Facilitating greener education and cleaner shipping through the development of NOvel bespoke microtextured metals to combat bioFOULing in niche areas on vessels

Abstract

Biofouling, the unwanted biological growth on ships, causes increase of fuel costs, emissions, corrosion and transfers non-native invasive species. With updated international regulations not only were biofouling guidelines improved but training for maritime personal and students has become essential. Our aim in the IAMU and Nippon Foundation funded project NOFOUL was to determine the antifouling efficacy of novel textures and plasma in different marine environments (Irish Sea, Black Sea, Marmara Sea, Bay of Bengal) while we engage with knowledge exchange between project partners (LJMU, CMU, ITU, ODU, AMET) and outside the project with our IAMU Biofouling Network. We used our research in the project as a tool for our case study demonstrating training and knowledge transfer in biofouling and antifouling. The first step was a 2-day workshop at LJMU during which LJMU used an interactive approach containing short lectures, discussions, laboratory visits and practical as well as a field trip to gauge the average understanding, to deepen the topic and exchange knowledge between all partners. The second step was site specific training by LJMU at the partner sites. During the one to one training partners were able to prepare for their field experiment to a common standard in order to compare research results and interpret in the context within the project. The outcomes of the training and knowledge exchange between partners in biofouling and antifouling were evaluated and interpreted with a view of expanding the approach for the wider IAMU community.

1. Introduction

Any surface in seawater will get biofouled first by biofilm and then by algae and invertebrates [2, 3]. These cause corrosion, material fatigue and increased drag, transfer of non-native invasive species, fuel consumption, emissions, thereby contributing to Global Climate Change [4]. Indeed, [5] estimated that the economic impact of biofouling just for the US DDG-51 fleet was $56M per year at the time. Recently, progress has been made with the updated and amended guidelines on the control and management of ship biofouling, Resolution MEPC.377(80) (International Maritime Organisation, 2023). This includes training and education for maritime personal such as ships' masters and crew, on impacts of invasive aquatic species from ships' biofouling (chapter 13.1, point 2), benefits to the ship of managing biofouling (chapter 13, point 3), and biofouling management measures (chapter 13, point 3), and marine training organisations need to include these in their syllabuses as appropriate. Still, biofouling is neglected in maritime training and education. Reasons for this may be because of lack of knowledge and confidence on the biofouling topic, as well as the importance of the topic may not be accepted in the maritime organisations, industry and educational institutions.

In the IAMU/Nippon Foundation funded project NOFOUL the research aim was to develop bespoke novel antifouling laser machined textures on metals for diverse maritime environments and niche vessel areas. This antifouling field testing at an international scale was used as a model training approach on biofouling and antifouling for non-specialist trainees, in this case engineers, and specialist trainers. The non-specialist trainees were the project partners from Constanta Maritime University (CMU, Romania), Istanbul Technical University (ITU, Turkey), Ordu University (ODU, Turkey) and the University Academy of Maritime Education and Training (AMET, India). The specialist trainers and facilitators were biofouling and antifouling researchers from the lead institution Liverpool John Moores University (LJMU, United Kingdom).

In NOFOUL, a number of teaching and learning tools were combined (training, knowledge transfer and exchange, coaching, participatory research, networks, Higher Education Teaching) and split into activities (2-day training workshop, site-specific training at the partners/trainees, training through coaching during the experiment, IAMU Biofouling Network organisation with webinar presentations, Higher Education maritime teaching on biofouling). Training as in training by demonstration and by doing while focussing on real-life experience. was used in the 2-day training workshop and site-specific visits. Coaching during the field experiment, the guidance of the trainee, was applied partly at site specific training as well. Knowledge transfer was introduced from the first activity onwards, the workshop, and the last activity, the webinar presentations and Higher Education maritime teaching. When the knowledge transfer was completed by the specialist trainers, the non-specialist trainees, changed into trained non-specialists and were able to train themselves non-specialists by contributing to webinars in the

network (connections between people with shared interests), and Higher Education maritime teaching at their institutions. All partners participated in wide discussions and knowledge exchange in the subject, the two-way knowledge transfer, from the start of the project.

In NOFOUL participatory planned international research, network organisation and Higher Education Teaching by non-specialists were enabled by training, knowledge transfer and exchange, and coaching. Participatory research methodologies emphasize collaboration between researchers, practitioners, and end-users throughout all stages of the research process, from problem definition to solution implementation (Cornwall & Jewkes, 1995, Roque et al., 2022). Thus, careful coordination, mutual respect, and shared commitment to co-learning, supporting by an agreement, is needed to integrate expertise within participatory frameworks.

The NOFOUL training and education aim was to develop a novel model training approach to facilitate biofouling and antifouling learning in the maritime industry and Higher Education while conducting an international antifouling participatory research study with trained non-specialists.

2. Biofouling Training

2.1 Biofouling Workshop

The aim of the Biofouling Workshop (Phase 1) was to inform and develop biofouling knowledge, background, skills, antifouling field trial approaches, biofouling assessment requirements and standardisation for the planned participatory and collaborative research (international experiment in 2025). The workshop was interdisciplinary, intercultural and an informal agreement was presented which included to 1) get to know other partners; 2) Appreciate each other knowledge, background and contribution; 3) Discuss openly, with respect. Non-specialist NOFOUL partners from India, Turkey and Romania were taken part in the Biofouling Workshop at LJMU (United Kingdom) on the 23rd and 24th July 2024 to receive training from LJMU biofouling specialists on biofouling and antifouling. The five visitors from Constanta Maritime University (CMU; 2 persons), Istanbul Technical University (ITU; 1 person), Ordu University (ODU; 1 person) and the University Academy of Maritime Education and Training (AMET; 1 person) engaged actively in person with the training while additional partners from CMU (1 person) and ODU (1 person) engaged virtually. The tools were short lectures (15 to 20 mins) followed by discussions in the group (15 to 20mins). Practical sessions (hands-on learning) were conducted in the laboratories (photonics laboratory, marine biosciences laboratory) and at the field site for antifouling testing (Liverpool South Docks, United Kingdom). These tools facilitated knowledge transfer, exchange knowledge and methodologies on biofouling and antifouling. Visiting the laser texturing and biofouling labs, the field site Royal Albert Dock as well as experiencing practical sessions on biofouling identification using microscopes, adhesion strength of biofouling using a force gage and using image analysis for assessment were designed in order to provide activity breaks from the intense discussions and facilitated the 2-way knowledge exchange. At the end of each day feedback sessions were included to discuss in the group and set up actions on key points. Trainees pointed out that they learned many new aspects of the biofouling they never had heard about before and how it changed their understanding and perspective of biofouling. Trainees were much inspired by the practical work.

The outcome of the workshop was agreed to offer the workshop as a NOFOUL group to IAMU members to benefit in their Higher Education Teaching. The trial workshop was agreed as template for future Biofouling Workshops, particular for IAMU scientists, engineers and mariners.

2.2 Site-specific Training

The aim of the Site-specific Training was to develop biofouling skills specific for the site to be able to run the standardised antifouling field trial, and identify specific biofouling assessment requirements for the planned participatory and collaborative research (international experiment in 2025). Trainees were engineers and had not conducted any field experiments before other than one trainee who worked on pre set up antifouling coating experiments for an engineering perspective. This lack of site knowledge required to introduce site specific training for the field experiment itself and the data collection.

Two separate training parts were considered that are site-specific and cannot be addressed by the trainer and coach when not on site. Thus, the trainer was required to complete a site visit to work with the trainee. The trainee is

needed to complete work following experimental protocols and virtual coaching prior to the visit. The visits to each partner site was conducted by the trainer in early to mid January 2025. Training part 1 was designed around the field trial with the tasks: 1) obtaining the materials, 2) building the experimental frame, 3) identifying the field site, 4) attaching the samples to be tested on the frame, 5) deploying the frame and the samples, 6) selecting environmental measurements during deployment of the samples, 7) determining the point of time for removal of samples, 8) removal, coding and preserving of samples. Trainees were required to complete Tasks 1), 2), and 3) based on a protocol and virtual coaching by the trainer. Tasks 1) to 3) were then corrected and validated during the site visit. Tasks 4) to 8) were prepared during the site visit with the trainer and trainee using knowledge transfer and coaching while after the visit the trainee was supported by virtual coaching and a guide for the samples. Training part 2 was designed around the treatment of the preserved samples with the tasks: 1) identification a dissecting microscope with suitable magnification, 2) taking photographs, 3) sending photographs to LJMU for assessment, 4) assessing photographs for percentage coverage of biofilm using a standard image analysis method used by undergraduate students up to researchers. Task (1 was required to be completed by the trainee prior to the visit by the trainer based on guidance. Tasks (2 and (3 were taught by knowledge transfer and guidance during the visit and after the visit via a protocol and virtual coaching by the trainer. Task 4 was included as an optional task for the trainee but was not expected because of the shortness of NOFOUL and the high time needs of the assessment. This task was supported by training during the visit, a protocol and coaching by the trainer past visit.

The outcome of the Training part 1 led to mostly completion of the tasks. Task 1) and 2) was only completed with the visit of the trainer. Task 3) was completed as so far as potential sites were identified and these were then validated by the trainer. Tasks 4) was demonstrated by the trainer during the visit while the coding was supported with a coding map for standardisation at all sites and virtual coaches. This task was then completed. Task (5 was completed while task (6 was not completed by all sites. Tasks (7 and (8 were completed late at sites with coding and preserving of samples were completed. Training part 2 demonstrated the difficulty for non-specialists to achieve specialist tasks. Particularly, Task (1 proved holding the progress of the data collection back. At no site was it possible to finalise the correct microscopes. Here, the variations in microscopes were underestimated and individual microscopes were not suitably checked by the non-specialist prior to the visit of the trainer. After microscopes were identified after the visit there were insecurity on magnification. This lead to the development of a calibration tool in the form of a small panel with a laser square in the size that the photograph should be showing using the microscope. This small simple panel was supporting the standardisation of the area the photographs of each site and tasks 2) and 3) were completed on the 25th May 2025. Task (4 was not completed by trainees but requested further training for assessment using image analysis. No experiments or samples were lost, photographs were mostly taken and in an adequate quality. Therefore the international participatory research experiment was completed. Teaching by demonstration (intentionally teaching) as in training and coaching together in the group followed by for each site separately was efficient showing that non-specialist can achieve the running of a field test and taking part in the assessment as far as sampling of panels using photography to be then assessed by specialists. The field experiments are planned to continue in 2025 by the trainee because of their benefits such as biofouling problem and invasive species identification, antifouling coating evaluation, collaborations

3. IAMU Biofouling Network and Webinars

The aim of the Biofouling Network was to facilitate outside of the NOFOUL project for experts and novices, interest groups, academics and mariners to exchange knowledge on biofouling and antifouling, networking, training, and collaborations in projects. The Biofouling Network was limited to IAMU members. The network was set as a tool to find people within IAMU sharing the same interest, here biofouling and antifouling. Within the network the NOFOUL project can transfer their learning and knowledge while non-project interestees can benefit and exchange knowledge depending on their level of knowledge.

The organised network has the function for NOFOUL to disseminate outcomes, introduce IAMU members to the issues of biofouling and antifouling, offer training, networking, and collaborating. Particularly, training was identified as a key aspect in Resolution MEPC.378(80) (International Maritime Organisation, 2023) requiring mariners being trained in the subject biofouling and antifouling. The training for mariners and Higher Education lecturers can be an important role of the network. NOFOUL trained non-specialists demonstrated their capability to transfer knowledge to the IAMU Biofouling Network via webinars and to students of one of the partner universities (CMU) increasing the pool of training opportunities for mariners and Higher Education lecturers.

Webinars are at this point in time the key tools for connecting the interest group in the IAMU Biofouling Network. Members are globally distributed and depended on virtual meetings. The IAMU Biofouling Network webinars are designed by NOFOUL to focus on one biofouling or antifouling topic. The topic is presented by slide show and at least two presenters. The followed discussion is open to everyone; questions or contributions are to be presented by chat or speech with or without camera. During the webinar a number of polls introduced while after the webinar a survey was optional available to complete. The IAMU Biofouling Network was initiated by NOFOUL during the IAMU AGA 25 in their progress report presentation and with flyers. The network grew from the initiation with each webinar. The IAMU Biofouling Network counts currently 47 members, from Asia, Europe, Africa, the Americas, and from 16 IAMU member Universities. The webinars participation decreased from the first to the 3rd webinar (71, 44, 20). This shows a trend of decrease in participation. This trend was expected; the first webinar demonstrated a new topic for IAMU to be offered by their association and more participants were attracted. In the following live webinars less participants may have been attracted with webinars being recorded. The survey at closure of the webinars included 11 questions. Three questions were considered 1) "Would you like to be a part of IAMU Biofouling Network?" 2) "Would you like to see follow-up sessions on related topics?". Most participants (90%, 86%, 83%; **Fig. 1**) would like to take part in the network or already were. The number of participants already in the network increased from webinar to webinar (14%, 27%, 33%). Most participants would like to see further webinars on the topic (100%, 95%, 92%; **Fig. 2**).

Overall, the IAMU Biofouling Network has a positive effect on IAMU members from webinar to webinar. During the webinars knowledge on biofouling is not just only transferred to participants but knowledge exchange is demonstrated in the question and answer sessions while developing into discussions. NOFOUL trained non-specialists disseminated the NOFOUL research and demonstrated their new knowledge and skill. During the last webinar participants requested training such as NOFOUL partners received and this demonstrated the importance for IAMU members to understand biofouling.

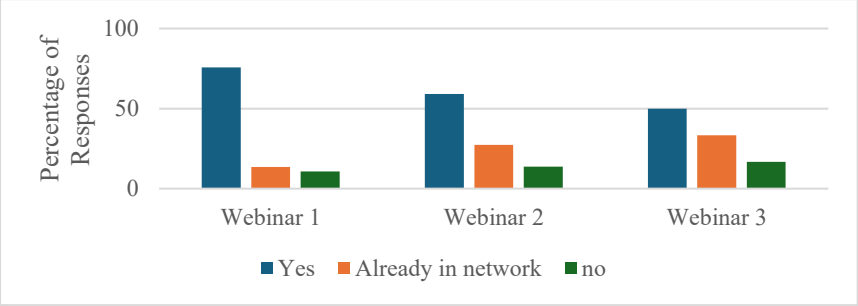

Figure 1: Percentage responses for each webinar (Question: Would you like to be a part of IAMU Biofouling Network?)

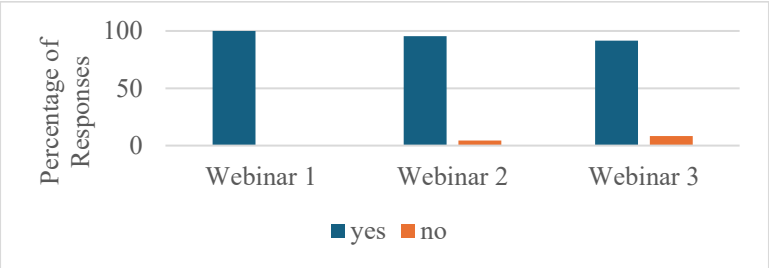

Figure 2: Percentage responses for each webinar (Question: Would you like to see follow-up sessions on related topics?)

4. Higher Education maritime teaching on biofouling

The NOFOUL Project's higher education initiative on marine biofouling has demonstrated remarkable success in generating student interest and engagement. After a teaching class about marine biofouling where NOFOUL results were shared to students in Electrical Engineering at Constanta Maritime University (CMU), Romania in May 2025, a feedback analysis based on survey responses from 40 students and one teacher demonstrated strong

overall interest in the topic, with a majority expressing desire to learn more about specific aspects of marine biofouling.

The survey results demonstrated a notably positive reception to the marine biofouling educational content. Among the 40 student respondents, 26 (65%; **Fig. 3**) rated their interest level as either "High" or "Very high" after completing the class. Specifically, 22 students indicated "High" interest, 4 reported "Very high" interest, 13 expressed "Moderate" interest, and only a single student reported "Low" interest. This distribution demonstrates that the NOFOUL project's educational approach successfully engaged the vast majority of participating students, particularly remarkable considering these were primarily engineering students from the electrotechnics specialization.

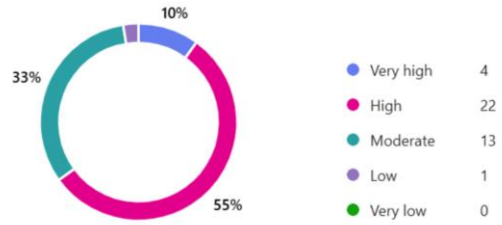

Figure 3: Student' rate of interest in marine biofouling

The strong interest levels suggest that marine biofouling, despite being a specialized topic, resonates with students when effectively presented. The overwhelming positive response indicates that the course content successfully bridged the gap between technical engineering concepts and environmental applications, creating relevance for students who might not have previously considered marine biofouling within their professional domain.

When asked about their interest in learning more about marine biofouling, students showed a balanced but positive outlook. The survey demonstrated that 18 students (45%; Fig. 4)) definitively wanted to learn more, 18 students (45%) were uncertain but not opposed ("Not sure"), and only 4 students (10%) had no interest in further learning. This demonstrates that 90% of students remain open to expanding their knowledge on the subject, suggesting the course successfully established the relevance of marine biofouling.

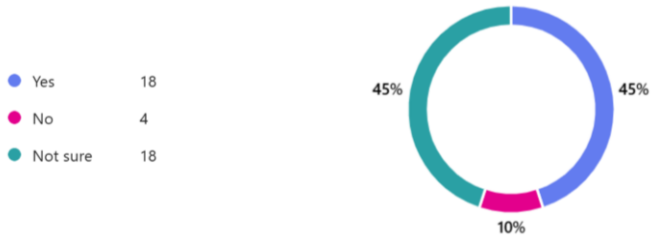

Figure 4: Students' interest in learning more about marine biofouling

Regarding participation in projects similar to NOFOUL (such as research, fieldwork, or engineering solutions), the results showed cautious but positive interest: 24 students (60%) selected "Maybe– I need more information", 13 students (32.5%) selected "Yes" and only 3 students (7.5%) selected "No". These responses indicate that while most students require additional information before committing to project work, there is substantial openness to practical engagement. The high percentage of "Maybe" responses suggests an opportunity for program enhancement by providing clearer pathways and information about project participation options.

Overall, the NOFOUL Project's higher education initiative on marine biofouling demonstrates impressive success in engaging Electrical engineering students with environmental marine science concepts. The strong interest levels reported by students, coupled with their openness to further learning and project participation, indicate effective educational content and delivery. The survey demonstrated valuable insights about student preferences, highlighting engineering applications, pollution concerns, and environmental impacts as particularly resonant topics. However, to maximize student involvement in marine biofouling research, structural support

(mentoring, resources, recognition) is necessary. The insights suggest that further investment in these areas could transform moderate engagement into high, sustained participation, and foster the next generation of researchers and innovators in marine environmental protection.

5. The Future of Biofouling Understanding in Maritime

The NOFOUL project developed training and knowledge exchange approaches and trained non-specialists for biofouling. Their training was evidenced with a 2-day workshop and a participatory research field experiment, and resulted in their knowledge transfer in a Biofouling Network with webinars and Higher Education teaching.
In the future, trained non-specialists from NOFOUL can transfer their knowledge to IAMU members and to colleagues and students even further.
The concept and approach of training non-specialists at LJMU may be able to benefit other IAMU members in the future with further training workshops together with NOFOUL partners. The transfer of knowledge may initiate and facilitate further field experiments promoting experiments such as biofouling baselines for monitoring biofouling problem and non-native invasive species, and antifouling testing at the local site. These data may be collated in an IAMU data repository for applications such as modelling in commercial and environmental penalties, and Maritime Higher Education. This may result in further participatory research.

6. Conclusion

The intersection of participatory research and marine antifouling innovation, driven by training, knowledge transfer and exchange, network development with webinars, and Higher Education maritime teaching facilitated the viability of trained non-specialists within the biofouling and antifouling field. Through participatory practices, the co-creation of context-sensitive biofouling and antifouling engagement benefitting IAMU members was motivated by the intercultural and interdisciplinary team.

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