INNOVATIVE APPROACHES FOR THE DEVELOPMENT OF NEW COPPER-FREE MARINE ANTIFOULING PAINTS

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Introduction

Marine biofouling can be defined as the undesirable adhesion to surfaces and further growth of organisms, mainly biofilm-forming microbes, macro-algae and invertebrates that are defined as foulers. Following adsorption of a conditioning film of macromolecules, microorganisms such as bacteria and microalgae, which are the primary colonizers, are found on unprotected surfaces after only a few minutes to hours of immersion. Secondary colonizers, consisting mostly of protozoa and spores of macroalgae, settle and start to grow on surfaces within a week. Finally, larvae of hard macrofoulers (or tertiary colonizers, e.g., barnacles, mussels, tubeworms, bryozoans) will settle on unprotected surfaces two to three weeks after immersion. Any new structures immersed in seawater can be attractive for foulers and can thus lead to extra costs due to increased maintenance, or/and even mechanical wear, and/or biodeterioration that require costly antifouling (AF) measures.

The expansion of goods transportation by maritime routes has led to significant energy and environmental impacts. Thus, according to the International Maritime Organization, the world trading fleet is responsible for about 90% of the global trade of goods and a large contributor to the so-called “welfare society”: the total fuel consumption for ship transportation was estimated to be approximately 370 million tons per year in 2007 (with corresponding 1,120 million tons of CO_2 emitted) and will be burning about half a billion tons of fuel per year by 2020 (1,475 million tons of CO_2 emitted). According to some estimates, the potential absence of fouling protection on ship hulls may roughly require an increase of propulsive power by 70% compared to a largely fouling-free hull. Based on these data, it has been proposed that a highly efficient AF protection will save over $150 billion per year globally and about 450 million tons of CO_2 from being emitted in the atmosphere every year (excluding indirect costs resulting from transport delays, hull repairs, sunk vessels due to biocorroded hulls, etc.).

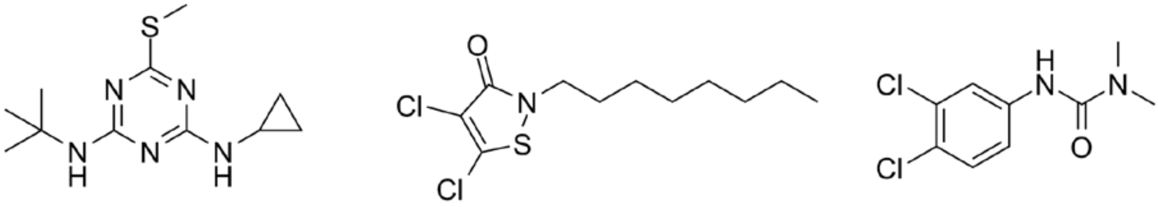
Besides shipping industry and maritime transportation, other key sectors are negatively impacted by the development of biofouling communities. For example, biofouling leads to significant problems for the energy production industry by obstructing the cooling systems of some nuclear power stations and by affecting the operation of immersed new renewable energy infrastructure. Studies have demonstrated that the colonization of barnacles on marine current turbines has a detrimental effect on turbine efficiency. Another study showed that offshore wind power plants offer atypical substrates for fouling assemblage in terms of orientation, depth range, structure and surface texture, and thus efficiency can be affected. Biofouling can also severely affect wave energy plants by having a negative impact on material, weight, shape and efficiency. Biofouling is further responsible for a significant gain in weight of static structures in aquaculture and sometimes cause mechanical failure. Fouling organisms growing on immersed manmade surfaces can also trigger biocorrosion, and transport of biofoulers may promote the spread of non-indigenous species.

The strongest driving forces in AF research are obviously fuel saving for sea transportation and reducing the biodeterioration of structural material. The challenge is to reach this goal with minimum negative impact on the marine environment, and the necessary research and development here draws on successful synergies between academy and industry. Another cost related to AF is that, no matter which AF system employed, at regular intervals (three to five years) depending on the operating conditions, the ship has to be drydocked in order to clean the hull and to repaint. The docking operation represents a downtime for the ship owner that is very expensive. This is why long service life of the coating is demanded by the market. Novel AF solutions with low impact on the environment need to meet economically realistic requirements in terms of efficiency and service life, otherwise they will not leave the drawing board or laboratory. The hard equation to solve is to maintain feasibility and economic viability with sufficiently long-lasting efficacy and acceptable environmental impacts. Solutions offering only long-term efficacy is not enough for future sustainable AF technologies.

Current AF Copper-Based Solutions and the Need for Innovative New Projects

The battle to control biofouling goes back to the dawn of civilization when man constructed boats and began his ocean travels. The earliest documented accounts date from the Greek and Roman civilizations when copper or lead sheathing was used to protect wooden boats. In modern time tributyltin (TBT) was widely used from the 1960s to its recent ban in 2008. Its efficiency was the best ever recorded for AF formulations. However, the use of TBT-based paints was phased out after being shown to be highly toxic for many aquatic organisms and accumulated in biological tissues leading to contamination through the marine food chain. Nowadays, most AF paints rely on the use of seawater-soluble copper oxide combined with various organic booster biocides (e.g., Irgarol 1051, diuron, SEA-NINE™, zinc pyrithione, zineb) to prevent biofouling (Figure 1).

Nevertheless, numerous scientific publications have highlighted that copper is also toxic to a broad range of non-target marine species. The three most sensitive animal species are the embryo/larvae of the oyster, mussel and sea urchin, and among microbes the cyanobacteria are the most sensitive group to copper toxicity. Recent data have shown toxicity in salmon



Irgarol 1051 SEA-NINE™ Diuron

Figure 1: Examples of commercial organic booster biocides in current use together with copper salt in antifouling paints. LEAF PROJECT

due to copper-induced olfactory impairment leading to neurobehavioural response changes critical to survival which depends on successful migrations. Copper toxicity from AF sources becomes a problem in the marine environment, especially in isolated water bodies such as enclosed marinas and harbours that experience little water exchange combined with high levels of boating activity. For example, it has been estimated that in San Diego's Shelter Island Yacht Basin, an estimated 2.5 tons of copper leaches from the hulls of two thousand boats each year. It is thus urgent to develop new environmentally friendly AF solutions. In the United States, western states are leading the campaign against copper AF paints. Washington recently became the first state to ban copper-based paints beginning in 2020 when owners of recreational boats (under 20 metres) will be prohibited to buy and apply bottom paint that contains more than 0.5% copper. Starting in 2018, recreational boats on the market will need to be stripped of copper paint or sealed. In California, a similar bill to ban copper paints for recreational boats has been passed in the State Senate enforcing that from 2015 there will be a ban on the sale of new recreational boats with copper bottom paint, followed by total ban of usage for recreational boats in 2019. Protection against biofouling and biodeterioration of renewable energy devices in the marine environment – both important areas in which the global society will invest more in the future – will be crucial for service life and efficiency. The solutions proposed in the past years have revealed numerous drawbacks and several approaches have been banned. The currently most-used solution, copper containing paints, is not sustainable. It is thus urgent to develop new environmentally friendly AF solutions using innovative concepts such as biomimetics or low-emission coatings.

Biomimetic Solutions

Even though the interest in the fouling process mainly originates from its detrimental effects on manmade structures, it also occurs on the surfaces of living marine organisms and leads to problems in aquaculture of seaweeds and shellfish, for example. Many sessile marine organisms do not possess any physical or mechanical means of defense against possible colonizers, or predators, but nevertheless resist colonization and overgrowth by epibionts (an organism that lives on the surface of another organism) as shown in Figure 2.

Studying the natural defenses against fouling of organisms has led to a biomimetic approach that can be used to better understand the structure and function of biological systems as models or inspiration for the sustainable design and engineering of materials and machines. Natural AF strategies developed by marine organisms have been reviewed and classified into four categories: chemical, physical, mechanical and behavioural. So far, with special focus on biofouling, two main topics have been studied for biotechnological applications: chemical defense and effects of surface topography.

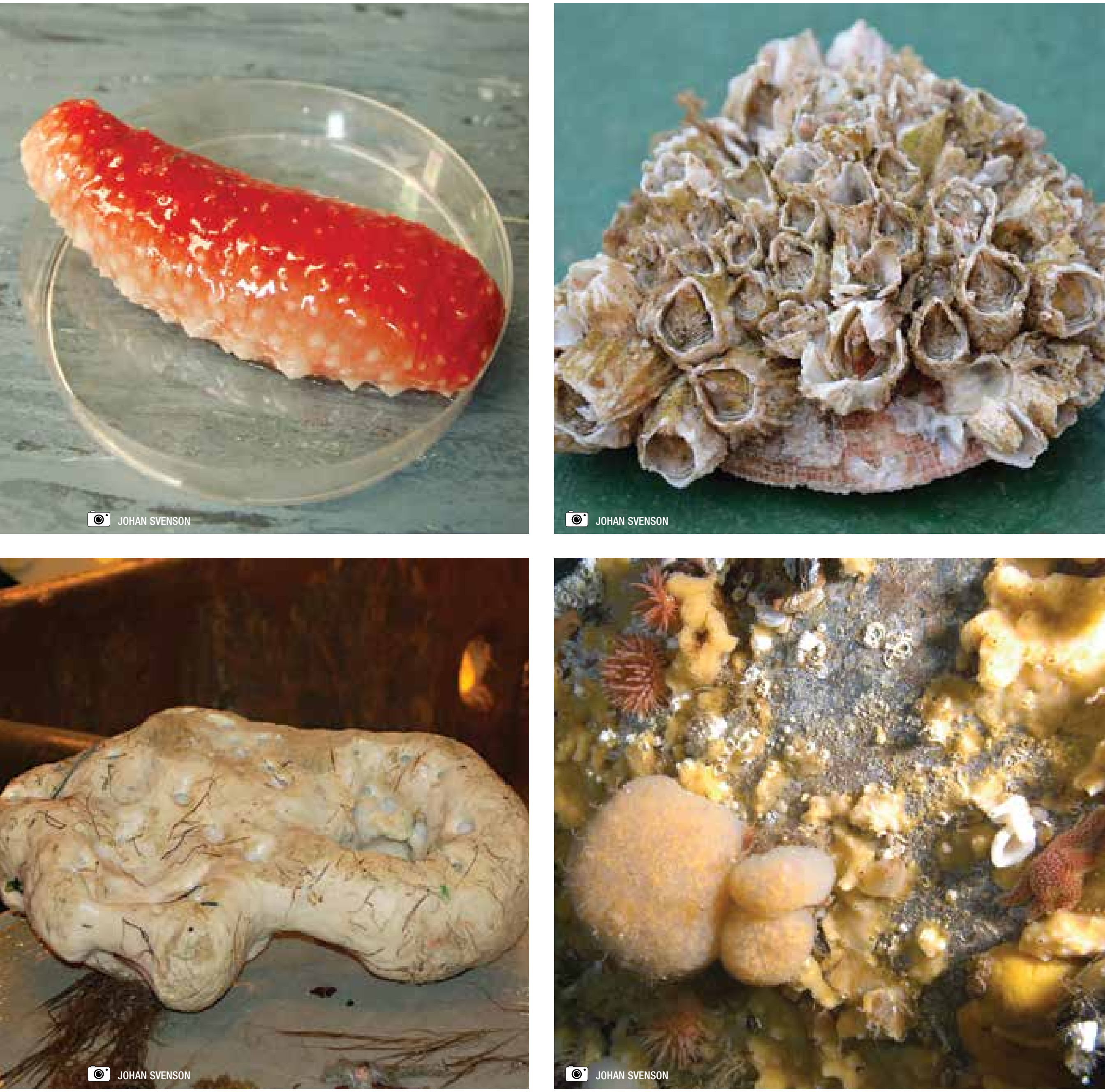


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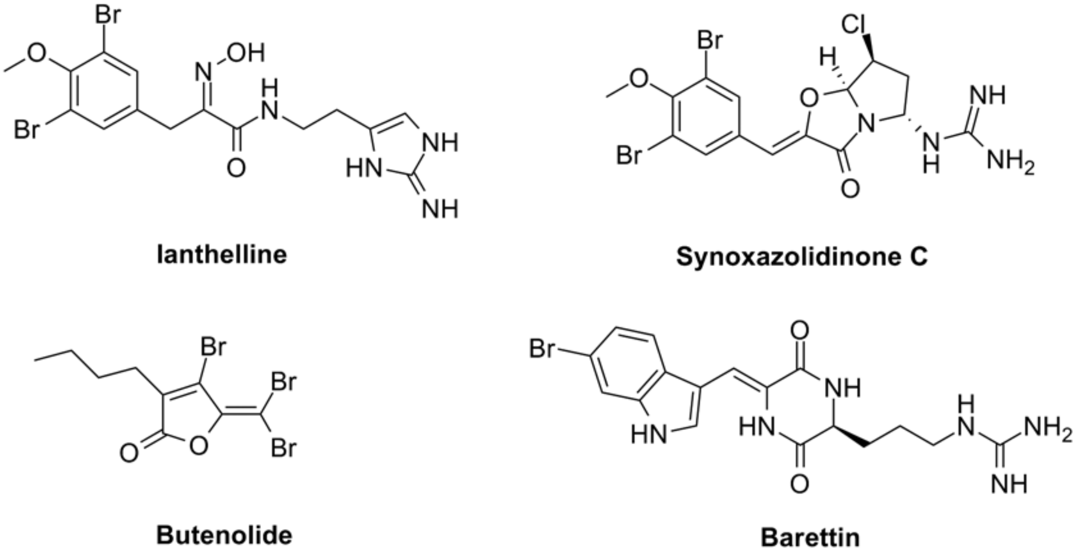
Figure 2: Marine organisms with varying defence against epibionts. Top row: Examples of a marine organism that is free of biofouling (*Stichopus tremulus*, top left) and one that is severely overgrown by barnacles (*Chlamys islandica*, top right). Bottom row illustrates two stationary marine organisms (the sponge *Geodia baretti*, bottom left, and the ascidian *Synoicum pulmonaria*, bottom right) that are effective producers of antifouling natural products such as barettin and the synoxazolidinones.

Natural Products with AF Activities
The ability of some organisms to chemically combat fouling by epibionts is associated primarily with production of so called secondary metabolites, compounds not involved in core life-supporting systems (the primary metabolism), and are commonly involved in chemical defense against predators, pathogens and also against fouling. The discovery of potent AF compounds such as brominated furanones, meriditerpenoid, floridoside, ianthelline, synoxazolidinones, and pulmonarins has highlighted the potential of natural products as a source of potent new AF compounds. A selection of marine AF compounds are shown in Figure 3.

Research efforts in this area have been intensified thanks to the creation of bioprospecting platforms such as Biodimar® in France (Brest University) and MabCent® in Norway (Tromsö) (Figure 4).

The discovery and further development of a new lead compound with AF activity requires large quantities of product for laboratory screening, field assays, and tests of paint format. However, the real challenge using natural products is the up-scaled production for the coating market. There are four main strategies to produce larger quantities of natural products.

1. First, natural products can be extracted from organisms collected in the field. This is the first step during development but is usually prohibitive during up-scaled production because of unsustainable use of natural resources. Controlled harvesting is an ideal solution when bioactive compounds are produced from unwanted biomass such as marine invasive species but a major constraint consists of the potential natural variation of bioactivity and ecological impact of harvesting should be carefully monitored.
2. A second option is to extract natural products from cultured organisms and plants (e.g., capsaicin from pepper plants). Aquaculture and mariculture can be used as a possible strategy for production of marine natural products for initial studies. Economic projections suggest that in-sea culture can be a cost-effective option



Ianthelline **Synoxazolidinone C**

Butenolide **Barettin**

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Figure 3: Examples of small halogenated natural antifouling (AF) compounds produced by sessile marine organisms that have been evaluated as new "green" AF compounds in biomimetic AF solutions.

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Figure 4: Marine bioprospecting provides access to marine organims that are studied for the ability to produce AF compounds as well as compounds that can be developed into pharmaceuticals.

for the supply of natural compounds. Culturing may be a particularly successful strategy if the natural product has a microbial origin (e.g., avermectins). However, most organisms are very difficult to culture.

3. A third solution is to culture recombinant microorganisms that are transfected with genes involved in the synthesis of the natural product. This is usually only practical if the desired natural product is a direct gene product, i.e., a peptide. However, the recent development in in vitro synthesis using isolated enzymes may be used to design new synthetic pathways that produce novel bio-inspired compounds.
4. The fourth option is to produce the natural product through chemical synthesis. The success here depends on the cost of initial reactants and the number of synthetic reactions, which largely determines the yield of the final product. In practice, many natural products are too complex and expensive to synthesize and the synthesis of natural products is still considered highly inefficient as the exact build-up of functional groups with a complex molecule still represents a challenge. An attractive alternative is to synthesize analogues of the natural product that are less expensive but with similar bioactivity.

One example of research and development of natural products for AF is the compound known as Platelet Activating Factor (PAF). PAF is found in many species of marine sponges and is a bioactive glyceraphospholipid (GPL) with powerful cellular action. A study in 2014 synthesized an analogue structurally related to PAF using lecithin as raw material that is obtained in great amounts from soybean. Initially the analogue was successfully tested against marine bacteria in laboratory assays and then tested in field experiments as a booster biocide in AF marine coatings. Panels painted with the synthesized biocide showed better results when compared with panels coated with a paint containing the commercial halogenated biocide ECONEA™ at similar concentrations. The results showed that the synthesized GPL, based on the molecular structure observed in marine sponges and produced from low cost raw material, can be a potential alternative to commercial antifouling paint formulations.

There are still many challenges to develop AF solutions from natural products, such as difficulties and drawbacks in up-scaled production, but despite these, numerous field studies have provided proof of efficiency of AF coatings enriched with marine natural products.

Physical Defence Based on Surface Topography

A strategy different from natural products in the search for novel environmentally friendly AF solutions is to exploit physical defence mechanisms shown by some marine organisms, e.g., molluscan shells, sloughing of epidermis, and shark skin teeth. Some studies have attempted to replicate such natural hostile surfaces and assess possible AF activity. Most focus has been on microtextured surfaces. The effectiveness of topography as an AF strategy appears to be a function of the scale of surface texture and the settling organism. One limitation of using microtextured surfaces in AF is that a specific scale of the microtexture may be effective only against some foulers, e.g., micro- and macrofoulers differ significantly in their perception of hostile surfaces. Previous studies concluded that macrotopographies (1-100 mm) are not suitable for AF applications as they are attractive to many marine fouling taxa; microtopographies (1 to ≤ 1000 µm), usually consisting of one uniform arrangement of geometry and scale, provide better AF efficiency but again depending on the fouling community. An interesting and promising approach to improve efficiency against several foulers is the development of multi-scale topographies consisting of periodical sine wave riblets (0.005-500 µm in wavelength) overlapped with smaller micro peaks (1-5 µm in width and height). Such multi-scale textures reduced both barnacle and mussel settlement. The approach of surface modifications in AF has shown success against some fouling species or groups but has failed to achieve broad-spectrum fouling resistance and inhibition of biofilm formation. Concerns can also be raised about the long-term efficacy, which may be impaired due to the build-up of biofilms which will ultimately hide the original surface topographical features. Another constraint of micro-textured surfaces is that they need to be hydrodynamically smooth to not increase hull friction. Similar to natural products there may be technological constraints in the up-scaled production of microtextured surfaces for AF coatings, despite continuing advances in large scale nano- and microfabrication. Nevertheless, non-biocidal based approaches, relying on the physical properties of the surface either to deter the organisms from settling by topographical features or to reduce their adhesion strength (fouling release), have shown promising results. The environmental cost/benefit analyses are very good while economic cost/benefit analyses are still not comparable with the biocide-based coatings.

Synergy of Solutions

Based on experiences from research on natural products and surface topographies, there is still much to learn from the strategies used by marine organisms to inhibit epibiosis. AF solutions based on natural products or natural topographies face a key challenge, which is to achieve a good efficiency and to maintain surface performance for long periods. When looking closer at how most of the marine organisms fight fouling, it appears unlikely that a single natural AF mechanism (based on behaviour, chemistry or physics) will be sufficient to prevent fouling. Most of the marine organisms that are successful at inhibiting epibiosis do indeed use a combination of defences. So far, most of the research investigating biomimetic solutions have mainly focused on single mechanisms.

Natural products often have specific bioactivity, e.g., AF effects against one or a few taxonomic groups of biofoulers. The advantage of specificity is that natural products may have a reduced broad-spectrum toxicity compared to traditional biocides such as copper, thus avoiding unwanted effects on non-target marine organisms. A potential problem with specificity is that one natural product may not offer sufficient AF protection. Many marine organisms counteract this by producing a cocktail of different AF compounds. Future environmentally friendly AF technologies may thus depend on a combination of several strategies. Several natural products may together cover a broader range of AF species. Natural products may also be combined with biocide-free technologies, e.g., silicone coatings that reduce adhesion and promote fouling release are boosted with natural products with AF effects, or combined with hostile, textured surfaces.

Recently, a promising study based on biomimicry showed synergistic AF effects between surface topography and chemistry. The aim of the study was to create an AF material with a combined bio-inspired defence mechanism taken directly from two macroalgae: *Saccharina latissima* and *Fucus guiryi*. For this purpose, the macroalgal surfaces were characterized and further replicated using polymeric reproduction methods. Concomitantly, the AF efficiency of a pre-extracted algal natural product (a brominated furanone) was evaluated. From this study, it appears that the highest AF potential was obtained when using a combination of chemistry and topography. These results demonstrate that future work should focus on combining several types of AF solutions and this opens the door to a new range of innovative solutions.

A study that investigated the factors behind the higher efficacy of the invasive brown seaweed (Phaeophyceae) *Fucus evanescens* in fighting fouling barnacle on their fronds compared to the congeneric *F. vesiculosus* showed an interesting AF strategy. The results demonstrate that the differences in antibarnacle

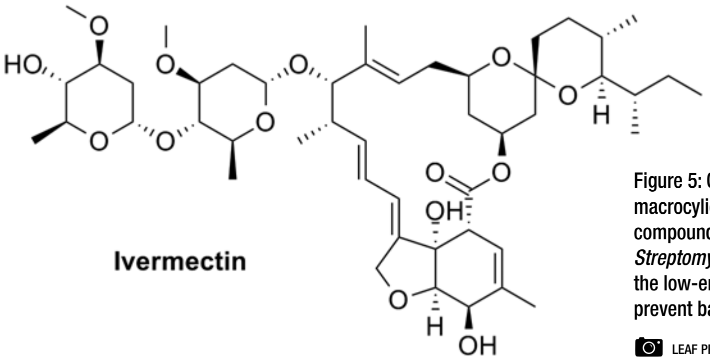

Figure 5: Chemical structure of the macrocylic, highly effective antifouling compound Ivermectin produced by *Streptomyces avermitilis*, and used in the low-emission antifouling program to prevent barnacle attachment.

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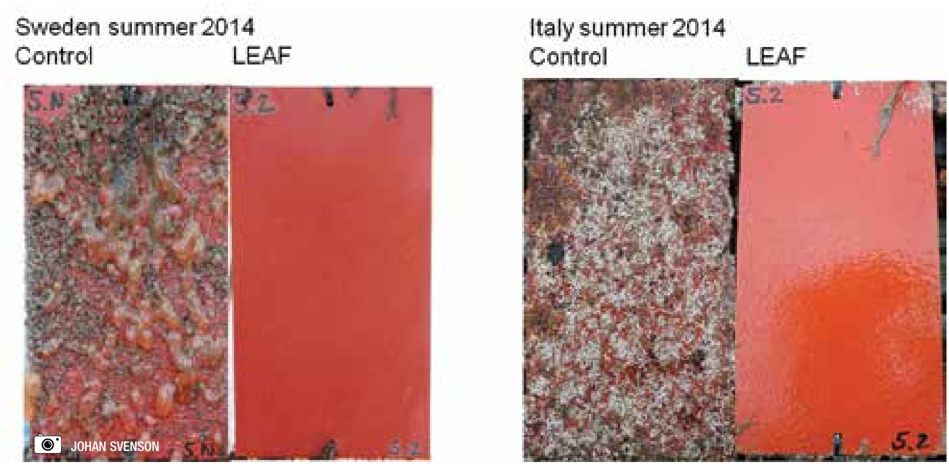
efficiency between the two brown algae cannot be explained on chemical basis (where *F. vesciculosos* showed higher settlement inhibition for both intact tissue and extracts in bioassays) but instead by a so called enhanced post settlement mortality of the settled barnacles that occurs specifically and only on the frond of *F. evanensces*. According to this study, the same natural AF product seems to be utilized in two completely different ways. *F. evanenscens* takes advantages in allowing the barnacles to settle and to come in contact with the embedded biocide inside the tissue.

This particularly smart approach allows *Fucus evanescens* to reduce release of defense compounds into ambient water and to instead channel valuable chemical energy into growth. This approach of bringing foulers into contact with AF compounds with no or little release into the water inspired the new low-emission concept developed within the low-emission antifouling (LEAF) coatings project.

Low-Emission Antifouling (LEAF) Coatings – a New Concept

A long standing view in AF using biocide loaded coatings has been that a steady state release of the biocides into the surrounding water is needed in order to prevent attachment of marine organisms. According to this view, the AF action is assumed to be based solely on interaction between biocide and fouling organisms outside the coating. This scenario, however, does not completely describe what actually happens at the paint surface during barnacle colonization. For example, the synergistic effect of an embedded biocide at low concentrations together with mechanical properties of the coating system was recently highlighted to be important for preventing the recruitment of barnacles. It was shown that 0.1% of the biocide Ivermectin embedded in a soft coating (same hardness as for commercially available AF-paints) (Figure 5) totally prevented the establishment of adult barnacles, while no effect on barnacle recruitment was seen when Ivermectin was added to a harder (polystyrene based) coating.

Both coatings were initially fouled by settling barnacle larvae, but on the softer coating the growth stopped shortly after metamorphosis. Very low release rates, in the order of a few ng cm^{-2} day^{-1}, were measured, but most importantly, there was no difference in release rate between the two coatings of different hardness. The results indicated that a new AF strategy could be employed, whereby intoxication is triggered by the organism itself upon contact and interaction with a coating containing embedded biocide. This finding opens new possibilities of controlling macrofouling by LEAF coatings for which no release of biocide is ultimately needed. The AF mechanism of action could thus be shifted from the solid/water interface to the first layers inside the coating, avoiding the otherwise necessary exposure of biocides in the free water column.


Sweden summer 2014

Control LEAF

Italy summer 2014

Control LEAF

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Figure 6: Growth on untreated control panels and panels treated with a LEAF coating after being submerged in the ocean for three months at a Swedish location (left) and in Italy (right).

A paradigm shift towards LEAF in AF requires molecules displaying some characteristic properties. In order to maintain the molecules within the paint film, the rate of diffusion must be minimized. This can be achieved by having a low concentration of the molecule in the paint film as indicated by Adolf Fick's first law of diffusion (a solute will move from a region of high concentration to a region of low concentration). The diffusion constant (D) also affects the rate of diffusion where D correlates negatively with the size of molecules as described in the Stokes-Einstein relation, i.e., larger molecules diffuse slower. A high physical-chemical affinity of the molecule to paint components has also has been proposed to decrease the diffusion constant. A low concentration in the paint film means that the molecule must be highly bioactive in order for the LEAF paint to be functional.

Ivermectin, which was used in the above proof-of-concept study, demonstrates the required properties of a LEAF compound. Ivermectin is produced by the actinomycete, *Streptomyces avermitilis*, and is thus a natural product. Additional AF substances suitable for the LEAF concept could most likely be found among natural AF substances targeted against epiphytes. The LEAF concept is energetically advantageous for organisms defending their body surface, as there is no need for a continuous release of bioactive molecules if they instead are immobilized in the outer layer of the organism.

The LEAF project is a European Union 7th Framework project based on a collaboration between seven partners from Europe and Brazil, aiming at developing the LEAF concept beyond the laboratory to successful demonstration in the field. The consortium covers the complete value chain required for such an endeavour, including research institutes (SP Technical Research Institute of Sweden and Instituto de Estudos do Mar Almirante Paulo Moreira), universities (University of Gothenburg, University of Portsmouth), industries (Boero Group and Entarco) and the Community of European Shipyards' Association. This consortium ensures a balance between understanding the fundaments of this innovative AF approach and at the same time maintaining an end-user perspective. It is the mission of the LEAF project to produce evidence of the possibility of achieving an efficient, economically and industrially feasible and not the least more environmentally friendly alternative to copper paints.

Field tests have been carried out during two of the three years of the project duration and are currently followed up by demonstration activities in the form of boat tests. The field tests are still ongoing at five different locations in the world with differences in water conditions, water quality, and fouling pressure. Representative panels can be seen in Figure 6.

LEAF test stations are located in Sweden (west coast), in the United Kingdom (English Channel), in Italy (Mediterranean Sea), and in two different locations in Brazil (Rio de Janeiro).

Conclusions

Most of the AF solutions present on the market today contain copper in combination with co-biocides. Even after more than two decades of research on alternative strategies, copper-based AF solutions still offer the best performance available on the market. However, the benefits of the present AF technology are currently questioned based on known environmental risks linked to AF biocide use, especially in marinas and enclosed bodies of water. The growing awareness of copper toxicity has led to a change in legislation in two states in the United States and a future ban of copper-based AF for small recreational boats. These legal decisions boost the search for new environmentally friendly solutions. In the last several years, innovative approaches have focused on the field of biomimetics by combining chemical and physical defences, and by a new paint concept based on low emission of AF biocides. These new routes of research should set the direction for future biotechnological development and hopefully will lead to new environmentally friendly AF solutions.

Acknowledgment

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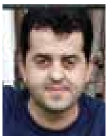
Rozenn Trepos is a research associate at the University of Portsmouth. Her work focuses on chemical ecology and the research of new marine bioactive compounds. She was employed on a European project that focused on finding new solutions against the fouling of surfaces for the elaboration of green intelligent “smart” biomaterials (GIMs project). Currently Ms. Trepos works on the design of new environmentally friendly solutions for the development of new antifouling solutions (LEAF project).



Emiliano Pinori has been employed at SP Technical Research Institute of Sweden since 2008. He has focused on antifouling research since 2008 starting with MARINORD project (2008-2011), an international research program (Nordic countries) focusing in encapsulation of biocides in nano-pourous silica particles and on new biocides with reduced release rate. He received his PhD in Surface Biophysics in 2013 from the University of Gothenburg. Since then, Dr. Pinori has been employed as PhD Research Scientist at SP and is Technical Coordinator for the FP7 LEAF project. He has authored publications on the post settlement enhanced mortality used in the LEAF project.

Per Jonsson is a professor in marine ecology at the Department of Biological and Environmental Sciences, University of Gothenburg, and based at the Tjärnö Marine Laboratory. His research interests lie in population ecology, hydrodynamic effects on marine life including dispersal of marine organisms and biofouling, chemical ecology, and design of marine protected areas.

Mattias Berglin received his PhD in polymer chemistry at Chalmers University of Technology in 2002. His interest in marine bioadhesives encouraged him to carry out his post-doctoral period at Gothenburg University working with algal polyphenols. The following years he was employed in large international and national antifouling projects with focus on lowering the release of bioactive substances to the environment. Dr. Berglin is currently employed at SP Technical Research Institute of Sweden as senior scientist and is an adjunct associated professor at Gothenburg University.

Johan Svenson received his PhD in Bioorganic Chemistry in 2003 from the University of Kalmar in Sweden. After post-doctoral stays in New Zealand, he moved to the University of Tromsø, Norway, for additional post-doctoral studies on the medicinal chemistry of antimicrobial peptides. In 2007, Dr. Svenson joined the Mabcent marine bioprospecting program and was employed as senior scientist and manager for the Smallstruct platform working on bioactive secondary metabolites. In 2013, he established his own lab focused on marine derived antifouling natural products. Dr. Svenson was recently employed by SP Technical Research Institute of Sweden as senior scientist working with antifouling for both marine and medical applications.

Ricardo Coutinho received his PhD in Marine Ecology at University of South Carolina, and gained post-doctoral experience at Duke University and Woods Hole Institute working on barnacle settlement and recruitment. He is a senior researcher and head of the Division of Marine Biotechnology at the Brazilian Navy's Institute of Marine Studies Admiral Paulo Moreira (IEAPM). His research is focused on biofouling studies, particularly fouling ecology, antifouling technology, natural antifouling, and biocorrosion. Dr. Coutinho is the coordinator of the National Institute of Science and Technology in Marine Science, Integrated Oceanographic Process Studies from the platform to the slope (INCT-PRO-OCEANO).

Jukka Lausmaa earned his PhD in Physics from the University of Gothenburg in 1993. In 1996 he moved to SP Technical Research Institute of Sweden for a position as senior research scientist. He is now head of research for Chemistry, Materials and Surfaces, a department consisting of 180 engineers and scientists. Dr. Lausmaa's own research is focused on understanding interactions between materials and biological systems and how these are influenced by structural and chemical properties of surfaces. He is the author or co-author of over 90 scientific articles in peer-reviewed journals.

Claire Hellio received her PhD in Marine Chemical Ecology in 2000 from the University of La Rochelle (France). She then worked for four years as Research Associate at Newcastle University (UK) focusing on biofouling studies. She was appointed as Reader in Environmental Biotechnology at Portsmouth University (UK) and has been involved in several EU (ChemFree, GIMS, LEAF) and international Projects. Dr. Hellio was recently appointed as Professor in Marine Chemical Ecology and Biotechnology at the European Institute for Marine Sciences (UMR6539, UBO, Brest, France) and as Director of the Biodimar marine bioprospecting platform to work on marine bioactive secondary metabolites.