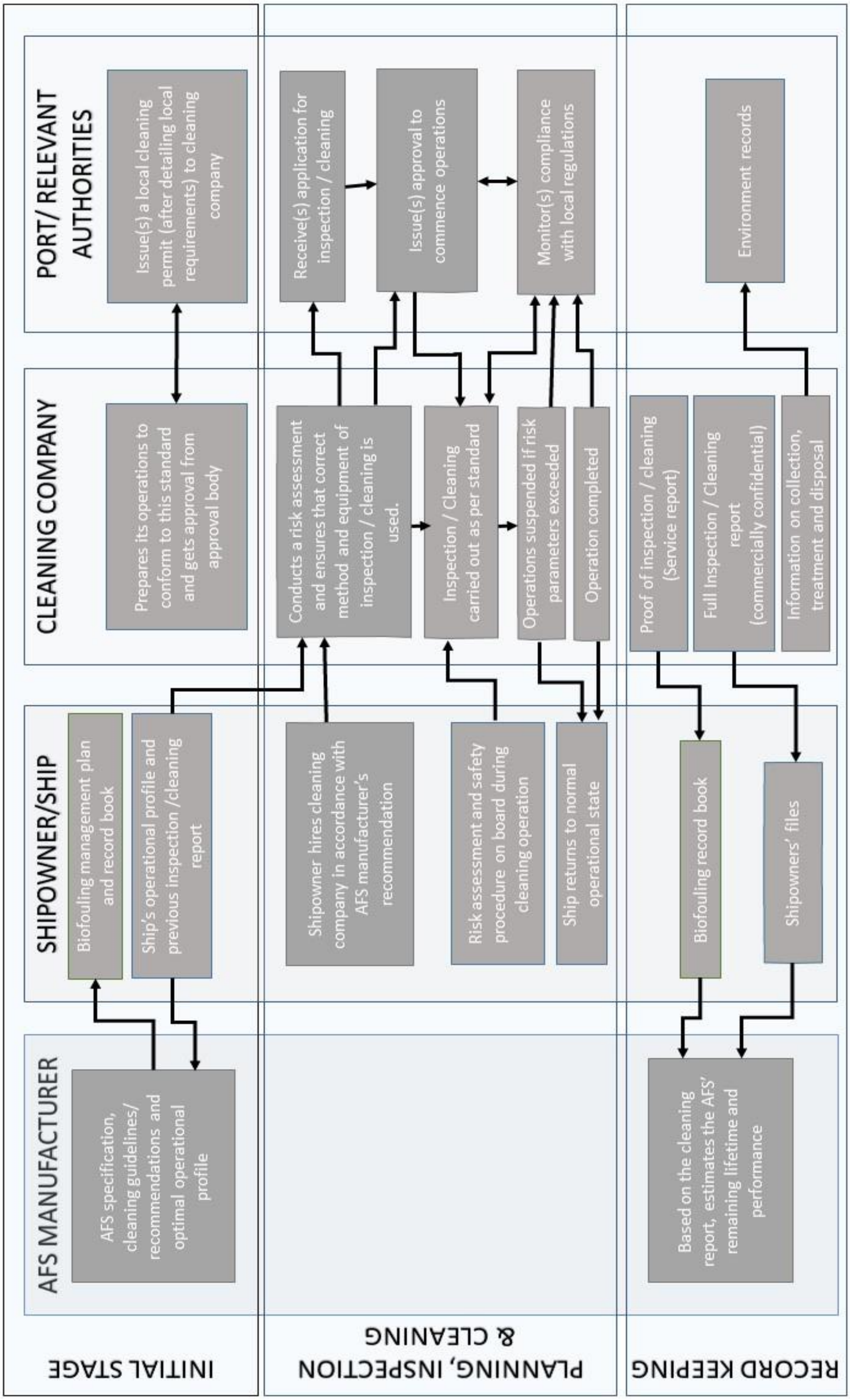



Fig.1: Communication flow chart

# Ultrasound - The Future Way to Match IMO's Biofouling Guideline

**Jan Kelling**, HASYTEC Electronics GmbH, Schönkirchen/Germany, j.kelling@hasytec.com

**Abstract**

*Matching Biofouling Management with the IMO Biofouling Guideline is mandatory for future vessel operation and already crucial when sailing into first mover`s territorial waters like Australia, New Zealand, US California State, Hawaii State and more to come. Innovative, sustainable and overall reliable solutions are required. The HASYTEC paper will focus on development steps of ultrasonic technology, hull fouling protection, and niche areas fouling protection. Case studies of different vessel types illustrate results and benefits.*

## 1. Introduction

Fouling develops in stages, where the initial stage is a microscopic fouling, which collectively may form a biofilm visible to the human eye, Fig.1. See *Kelling (2017a,2018)* for a more extensive discussion. If the biofilm formation is inhibited, the subsequent stages of macrofouling will not develop. Much of the focus of recent research and development into biofouling management have been focused – rightfully and logically – then on inhibiting biofilm formation and development.

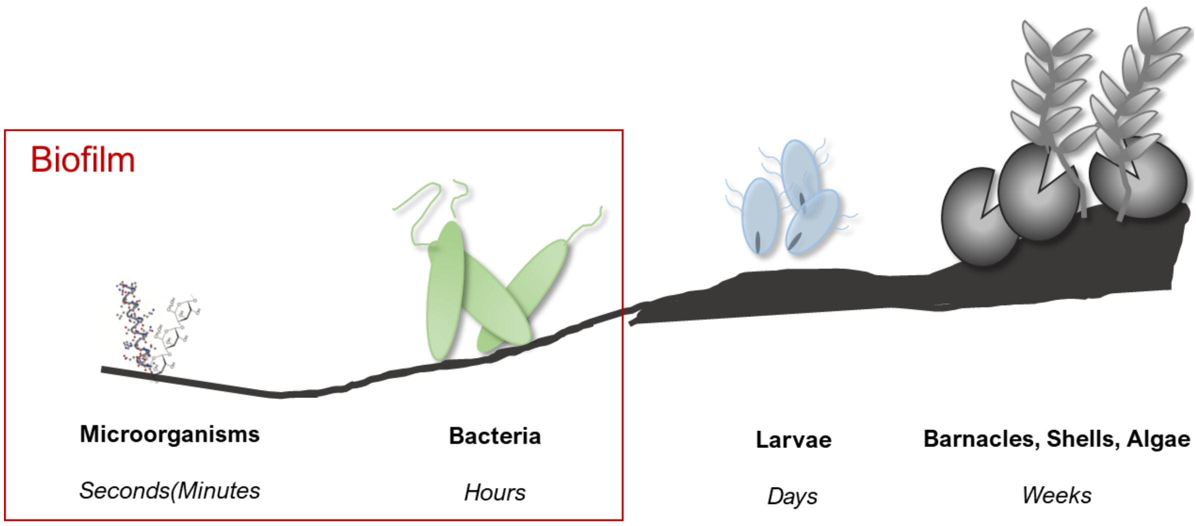



Fig.1: Biofilm as the initial step of marine growth

The classical approach to combat biofouling on ships has been using biocide-containing paints, *Bertram and Yebra (2017)*. In relation to the IMO convention "International Convention on the control of harmful Anti-Fouling Systems on Ships (2001)", the European Union finalized the EU Regulation No. 528/2012. This regulation on biocide containing products regulates the marketing and use of biocide containing products, which due to the activity of the active ingredients contained in them for the protection of humans, animals, materials or products against harmful organisms such as pests or bacteria, may be used. The aim of the regulation is to ensure a better functioning of the biocide containing products market in the EU, while ensuring a high level of protection for human health and for the environment. As an example, almost no copper based active substance will get permission to be used in the future. Every system must be approved to be marketed and the environmentally harmful systems shall be sorted out. This leaves essentially two options:

- taking the risk of using less effective antifouling systems which leads to higher costs for maintenance and repair as well as to higher fuel expenses
- looking for alternatives to replace the currently used antifouling systems

While robotic cleaning solutions are often a cost-effective solution for large, smooth areas, niche areas are unsuited for robotic cleaning. However, niche areas are particularly critical in terms of biofouling and the threat of aquatic invasive species. This is explicitly addressed in IMO's biofouling management guideline. Niche areas are also the focus of inspections of authorities already enforcing biofouling management policies, such as Australia, New Zealand, California and Hawaii State. A complementary solution is needed, and the Dynamic Biofilm Protection (DBP) based on ultrasound is the perfect match for the requirements of IMO's biofouling guideline. It will be described in the following.

## 2. Dynamic Biofilm Protection

Using low-powered ultrasound (which does not cause cavitation in a certain combination of frequencies, altitudes and power consumption) avoids biofilm formation on any liquid carrying surface, *Kelling (2017b)*. This working principle is still relatively unknown in the shipping industry, but it has large potential and enjoys a rapidly growing customer base.

The Dynamic Biofilm Protection based on ultrasonic protection against biofouling may be used for external spaces, such as pipes, heat exchangers, sea chests, or tanks, Fig.2. But they may also be used for hull protection. For smaller vessels, the complete hull may be protected, but for large cargo vessels, the typical applications focus on niche areas, such as side thrusters, sea chests, etc.

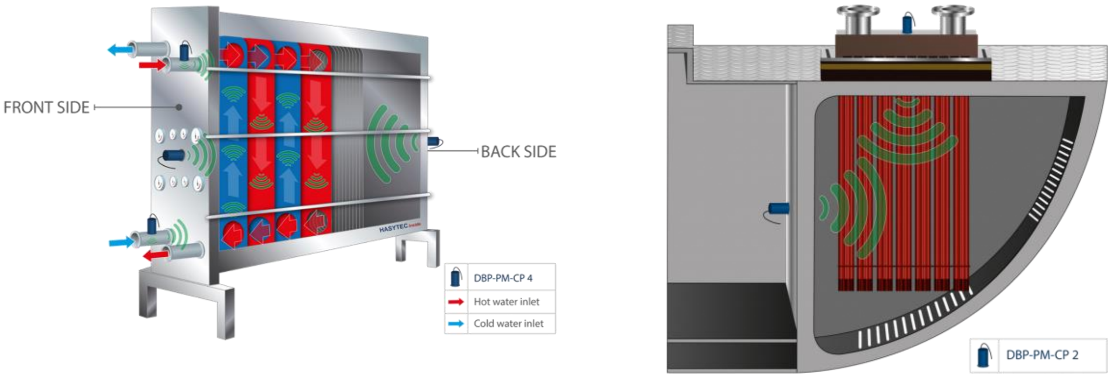



Fig.2: Internal biofouling protection using DBP. Small blue cylinders are 'transducers'

The ultrasonic vibrations are brought into the water via 'transducers', Fig.3, which are attached to the steel hull on the inside, e.g. in the engine room where electrical supply to the transducers is easy. Transducers are relatively low-powered, e.g. 12 W per transducer for average output, 20 W per transducer for maximum output.


Fig.3: Examples of installed transducers

Figs.4 to 7 show results from sample installations, demonstrating the effective protection against biofouling. More such results from shipping industry applications are found in *Kelling (2017a,b).*

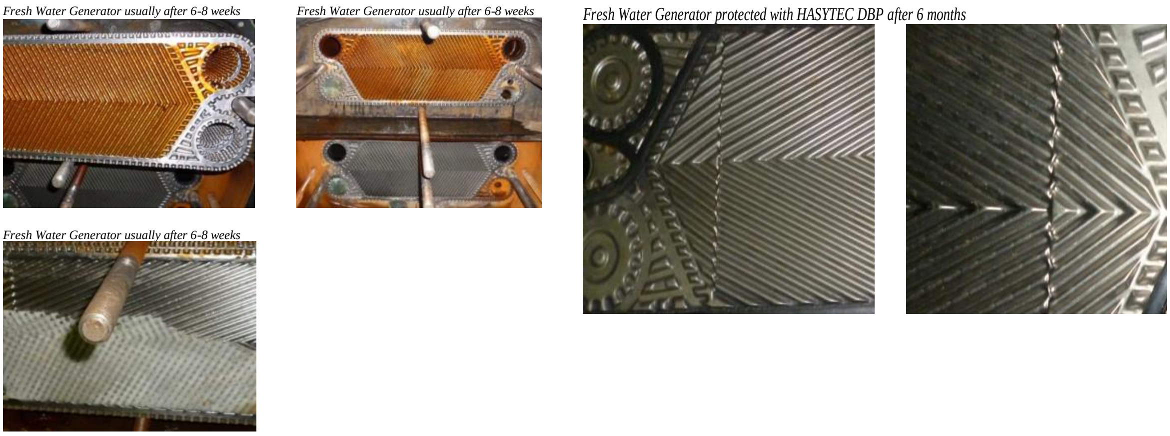



Fig.4: Fresh-water generator after 6-8 weeks without DBP / after 6 months with DBP

Fig.5: Sea Chest view from outside after 3.5 years in operation with DBP

Fig.6: Propeller after 6 months without DBP and comparable propeller after 3 years with DBP

Fig.7: Side thruster before (left) and after (right) installing DBP

## 3. Summary

Ultrasonic biofouling management continues to gain traction in the maritime industry. We have more then 4500 transducers installed, on a total of more than 230 ships. In a nutshell, the Dynamic Biofouling Protection system is summarized as follows:

- environmentally friendly and sustainable
- maintenance free
- reducing OPEX
- increasing lifetime of vessel`s components & operational safety
- design following shipping industry standards and IP 68 approved

**Acknowledgements**

HASYTEC electronics GmbH has enjoyed great support from customers and media which have accompanied us from the beginnings of a small start-up to where we are now: the technology leader in maritime ultrasonic biofouling protection. We are grateful for the many awards bestowed upon us: Environmental Performance Award (2017), Hansa Maritime Innovator Award (2017), PitchBlue Jury and Audience Awards (2018), Ocean of Opportunities Award (2018), SEATRADE Engineering Award (2019), and Deutscher Innovationspreis (2020). Thank you.

## References

BERTRAM, V.; YEBRA, D.M. (2017), *Past, Present and Prospects of Maritime Antifouling*, 11th HIPER Conf., Zevenwacht, pp.32-43, http://data.hiper-conf.info/Hiper2017_Zevenwacht.pdf

KELLING, J. (2017a), *Ultrasound-based antifouling solutions*, 2nd HullPIC, Ulrichshusen, pp.43-49, http://data.hullpic.info/hullpic2017_ulrichshusen.pdf

KELLING, J. (2017b), *Ultrasonic Technology for Biocide-Free Antifouling*, 11th HIPER Conf., Zevenwacht, pp.70-76, http://data.hiper-conf.info/Hiper2017_Zevenwacht.pdf

KELLING, J. (2018), *Ultrasound – The Silent Revolution in Antifouling*, 3rd HullPIC Conf., Redworth, pp.346-353, http://data.hullpic.info/hullpic2018_redworth.pdf

# Biofouling Management at the Dawn of a Mechanical Era

**Volker Bertram**, DNV GL, Hamburg/Germany, volker.bertram@dnvgl.com

**Abstract**

*This paper describes mechanical biofouling management solutions for ship hull management, namely robotic cleaning and ultrasonic protection. After briefly describing the state of the art in antifouling using biocide-based paints, the development of robotic cleaning is described, and current challenges discussed. Ultrasonic protection is seen as a complementary technology addressing niche areas.*

## 1. An ecological and economic necessity

Fouling has always been a problem for shipping and mankind has tried many things throughout history to protect ships from fouling, *Bertram (2000), Bertram and Yebra (2017), Doran (2019)*. The state of the art in the industry is the use of biocide-containing paints with occasional cleaning. With this approach, remaining fouling on average between docking intervals on many ships leads to 30-50% higher fuel consumption compared to a clean hull. Both fuel costs and emissions associated with fuel consumption are a concern. In addition, another aspect is increasingly attracting the attention of the IMO and regional legislators: with fouling, ships transport aquatic invasive species into new biotopes. It is to be expected that legislation will force increasingly restrictive requirements in this area over the next 10 years. Measures to prevent biofouling are therefore both an economic and an ecological necessity. Future solutions should be both more effective and environmentally friendly.

### 1.1. Principle of biocidal antifouling as current standard biofouling management approach

From the middle of the 19$^{th}$ century, antifouling paints were the predominant method of preventing fouling on ship hulls. The basic principle was the same as for most of today's antifouling paints, Fig.1: In contact with seawater, the paint releases biocides that form a protective boundary layer. For effective protection, a certain concentration of these biocides must be maintained. As the ship moves through the water, the biocides remain in the wake together with surrounding paint particles, and the paint layer on the ship must permanently resupply biocides. (This is the case with self-polishing copolymers (SPC) and controlled depletion (CDP) paints; the surrounding paint ("matrix") and biocides contained in the paint dissolve slowly in the water and the paint layer becomes thinner and thinner. The paint layer must be so thick that the paint is almost completely dissolved by the next docking. Then paint is applied again, and the process starts all over again.) The biocides get into the water by contact and frictional forces, which are created when the ship is moved by water. How fast the paint dissolves ("leaching rate") depends on the speed of the ship. Depletion is much faster when brushes exert high frictional forces during cleaning.

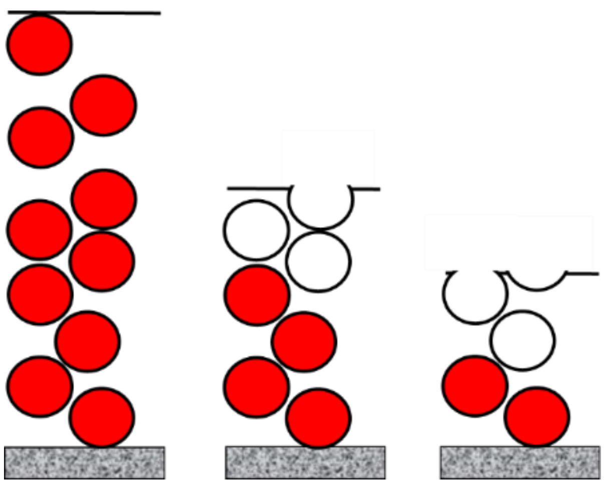


Fig.1: Principle of self-polishing co-polymers with biocides (red) and leached layer (empty circles)

The approach of self-dissolving paints with embedded biocides has been the standard antifouling solution for the shipping industry since the World War II. However, the general approach offers a wide spectrum of variation, both for the matrix and for the biocides. The biocides are leached out of the paint before the leached layer peels or flakes off. Thicker leached layers mean more variation in biocide leaching (effectiveness) and more frictional resistance. At the top end, paints with a very thin leached layer (typically with silyl as matrix material) are expensive and have a very uniform performance between dockings, thus saving fuel for the operator.

There is also a wide range of biocides on offer. Until 2003, TBT (Tributyltin) was almost a standard solution as a biocide. TBT is a highly effective biocide; even small quantities provided sufficient protection against fouling. TBT paints were relatively inexpensive, easy to handle and effective in protecting against fouling. The centuries-old antifouling problem seemed to be finally solved. But then, in the 1980s, critical voices began to be raised. In waters with heavy shipping traffic, alarmingly high concentrations of the biocide were found in oysters and fish. Over time, political pressure grew in the IMO (International Maritime Organization) and from 2003 TBT paints were banned worldwide for repainting, and from 2008 for all ships.

### 1.2. A bridging technology – But bridging to where?

The short-term solution for the shipping industry was antifouling paints with copper-based biocides. Since TBT is 10-20 times more effective (toxic) than copper compounds, copper-based paints require much higher leaching rates than TBT paints. Therefore, more paint is usually required, and even then the paints are not 100% effective. Various herbicides and fungicides are added to combat plant fouling where the copper biocides are not effective. These additional biocides are somewhat misleadingly referred to by marketing as "boosters". Some of the boosters are scientifically and politically controversial (including Irgarol 1051 and Diuron) and have been banned in the EU, for example.

Although ecologically less problematic than TBT paints, there is cause for concern for copper-based (and generally biocide-containing) paints:

- Some organisms become resistant to the biocides. Such "gladiator" species contribute to the spread of invasive species.
- Marine biologists publish concerns about the long-term effects of copper-based paints, e.g. *Chambers et al. (2006)*. Bans on copper-based coatings for recreational craft have already been discussed in some regions. The ban of TBT started in the same way.
- The "precautionary approach" sees the responsibility for demonstrating the safety and sustainability of a product as being with the industry. This means that industry is responsible for ensuring that a substance or process does not harm the environment. The EU has already made the precautionary approach a legal obligation. It is expected that the precautionary approach will increasingly be incorporated into IMO regulations.
- Many ports prohibit hull cleaning, partly to reduce problems with invasive species, and partly because they fear that biocides and paint particles (seen as microplastics, *IMO (2019)*) will contaminate water and port soil. The disposal of contaminated silt costs a lot of money.

Biocide-based antifouling paints are seen as a bridging technology even by major paint manufacturers. An IMO ban as for TBT is unlikely unless effective and affordable alternatives are available. However, we may see the fading antifouling paint and the dawn of a new era. And many, including myself, see this new era based on mechanical solutions, using frequent proactive cleaning and/or ultrasonic vibrations to curb biofouling at an early stage.

## 2. The dawn of a new mechanical age

A host of alternatives to biocidal coatings has been proposed over the year, e.g. *Bertram and Yebra (2017)*, and the process continues, e.g. with ultraviolet LED tiles for fouling protection as one of the latest ‘new kids on the block’.

### 2.1. Robotic hull cleaning has come a long way

For centuries, seafarers have beached and careened their ships to removed biofouling using ‘elbow grease’, as a simple, but effective way of keeping hull clean, *Doran (2019)*. Ideas to substitute human labor by machines for the cleaning of hulls are not new. As early as 1862, a patent proposed mechanical scrubbing of the hull by rotating knives. This proposal can be seen as the forefather to current developments using robot technology for mechanical cleaning of hulls.

Appropriate cleaning strategies depend on the coating used. Copper-based antifouling paints release toxins under shear forces. Thus, any brushing or wiping will release more toxins and each cleaning will deplete more toxins, leading to premature degradation of the coating. Foul release coatings are easily damaged by hard cleaning and require more frequent soft grooming. Hard coatings, similar to car varnish, are suited for frequent cleaning. Such hard coatings are currently used on ice breakers, where biofouling is not a big concern due to the very cold water temperatures, but frequent impact of ice floes and friction against harsh ice ridges require a mechanically robust coating. In itself, these coatings offer no fouling protection, but they allow frequent cleaning. “Frequent” may mean every two weeks, to give an idea.

In proactive cleaning (a.k.a. grooming, *Hunsucker et al. (2018)*), the ship is cleaned so frequently that advanced biofouling stages (barnacles, mussels, seaweed, etc.) are prevented from developing. While the coating technology is available, more work is needed to provide cost-effective, rapid and globally available cleaning. Recent developments in robot cleaning, e.g. *Noordstrand (2018), Doran (2019), Oftedahl (2020)*, Fig.2, are very interesting first steps in this respect. In-water robotic cleaning is evolving at a stunning pace. Typically for such young, rapidly developing technologies and markets, there are teething problems.

Fig.2: Pioneering in-water robotic cleaning solutions: Fleet Cleaner (left) and HullWiper (right)

Despite pioneering solutions gaining track, there remains work to be done on several fronts:

- Legal issues – Standardization and guidelines aligning designs, operational procedures and reporting overcoming the current “Wild West”, *Noordstrand (2020)*. In addition, many port authorities have yet to develop policies for robotic cleaning including postprocessing of removed biofouling and debris.
- Commercial issues – Market perception for robotic cleaning technology still has to penetrate wider parts of the shipping industry. This includes dissemination of the state of the art, beyond conferences like PortPIC and HullPIC.
- Technical issues – Integration of inspection and cleaning devices as in Jotun’s Hull Skater robot, *Oftedahl (2020)*, Fig.3, indicates a general trend. However, cleaning robots should learn a few more tricks, most notably teamwork. Small robots are agile, but in order to clean a large ship during the available time in port, ideally teams of robots should work together. While

there have been prototype applications of cooperative maritime robotics, Fig.4, *Odetti et al. (2016)*, I am not aware of any research activities for hull cleaning.

Fig.3: Hull Skater combines inspection and cleaning, source: Jotun

Fig.4: Cooperative robotics is still in its infancy, *Odetti et al. (2016)*

**2.2. Ultrasonic protection sounds like a good idea**

Ultrasonic vibrations cause very high accelerations, which destroy the cell structures of algae and weed. The technology has progressed from research to industrial applications, Fig.5, *Kelling (2017,2020)*. However, ultrasonic protection against biofouling requires oscillators ("transducers") every 6-8 m. The technology has been used for hull protection in yachts and workboats. For large cargo vessels, protecting the whole hull surface is more difficult, as the many oscillators require a network of electrical supply in areas with difficult access. Here, the technology is most interesting for areas such as pipes or sea chests, where power supply from the engine room is easy and the ultrasonic vibrations protect through the steel the surfaces on the far side. If current restrictions for operation in immersed environments (double bottom filled with water or fuel) are overcome, we may see wider applications. A strong point of this approach is that it offers biocide-free protection even for ships at zero speed, e.g. laid-up ships.

Fig.5: Ultrasonic transducer, source: Hasytec

**3. Conclusions**

The shipping industry moves towards more sustainable operation. Biofouling management is no exception. We can expect stricter regulations, both on regional level and coming from IMO. The best alternative to current biocide-based coating and cleaning strategies may lie in combining and coordinating technical and operational levers.

On the technical side, hard coatings and frequent pro-active cleaning (grooming) for large areas using robotic technology is evolving rapidly as an industry-mature and (total) cost-efficient option. For niche areas, ultrasonic protection makes sense as a complementary technology.

On the operational and legal side, more work needs to be done. Performance-based contracts, guidelines for operations and quality assurance are yet to be developed and aligned globally. Port operations from in-water cleaning permits to disposal of removed biofouling should follow documented sensible guidelines, which also will take some time to evolve and be aligned.

There is still a lot of work to be done, but activities on the engineering and regulatory side are gaining momentum and the progress of the last few years is encouraging. Alignment and consolidation of current activities will come naturally as biofouling management matures. The PortPIC conference will be instrumental in achieving this goal.

**Acknowledgements**

I would like to thank Marco Bibuli (CNR-ISSIA), Alex Noordstrand (Fleetcleaner), Jan Kelling (Hasytec), and Geir Axel Oftedahl (Jotun) for their support in providing material and patiently answering my many questions. The statements made in this paper do not reflect their opinion or that of DNV GL as a company, but are my personal view of the fascinating world of biofouling management and where we may be heading.

**References**

BERTRAM, V. (2000), *Past, present and prospects of antifouling methods*, 32nd WEGEMT School, Plymouth, pp.87-97, http://www.wegemt.com/wp-content/uploads/2019/04/32nd_WEGEMT_School_on_Marine_Coatings.pdf

BERTRAM, V. (2014), *Antifouling – High-tech strategies for an ancient problem*, 9th Int. Conf. on High-Performance Marine Vessels (HIPER), Athens, pp.204-2010, http://data.hiper-conf.info/Hiper2014_Athens.pdf

BERTRAM, V.; YEBRA, D.M. (2017), *Past, Present and Prospects of Maritime Antifouling*, 11th Symp. High-Performance Marine Vehicles (HIPER), Zevenwacht, pp.32-43, http://data.hiper-conf.info/Hiper2017_Zevenwacht.pdf

CHAMBERS, L.D.; STOKES, K.R.; WALSH, F.C.; WOOD, R.J.K. (2006), *Modern approaches to marine antifouling coatings*, Surface & Coating Technology 201, pp.3642-3652, http://eprints.soton.ac.uk/43767/1/our_anti-fouling.pdf

DORAN, S. (2019), *A Short History of Hull Cleaning and Where Do We Go Now*, 4th HullPIC Conf., Gubbio, pp.97-102, http://data.hullpic.info/HullPIC2019_gubbio.pdf

HUNSUCKER, K.; BRAGA, C.; ERGODAN, C.; GARDNER, H.; HEARIN, J.; RALSTON, E.; GEOFFREY SWAIN, G.; TRIBOU, M.; WASSICK, A. (2018), *The Advantages of Proactive In-Water Hull Grooming from a Biologist's Perspective*, 3rd HullPIC Conf., Redworth, pp.210-222

IMO (2019), *Hull scrapings and marine coatings as a source of microplastics*, Int. Maritime organisation, London, http://www.imo.org/en/OurWork/Environment/LCLP/newandemergingissues/Documents/Hull%20Scrapings%20final%20report.pdf

KELLING, J. (2017), *Ultrasonic Technology for Biocide-Free Antifouling*, 11th HIPER Conf., Zevenwacht, pp.70-76, http://data.hiper-conf.info/Hiper2017_Zevenwacht.pdf

KELLING, J. (2020), *Ultrasound: The Silent Revolution in Antifouling*, 1st PortPIC Conf., Hamburg, pp.83-86

NOORDSTRAND, A. (2018), *Experience with Robotic Underwater Hull Cleaning in Dutch Ports,* 3rd HullPIC Conf., Redworth, pp.4-9, http://data.hullpic.info/hullpic2018_redworth.pdf

NOORDSTRAND, A. (2020), *Roadmap from the Wild West to the Promised Land of Ship Cleaning*, 1st PortPIC Conf., Hamburg, pp.38-41

ODETTI, A.; BIBULI, M.; BRUZZONE, G.; CACCIA, M.; RANIERI, A.; ZEREIK, E. (2016), *Co-operative Robotics – Technology for Future Underwater Cleaning*, 1st HullPIC Conf., Pavone, pp.163-177, http://data.hullpic.info/HullPIC2016.pdf

OFTEDAHL, G.A. (2020), *Proactive Cleaning and the Jotun Hull Skating Solution*, 1st PortPIC Conf., Hamburg, pp.66-78

# Is Effective Biofouling Management for Every Ship Possible?

**Burkard T. Watermann**, LimnoMar, Hamburg/Germany, watermann@limnomar.de

**Abstract**

*Shipping is currently facing massive challenges, which at first glance may appear to be a burden, but in the long term can lead to sustainable and efficient marine transport. Anti-fouling is a decisive factor in reducing fuel and emissions and preventing the spread of organisms. The compulsion to actively manage biofouling will prove to be cost-reducing in the long run and a guarantee for unhindered access to all seaports. With variable operation profiles of ships, ship owners and paint companies must find more joint solutions and combine classic coatings with novel biofouling management processes.*

## 1. Introduction

Due to its high transport performance, shipping is one of the most environmentally friendly and energy-efficient modes of transport. Nevertheless, not only the IMO demands that the burden on the environment and climate caused by ships must be reduced. These demands relate not only to the reduction of climate-relevant emissions, but also to the pollution of the oceans, *VDR (2019)*. A smooth, low-resistance hull is the decisive criterion for achieving optimum ship performance. However, this depends not only on an effective antifouling coating, but also on a predictable ship profile.

## 2. New challenges

However, since the crisis of 2008, the shipping industry has faced very heterogeneous requirements:

- There is still overcapacity in the world fleet and therefore, among other reasons, freight rates are at a low level. Although there are still numerous liner services, many ships are forced to operate in constantly changing trade lanes, which makes the application of an optimal antifouling coating almost impossible. Even for the liners, the individual ships no longer have fixed sailing areas. The rapid growth of ship sizes (containers) in recent years has led to many changes in shipping areas, in addition to changes in the flow of goods. Also, locally changing regulations, such as Shore Power (not all ships are equipped) have a strong influence on the respective trade area.

- Berthing times of more than 30 days off congested ports of West Africa and South America. Berthing times of more than 30 days for loading and unloading (bulkers) or mooring in front of loading stations (tankers, Strait of Hormuz). This may void any warranty on the effectiveness of the existing antifouling coating.

- Significantly lower service speeds than a decade ago ("slow steaming") with 8 - 14 kn, which is too low to activate numerous antifouling products. For many ships, 14 kn is rather the lower limit. Older ships usually cannot operate below this value in the long term. There are technical reasons for this. Nevertheless, we see an average reduction in the speed profile of about 10 kn.

- Fuel costs are a decisive part in operating costs at low freight rates. But even minimal fouling (biofilm) increases fuel consumption and thus costs and emissions, which should actually be significantly reduced, *Demirel et al. (2019)*. To prove this connection to a controller conclusively is unfortunately still a challenge, even if performance monitoring is gradually becoming easier and more rational.

- In order to save fuel and keep operating costs low, many shipowners have their hulls cleaned as soon as a biofilm appears or at regular intervals. This is currently common practice, although the cleaning process damages or removes the antifouling coating on the surface and suddenly releases biocides.

  Antifouling coatings as CDPs (Controlled Depletion Polymers) or SPCs (Self-Polishing Coatings) are actually too soft and not suitable for cleaning, so that the guarantee of the paint manufacturers for freedom from fouling often expires. Due to the present high cost pressure, cleaning is nevertheless considered the "ultima ratio". Organizations such as BIMCO, IMaREST and NACE are currently discussing the development of standards in order to allow using cleaning processes that are as gentle as possible.

  Liabilities and guarantees of the paint manufacturers usually play a minor role for the ship owners, as these can be very small compared to the possible damage/additional costs of a failing antifouling coating. Many ship owners prefer to point out to the manufacturers in case of poor performance that these should participate with more suitable products for the next tenders, be cooperative in failure analysis and show a proactive plan for the future.

  An important aspect in this context is the presence and service of the manufacturers on site in the shipyard. Shipowners expect the manufacturer to be committed to the quality of the application by ensuring correct pre-treatment and application in the dock. Since initial roughness also affects antifouling efficacy, pre-treatment and application are critical factors in the expected effectiveness, *Munk (2006), Kane (2009*).

  Many ship owners would like to see a stronger commitment of the manufacturers in the shipyards, regardless of the price of the antifouling products.

- Even though cleaning with collection devices and filtration of fouling and removed coating particles is more expensive, ports will only approve cleaning with these techniques. This is the only way to minimize the introduction and spread of alien species, *Woods et al. (2012)*. It is still pending whether such strict requirements as set out in the IMO's Ballast Water Treatment Directive will also have to be applied to underwater cleaning.

- From the beginning of 2018, national and international regulations required proof and measures for active fouling management in numerous shipping areas (west coast USA, New Zealand). In 2017, the first bans on entering Australian ports were imposed due to excessive fouling on a ship under Indonesian flag.

  These measures are intended to prevent the introduction of alien species, especially to Australia/New Zealand, but also to California, and have been strongly fueled by IMO ballast water regulation entering into force in 2016. This has increased the pressure for mandatory biofouling management also on the hull and in its niche areas. At present, the IMO guidelines, which have so far been non-binding, only set fuzzy limits for fouling management. However, countries such as New Zealand and Australia are expected to formulate these limits or criteria more precisely and submit them to the IMO. This will also affect all globally operating shipping companies, *Intertanko (2016), MPI (2018)*.

The maritime industry therefore currently has to install retrofits for very different components and systems. This concerns both measures for reducing pollutant emissions and now mandatory ballast water treatment systems. In view of energy efficiency targets, also intelligent hull optimization schemes and better hull management solutions will be in demand.

## 3. Is there the "optimal" antifouling or the optimal ship profile?

Against the background of the above-mentioned conditions and constraints in global shipping, it has become increasingly difficult to find the optimal antifouling system for ships. This is not because paint manufacturers do not provide effective products and techniques, but on the contrary, antifouling products can now be tailored for each ship.

All major paint companies include the ship profile with key data average speed, degree of activity, navigated waters and the expected lay-up times in their selection for the optimal antifouling coating. The difficulty for ship owners, however, lies in the predictability of such a profile. Keeping their own ships in a certain profile is already extremely difficult, but if the ships are chartered out, there are often changing sailing profiles. The water temperature, for example, greatly influences short-term performance and long-term performance. With more expensive SPCs, this has a direct influence on the leaching rates, and thus on required layer thickness and the price. This is where the circle closes, since for unpredictable operational areas, the layer thickness would have to be selected for higher temperatures, which of course causes higher costs.

All paint manufacturers offer antifouling coatings for typical operational profiles:

- High activity level, high service speed, all waters, short demurrage
- Average activity level, slow service speed, waters with moderate vegetation pressure, frequent but not too long demurrage
- Low activity level, slow speed, coastal waters, recurring demurrage

These specifications can be found at all manufacturers for CDPs and SPCs. Since even biocide-free SPCs have become available on the market, the adjustments to the operational profile have become even more important. E.g. for bulkers or ships with very strongly changing freight volumes, frequent demurrage (tramp shipping), biocide-free and biocide-containing non-stick coatings on a silicone basis are offered, which should even allow demurrage of up to 120 days.

Since all ship voyages can be tracked via AIS (Automatic Identification System), paint manufacturers have the possibility to follow the profile of each ship. This allows checking claims for macro-fouling (e.g. algae with thread lengths > 5mm, a degree of coverage > 10% with hard-shelled fouling) caused by excessive demurrage, insufficient demurrage or voyages in waters not planned in advance; consequently, such checks often lead to loss of warranty. AIS also enables new forms of analysis. The fact that sister ships with similar routes, activity profiles and the same products show different fouling development is still difficult to explain. Some manufacturers now link AIS data with satellite data, such as chlorophyll alpha content as an indicator of fouling pressure, to derive a better understanding of biofouling mechanisms on ships.

Since shipowners now place greater importance on reducing fuel costs than on warranties, there is massive cleaning worldwide for failing antifouling coatings. For some years now, many diving companies on an international level have specialized in cleaning ship hulls in water.

## 4. Current practice of underwater cleaning

As mentioned above, ship owners, diving and cleaning companies and coating material manufacturers are taking numerous initiatives to take a completely different path to get out of these constraints. This includes the practice of not using biocide-containing antifouling products at all. Instead, effective antifouling protection is to be achieved by proactive or regular cleaning at the biofilm stage (grooming) on biocide-free, cleanable hard coatings, *Tribou and Swain (2010), Watermann (2019)*. This makes the hull both smooth and thus keeps frictional resistance low. Numerous ferry companies in the Baltic Sea practice this type of antifouling protection, as antifouling coatings would be worn off by drift ice in winter and would have to be renewed every year.

Similarly, shipping companies that regularly offer a liner service from the northeast Baltic Sea to the Bay of Biscay and only use coatings to protect hulls against corrosion. The constant change from fresh water to sea water greatly reduces the biofouling.

Cleaning on abrasion-resistant hard coatings with non-stick properties at the biofilm stage is much quicker than cleaning at a stage with advanced macrofouling. It must be carried out more frequently, but it is more cost-effective due to its greater speed. In addition, the coating is only subject to low shear stress and will last for the duration of normal docking intervals of 36-60 months, *Tribou and Swain (2010)*.

**5. Conclusions**

As shown in the above, there is currently no universal solution and, in all probability, there will be none in the future. On the contrary, the stronger focus on active biofouling management will lead to paint manufacturers and ship owners entering into even closer consultation and discussion to explore ship-specific antifouling systems. Supporting technologies such as air lubrication may can also be combined with coatings.

**References**

DEMIREL, Y.K.; SONG, S.; TURAN, O.; INCECIK, A. (2019), *Practical added resistance diagrams to predict fouling impact on ship performance*, Ocean Engineering 186, 106112

INTERTANKO (2016), *INTERTANKO Guide to Modern Antifouling Systems and Biofouling Management*, Intertanko, London, 20 pp.

KANE, D. (2009), *Paints and Coatings, Ship Technical Performance, Hull Blasting and Emissions*, Drydock 9, pp.26-28

MPI (2018), *Guidance document for the Craft Risk Management Standard for Biofouling*, Ministry for Primary Industries, New Zealand, 31 pp.

MUNK, T. (2006), *The Effect of Drydock Treatment and Coating Selection on Hull Efficiency*, Shipbuilding Machinery and Marine Technology, Hamburg

TRIBOU, M.; SWAIN, G. (2010), *The use of proactive in-water grooming to improve the performance of ship hull antifouling coatings*, Biofouling 26/1, pp.47-56

VDR (2019), *Grundlagen einer europäischen und internationalen CO2-Datensammlung für Schiffe*, Verband Deutscher Reeder, Hamburg, 4 pp.

WALLENTIN, B. (2011), *The illusion of fuel savings*, Naval Architect 7/8, pp.16-20

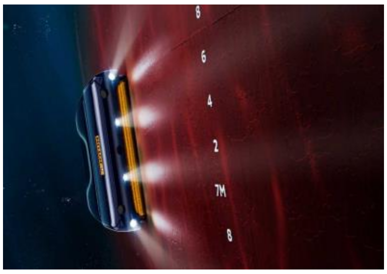
WATERMANN, B. (2019), *Hull performance management and biosecurity by cleaning*, Ship & Offshore 3, pp.18-20

WOODS, C.M.C.; FLOERL, O.; JONES, L. (2012), *Biosecurity risks associated with in-water and shore-based marine vessel hull cleaning operations*, Mar. Pollut. Bull. 64, pp.1392-1401

# Index by Authors

# 2nd In-Port Inspection & Cleaning Conference (PortPIC)

**Pontignano / Italy, 30.8.-1.9. 2021**

**Topics:** Aquatic Invasive Species / Diver operations in port / Next-generation antifouling technologies / Operator perspective on cleaning / Performance-based cleaning / Regulations & Guidelines / Robotic cleaning & inspection

**Organiser:** Volker Bertram (-)
Geir Axel Oftedahl (Jotun)

**Advisory Committee:**

| | | | | | |
|---|---|---|---|---|---|
| **Jasper Cornelis** | Port of Zeebrugge | **John Lewis** | ES Link Services | **Buddy Reams** | NACE |
| **Simon Doran** | HullWiper | **Richard Marioth** | Idealship | **Geoff Swain** | FIT |
| **Johnny Eliasson** | Chevron Shipping | **Justin McDonald** | Gov. Western Australia | **Burkhard Watermann** | Limnomar |
| **Stein Kjolberg** | Jotun | **Alex Noordstrand** | FleetCleaner | | |

**Venue:** The conference will be held at the Certosa di Pontignano near Siena

**Format:** Papers to the above topics are invited and will be selected by a selection committee. The proceedings will be made freely available to the general public.

**Deadlines:**

| | |
|---|---|
| anytime | Optional "early warning" of interest to submit paper / participate |
| 02.04.2021 | First round of abstract selection (1/2 of available slots) |
| 15.05.2021 | Second round of abstract selection (remaining slots) |
| 21.07.2021 | Final papers due |

**Fees:** **700 €** – early registration (by 21.08.2020)
**800 €** – late registration

Fees are subject to VAT
Fees apply also to presenting authors
Fees include proceedings, lunches, coffee breaks, and the conference dinner

**Sponsors:** Jotun, Idealship
(further sponsors to be determined)

**Information:** volker@vb-conferences.com