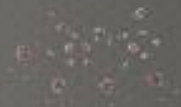




**ICMCF
2018**

June 24-29th



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The 19th International Congress on Marine Corrosion and Fouling – ICMCF 2018
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MONDAY 25TH JUNE 2018

OPENING ADDRESS

OPENING ADDRESS

Highlights from 30+ years of corrosion and biofouling research at
the Center for Corrosion and Biofouling Control

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The drivers and technologies available for corrosion and biofouling control are dynamic. The drivers respond to industrial, recreational and environmental requirements. Technologies continue to change as our scientific knowledge and manufacturing skills advance. This talk will highlight how the interaction between drivers and technology has fashioned research and development at CCBC over the last 30 years. In the 1980s the availability of the self-polishing tributyltin paints satisfied the operational requirements of the shipping and boating industries. During this period the focus was on improving both the corrosion and biofouling control for the offshore oil, utilities and aquaculture industries. The long-term design requirements (30+ years) for these structures led to the development of copper-based systems for biofouling control and recommended practices for the design of cathodic protection systems. In the 1990s the environmental problems associated with the use of organotins led to regulations and research for alternatives that included new chemistries for active compounds and the development of the fouling release coatings. These technologies continue to evolve and require methods that can quantify how their performance characteristics compare to existing methods. What does the future hold? Autonomous underwater vehicles to groom ships when they are not underway - coatings that incorporate UV light or other active agents - coating chemistries that are truly non-stick - coatings that generate oxidizing agents such as chlorine or hydrogen peroxide - air bubble systems etc. Acknowledge ONR grants: N00014-16-1-3050 and N00014-16-1-3123

PLENARY 1

Butenolide as a non-toxic, effective and environmentally friendly antifouling compound

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A good antifouling compound needs to be not only efficacious against the settlement of fouling organisms but also environmentally friendly. Ten years ago, we reported butenolide (5-octylfuran-2(5H)-one) from marine bacteria as a non-toxic antifouling compound. To ensure its environmental safety, extensive laboratory and field experiments have been conducted since to study the degradation kinetics, biosafety, mode of action, molecular targets, impact at genomic and transcriptomic level on fish, control release and so on, in comparison with other antifouling compounds such as DCOIT (SeaNine211), TPBP and DIM. The results showed that butenolide performed much better in the following areas: 1) being very effective in controlling both macro- and microfouling under desirable release rate; 2) being easier synthesized at low cost; 3) being non-toxic, biodegradable and thus more environmentally safe; 4) having well-documented modes of action and molecular targets in both target and non-target organisms (targeting on larval energetic metabolisms or bacterial fatty acid metabolism). For instance, butenolide is degraded rapidly in natural seawater while DCOIT and DIM had no obvious degradation after 96-h incubation; it only activates detoxification system in liver of fish while DCOIT disrupts endocrine homeostasis in teleost indicating DCOIT is not really environmentally antifouling compound. Successful incorporation of butenolide in polymer matrix and well-controlled, low and constant release rate from the coatings made of self-polishing copolymer and biodegradable polymer breaks down the last barrier for large-scale testing and commercialization. We believe that butenolide could be one of the first "real green" antifouling compounds, with most extensive documentation on its environmental safety and molecular mechanisms.

MONDAY 25TH JUNE 2018: TRACK A NEW ANTIFOULING TECHNOLOGY: SESSION 1

1A – ORAL 1

Development of hybrid antifouling coatings ecofriendly

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Antifouling paints are the main system used against the development of organisms on immersed surface and the most studied. Lots of researches have been done to increase their efficiency against the biofouling. However, these improvements have been done to the detriment of the environment. Nowadays two strategies are used: the biocide release system based on the incorporation of natural or synthetic biocides and the fouling release strategy based on paints with physico-chemical surface properties to limit durable colonization by organisms. Both kinds of paints have shown their limits, use of large amount of heavy metals for biocides systems and inefficiency in static conditions for fouling release coatings. In this aim, antifouling paints with a hybrid binder combining the two strategies have been developed. Poly(lactic acid) is well known for its degradation in seawater and poly(dimethylsiloxane) for its surface properties. Both polymers are non-toxic and already used in antifouling. The objectives of this study are to measure the efficiency of poly(lactic acid)-poly(dimethylsiloxane) system for antifouling paints and to observe the influence of the physico-chemical properties of the binder like the molecular weight on the antifouling activity. The use of a block copolymer should allow mixing the properties of erosion and hydrophobicity to obtain a more efficient paint with a reduced environmental impact. Antifouling activities have been evaluated by immersion in seawater in Lorient harbor. The hybrid paints have shown superior efficiency to a commercial paint during their immersion in situ in spite of inadequate static conditions of test and with a lower biocide amount. (Research funded by ANR SAFER).

1A – ORAL 2

Transforming materials to antifouling products by post-settlement inhibition (PSI) strategy

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Present biocide-based antifouling strategies that are based on a continuous release of biocides if the antifouling efficacy is to be maintained are not suitable for “materials” and other solutions are sought for. Instead of releasing substances we have tried to immobilize them in the material with maintained bioavailability. Thus it is first upon surface exploration and settlement the epibiont comes into contact with the substance i.e. post-settlement inhibition [1]. The paradigm shift from “release” to “no-release” opens up new possibilities as there is no need for eroding coating systems for long-term antifouling efficacy and common bulk polymers could be transformed into antifouling systems. In this presentation both theoretical background, i.e. requirements for antifouling substances and polymer matrix, and industrial applications will be discussed. Initial results of transforming a common polymeric film (wrap) made of polyvinyl chloride (PVC) into maintaining long-term barnacle protection will be used as an example (patent WO2016182491 A1 “Antifouling film”). In short, the PVC film was loaded at 0,1% with a natural substance (abamectin), which is produced by the bacteria *Streptomyces avermitilis*. The PVC hardness was controlled by varying concentrations of plasticizer, and the effect on release and antifouling efficacy was investigated. The surface properties of the PVC films were thoroughly characterized both prior and after immersion in artificial seawater (ASW) by SEM, ToF-SIMS and water contact-angle measurements. The PVC films were evaluated in a field study in Sweden and the convincing two year results will be presented. [1.] Biofouling, 2013, 29, 763-773

1A – ORAL 3

Antifouling compounds from marine microorganisms and their potentials as antifoulant

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Marine microorganisms are promising potential sources of nontoxic antifouling agents. In recent years, during the course of our searching for environment-friendly antifouling components from marine-derived bacteria and fungi, totally, over 50 antifouling compounds with antilarval and/or anti-biofilm activity were obtained. The mode of actions of several bioactive compounds against the biofilm-formation of marine bacterium *Bacillus amyloliquefaciens* were explored. And the antifouling potentials of some bioactive compounds and their fractions were further evaluated in field trial. Among them, several compounds and fractions displayed significant antifouling activity in different seasons in field trial. It seems that the combination of different antifouling compounds will do favor to improve the broad spectrum of the natural antifoulants against different fouling organisms.

1A – ORAL 4

Functionalization of intrinsically conductive polymers by thiol-terminated hydrophilic polymers

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Electrochemically grown polyaniline (PAni) thin films have been shown to react efficiently with thiols, which can dramatically change the surface properties of the material without significantly impacting bulk conductivity. Such films, however are difficult to process and are unsuitable for many applications. Here we demonstrate the grafting of thiol-terminated poly(ethylene oxide) (PEG-SH) of various molecular weights onto PAni nanorods. The resulting materials are characterized by spectroscopic, microscopic and thermal analytical methods to demonstrate the covalent attachment of the PEG polymers to the nanorods. The derivatized nanorods are water dispersible and maintain their original morphology and electroactivity. The number of thiols bound to the nanoparticles under a given set of conditions decreases as the size increases, but the total mass of PEG increases with increasing size. The reaction proceeds at room temperature, but is much faster at higher temperature and greater PEG density is observed. Similar results are obtained with polypyrrole nanorods and thiol-terminated poly(zwitterions). The latter may be grafted to the nanorods or may be grown from the surface using controlled radical polymerization reactions.

1A – ORAL 5

Quaternary ammonium-functionalized aluminum substrates:
Hydrophilic and antimicrobial nature facilitate antifouling performance

X. HE

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Due to the great loss induced by biofouling, developing new strategy for combating biofouling is urgently needed. Quaternary ammonium salts are potent cationic antimicrobials used in consumer products. Surface immobilized quaternary ammonium salts create contact-active antimicrobial coatings. Herein, we describe the facile preparation of a contact-active antifouling coating by tethering polyethyleneimine onto flat/nanostructured aluminum surface by the hydrogen bonding between polyethyleneimine and AlOOH in aluminum surface. The quaternary polyethyleneimine was obtained through quaternization reactions. These samples possess excellent antifouling performance, which could decline about 95% of *Phaeodactylum tricorutum* adhesion and 98% of *Chlorella pyrenoidosa* adhesion. The antifouling property of polyethyleneimine/quaternary polyethyleneimine are based on their hydrophilic and antimicrobial nature. The obtained results open the way to a new strategy to reduce biofouling on metal surfaces using grafted polyethyleneimine/quaternary polyethyleneimine on marine infrastructure.

1A – ORAL 6

Erodible fouling release coatings based on a hydrolyzable network

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Biofouling has harmful effects on ship hulls, increasing the drag resistance, and thus the fuel consumption and greenhouse gases emission of boats. Self-Polishing (SP) Coatings are one of the most efficient antifouling systems as they prevent fouling settlement thanks to a durable erosion of their surface and a release of active molecules. However SP coatings release a large amount of toxic molecules into seawater which leads to environmental concerns. Past and incoming regulations from the International Maritime Organization or the European Chemical Agency compromise the use of such substances. Thus, Fouling Release Coatings (FRC), based on a non-stick silicone surface without biocides, are considered as a “greener” category of antifouling systems and display good self-cleaning properties as long as the ship velocity exceeds 5 knots. In this work, the objective is to combine both strategies by designing a poly(dimethylsiloxane)-based network with small crosslinked hydrolyzable segments of polyesters to finally provide an eco-friendly antifouling system which is efficient even in static conditions. This hard-soft network is expected to maintain a low energy surface while, at the same time, ensuring a continuous renewal of its surface. Mechanical tests were performed to check the effect of the polyester links on the softness of silicone elastomer. A monitoring of the coating hydration with fluorescein tracer was useful to assess the ability of the coating to absorb water and thus to erode itself. (Research funded by the Direction Générale de l'Armement)

1A – ORAL 7

Selfstructuring materials base on thiol PDMS PEG acrylates as fouling release coatings

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Worldwide effective biocides against biofouling are subject to restrictions, which became increasingly stricter. Hence, new biocide free coatings are needed. One approach for the development of those coatings is based on thiol-acrylate chemistry. Due to the various reactions of this chemistry, it provides the opportunity to create self-structuring surfaces. This presentation deals with coating material based on this chemistry, which creates self-structuring surfaces in combination with special polydimethylsiloxanes and polyethyleneglycole monomers. Amphiphilic surfaces with hydrophobic and hydrophilic areas could be produced, which show geometric structures as well as different material compositions on a micrometer scale. Various structured surfaces were tested in laboratory and field tests and show interesting fouling release properties depending on structure. The results show not only an effect of coating composition but also of manufacturing and curing type on surface structure and resulting fouling release properties.

1A – ORAL 8

Self-repairing silicone coating for marine anti-biofouling

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Marine biofouling is one of the most challenging problems today. Silicone polymer based coatings with low surface energy and elastic modulus can effectively inhibit or release biofouling. However, their non-repairable property and poor antifouling ability on static conditions limit their applications. In the present study, we report a self-repairing coating consisting of poly(dimethylsiloxane) based polyurea (PDMS-PUa) and a small amount of organic antifoulant (4,5-dichloro-2-n-octyl-4-isothiazolin-3-one) (DCOIT). The coating can completely recover itself from damaging in mechanical properties either in air or artificial seawater at room temperature. Such recovery can be accelerated at a higher temperature. Moreover, the release rate of DCOIT is almost constant and can be regulated by its concentration. The six-month marine field tests demonstrate that the system has a good antifouling/fouling release performance even on static conditions (Funding provided by the National Natural Science Foundation of China).

MONDAY 25TH JUNE 2018: TRACK A
 MACRO & INTEGRATIVE BIOLOGY: SESSION 1

1A – KEYNOTE 1

Biofouling in multi-stressed coastal oceans: A synthesis of experimental data

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Anthropogenically caused shifts in coastal environmental drivers such as pH, temperature and salinity will affect a large variety of animals, but the way and extent to which a biofouling species is affected is largely unknown. We need multi-factor, multi-life stages and multiple end-point studies to address this knowledge gap for evaluating the performance of fouling species in future coastal oceans with ocean acidification (OA), warming and freshening. Over the past several years, we have carried out several laboratory experiments using a dominant tropical biofouling species to answer several globally important questions concerning biofouling in future coastal oceans. In this lecture, we will discuss our experimental approach and the overall results we have got so far. We have made series of simultaneous measurements using tools borrowed from variety of disciplines, especially from molecular biology and mechanical engineering, to understand mechanisms through which a tube-building biofouling worm, *Hydroides elegans*, might adapt or succumb to multiple stressors in future coastal oceans with elevated CO₂. The major questions we have answered through this project are: Are climate change related multiple stressors are more harmful for tubeworms in combination than alone? Our primary aim was to study the tubeworms structural integrity and physiological fitness in response to multiple stressors, primarily to the novel OA stressor. Specifically, we have tested the hypothesis that tubeworms will form impaired tubes with poor mechanical properties under multiple stressors. Our results suggest that climate change will disturb fast-growing larvae thereby poses a threat to their survival by affecting their timing and choice of attachment and accelerated growth afterwards. In collaboration with mechanical engineers, we have also mapped the architecture of the calcareous tubes and its mechanical properties in response to multiple climate change stressors using tools borrowed from mechanical engineering. Ultimately, our study provided new insights into how benthic biofouling communities would develop in near future-ocean with multiple climate change drivers.

1A – ORAL 9

Bacterial inductive cues for settlement of the tubeworm *Hydroides elegans*:
 Needles in a haystack or a haystack of needles?

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The circumglobally distributed serpulid polychaete *Hydroides elegans* has emerged as a major model organism for studies of factors leading to settlement and metamorphosis of its larvae. Multiple bacterial strains in multiple phyla are known to induce these processes. We have isolated bacterial products, including arrays of phage-tail-derived tailocins and outer-membrane vesicles, that carry the inductive capacity in cell-free preparations. In current efforts, we have examined coastal and oceanic biofilms to provide better understanding of their complexity, as well as their inductive capacities for larvae of *H. elegans*. Most coastal biofilms from Hawaii and Singapore include thousands of different OTUs scattered across many bacterial phyla, classes and genera, and all of those tested induced settlement of tubeworm larvae. Biofilms from our field site inside Pearl Harbor, Hawaii, analyzed by sequencing 16S DNA sequences, include about 4,200 distinctive OTUs. Of these, using a standard culture medium for marine bacteria, we cultured only 40 distinctive bacterial strains: 1% of the total present. Of these 40 strains, six were found to induce settlement in larvae of *H. elegans*, and all were identified by full-sequence 16S DNA analysis to be species of the genus *Pseudoalteromonas*. However, this bacterial genus makes up less than 1% of OTUs found in the total bacterial community. Limitations in “culturability” of many of the most abundant bacteria reduce our ability to fully analyze the complex biofilms that quickly accumulate on marine surfaces and to determine how differences among them impact the fouling communities that develop upon them.

1A – ORAL 10

Induction of larval settlement of the invasive biofouler, *Mytilopsis sallei*
by active substances from conspecific adults

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The Caribbean false mussel *Mytilopsis sallei* (Récluz, 1849) is an invasive dreissenid species in the Indo-Pacific Ocean. *M. sallei* usually forms dense aggregations and its aggregation on submerged artificial surfaces cause biofouling problems. In this study, the conditioned seawater (CSW) of *M. sallei* adults was prepared and larval settlement response of *M. sallei* to CSW was examined. The results showed that larval settlement was significantly induced by CSW after 48 h exposure, suggesting that there might be inducing cue(s) from *M. sallei* adults. Using bioassay-guided fractionation, three compounds were isolated from the coelomic fluid of *M. sallei* by ultrafiltration, Sephadex LH-20 and high performance liquid chromatography. They were identified as adeonosine, inosine and hypoxanthine based on NMR (Nuclear Magnetic Resonance) spectra and MS (Mass Spectrometry) data. These three compounds all showed significant inducing effects on larval settlement of *M. sallei*, at the concentrations of 0.5~50 μ M for adeonosine, 0.5~50 μ M for inosine, and 1~50 μ M for hypoxanthine. The present work identified the conspecific settlement-inducing substances in *M. sallei*, providing insights into the aggregation mechanism of *M. sallei*, which may be useful to develop strategies to combat this invasive fouling organism. (Research funded by the National Marine Economic Development Demonstration Project in Xiamen under Grant 16CZB023SF12)

1A – ORAL 11

Quantitative analysis of barnacle settlement behaviour

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For barnacle cypris larvae at the point of settlement, selection of an appropriate surface is critical. Since post-settlement relocation is usually impossible, barnacles have evolved finely-tuned surface sensing capabilities to identify suitable substrata, and a temporary adhesion system for extensive surface exploration. The pattern of exploratory behaviour appears complex and may last for several hours, imposing significant barriers to quantitative measurement and, thus, comparison of exploratory behaviour in different experimental conditions. Recently we have developed a novel tracking system that enables simultaneous analysis of the larval body movement of multiple individuals over their entire planktonic phase. This approach overcomes many of the difficulties faced by previous approaches which, for the most part, attempted to interpret and quantify behaviour from reconstructed track trajectories over short time-periods. For the first time we describe, quantitatively, the complete settlement process of cyprids as they explore and select surfaces for attachment. We confirm the “classic” behaviours of wide searching, close searching and inspection that comprise a model originally proposed by Prof. Dennis Crisp FRS over 50 years ago. Moreover, a short-term assay of cyprid body movement has identified inspection behaviour as the best indicator of propensity to settle, with more inspection-related movements occurring in conditions that also promote higher settlement. This approach constitutes the first practically applicable method for experimental quantification of cyprid settlement behaviour in wide-ranging investigations of barnacle ecology and applied studies of fouling management. (Funding provided by the Office of Naval Research and the European Commission SEAFRONT project)

1A – ORAL 12

Miata57 is a potent antifouling deterrent to marine larval invertebrate biofouling

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Miata57 is a fouling deterrent molecule that has shown a promising ability to deter fouling marine invertebrate larvae from settling, thus preventing biofouling, when it is covalently linked to a surface or included as part of a coating. It is a synthetic peptide that is based on the Chi-class of marine conopeptides, which are effectors of neuroendocrine transport in eukaryotic cells. Conopeptides derive from Cone snails, a highly successful marine gastropod predator species which has evolved these molecules to capture prey. Beyond their high efficacy, another distinct advantage for using conopeptide based systems is their stability in the marine environment. This stability is due to hydroxylation of the peptide chain which also improves ligand specificity. Our prior research has shown that noradrenaline mediated surfaces are as effective as copper in defeating larval biofouling yet are largely non-toxic due to being covalently linked to the hard surface. We now report a newly synthesized miata57 with a polyglyl-azide linker region that has been folded into the correct native confirmation thru disulfide bonding. Furthermore, we have achieved precise orthogonal covalent attachment of the miata57 molecule to the coating surface via click chemistry. The combination of proper molecular confirmation and surface geometry prevents cyprid biofouling at a much lower molecular density than previously hypothesized. This discovery sharply reduces the cost of the final formulations, and may be a promising alternative to copper as highly effective marine antifouling agent in the near future. (Funding provided by Clemson University Research Foundation, Clemson, SC 29634)

1A – ORAL 13

Chitin in the permanent adhesive of the barnacle cypris larva

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The barnacle, *Amphibalanus amphitrite*, is a common species that colonizes on ships' hulls and other submerged artificial structures, contributing to the problem of biofouling. The presence of sessile marine invertebrates increases frictional resistance on the hull and thus fuel consumption. Therefore, the problem of biofouling exacerbates greenhouse gases emission, it is also a major environmental concern that promote translocation of nonindigenous species. The free-swimming cypris larva is arguably the most important life stage of barnacles, in that it determines the colonization outcome. This larval stage is specialized for detecting suitable substrates and secret an adhesive that enables its spontaneous permanent attachment to a surface. Although this adhesive has been a popular topic of interest in biofouling research, the effort has been largely focused on the protein components. Therefore, the non-protein components including lipids and carbohydrates has become the main foci of our research. Chitin is the second most abundant polysaccharide. It is a popular form of natural biopolymer, that plays an essential role in providing a supportive structural framework in a broad taxonomic groups, which includes yeast, fungi, insects molluscs and crustaceans. Evidence exists that chitin is a significant component in the adhesive mixture of the cyprid, however, the occurrence of chitin and its role in facilitating a strong adhesion of the early attachment phase remain unexplored. A correlative microscopy approach was used to examine the presence and distribution of chitin in the cement gland and the adhesive plaque. A specific probe for chitin has been developed from the chitin binding domain (CBD) information of a bacteria species. Chitin structures were investigated by its fluorescence using confocal microscopy and immunogold labeling using transmission electron microscopy. The study indicated the presence of chitin in both the cement gland and adhesive plaque, and further characterization of the chitin associating proteins is ongoing.

1A – ORAL 14

Transgenerational effects of salinity and ocean acidification on the barnacle *Amphibalanus amphitrite*

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Ocean acidification, the decrease in seawater pH due to increased atmospheric CO₂, will greatly impact marine life. Changes in other environmental factors, such as salinity, could exacerbate or mitigate effects of acidification. Here, we assessed the response of the barnacle *Amphibalanus amphitrite* to decreased pH and decreased salinity over two generations. Larvae cultured from adults (salinity ~36) were settled on silicone coated panels. Animals were acclimated to four combinations of pH (8.02 and 7.50) and salinity (35 and 15) and exposed for 16 weeks. In the F1 generation, adhesion strength was not affected by pH, salinity, or their interaction. Both pH and salinity significantly affected base plate area. Barnacles tended to be smaller at lower salinity and higher pH. Larvae were then reared under seawater conditions of the F1 generation. Low pH had a dramatic effect on larval success; less than 5% of cyprids successfully settled at low pH under both salinity levels, and no juveniles survived under low pH. Hence, we could only assess the effect of salinity in the F2 generation. Consistent with the F1 generation, salinity did not affect adhesion strength in the F2 generation after 14 weeks growth, but had a strong effect on base plate area. Barnacles at salinity 35 were ~70% larger than those at 15. Assessments of environmental impacts over multiple generations provide a more realistic prediction of a species response to changes in seawater chemistry. (Research funded by ONR).

1A – ORAL 15

Salinity and thermal tolerances of the larvae and spat of three invasive marine byssate bivalves in Singapore

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Mytella strigata (Mytilidae) and *Mytilopsis sallei* (Dreissenidae) are alien invasive in Singapore and rapidly spreading around Asia. *Perna viridis* (Mytilidae) is native in Southeast Asia and has recently spread to the Americas. All three mussels occur in Singapore in fouling communities and were likely translocated to non-native regions via ship fouling, ballast water, or both. Field surveys conducted in Singapore from 2016 - 2017 found that *M. sallei* thrived in brackish water (5 - 20 psu), whereas *M. strigata* and *P. viridis* were present across a wider range of salinities, up to 31.9 psu. These bivalves complete their life cycles in temperatures ranging from 26.7 - 32.0°C. While the salinity and temperature limits of the adults are known, larval and juvenile tolerances are poorly characterized. Short-term laboratory experiments were conducted to determine the salinity and temperature tolerance of the larvae and spats of three species. Results showed that the *P. viridis* possessed the narrowest tolerances. *P. viridis* larvae did not survive at 5 psu and spats had low survival rates at 5 and 10 psu. *M. strigata* and *M. sallei* larvae and spats did not survive at 5°C across all salinities tested, but survival rates were high for all other treatments. Under low salinity conditions though, *M. strigata* spats had low survivorship at either end of the temperature spectrum. This study suggests that the larvae and spats of *M. strigata* and *M. sallei* possessed wide tolerance limits for salinity and temperature. Coupled with their proven propensity to spread quickly, these fouling species have great potential to survive and establish populations in non-native environments.

MONDAY 25TH JUNE 2018: TRACK B

FOULING AS A VECTOR FOR INVASIVE SPECIES

1B – KEYNOTE 1

The various benefits of the fouling community:
Roles in biodiversity, trophic dynamics, restoration, and indicators of change

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As a diverse, sessile, multi-phyla community the fouling community can play multiple roles in understanding the coastal ecology on local, regional and global scales. The small size of most species and their attachment to hard substrates as adults make observation and experimental manipulation relatively easy. Movement of whole communities, alteration of species composition, and other techniques have been used to delineate natural and anthropogenic causes of variation in diversity and community composition. Simple variation in substrate depth, length of exposure, time of initial exposure, artificial disturbance, etc. have all been used to determine causes of local variation. Simultaneous exposure of substrates across site, regional, and biogeographic scales has been used to elucidate variation at these scales. The community also plays an important role in local trophic dynamics feeding on plankton and serving as prey to larger motile species. Selective feeding by different species can result in community changes if the planktonic community changes. This enables the potential of serving as an indicator of change. For example, ascidians feed using a mucous sheet, which is fairly nonselective and captures particles as small as bacteria. Their dominance in many harbors and their ability to invade ports around the world may indicate the water quality of these areas. Finally, as an integral component of hard substrate communities these species are integral to reefs and can be an important component to restoration, both using artificial substrates and natural ones such as oysters. They may serve as food for small invertebrates and fish that attract larger fish to these structures.

1B – KEYNOTE 2

Assessing patterns of secondary spread for marine nonindigenous species
and the role of vessel biofouling in North America

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Over 450 nonindigenous species (NIS) of invertebrates and algae have established populations in coastal marine waters of North America, and vessels have been a dominant mechanism (vector) for the initial introduction of these species, resulting from transfers of ballast water and hull biofouling. While considerable attention is given to the initial invasion, most of these species also have spread coastwise beyond the initial bay or port of introduction, expanding their geographic range and potential impact. We evaluated the spatial, temporal, and taxonomic patterns of secondary spread along the Pacific and Atlantic coasts of North America, using latitudinal range as a measure of spread. Overall, the frequency of secondary spread among NIS was higher on the Atlantic than the Pacific coast, possibly due to differences in distance and connectivity among estuaries for the two coasts. The latitudinal range of NIS was correlated to time since first reported invasion on the Atlantic coast but not the Pacific coast. Analysis of NIS traits and spread dynamics suggests that human-mediated transfer, and especially hull biofouling, drive much of the observed coastwise spread and range expansion in North America. Our results underscore the importance of biofouling in marine invasion dynamics and that effective strategies for biosecurity must address coastwise (including domestic) vessel traffic, including recreational and fishing vessels.

1B – ORAL 1

Managing marine pests before they get here:
New Zealand's Craft Risk Management Standard for Biofouling on Vessels

T. BATES

New Zealand Ministry for Primary Industries

Biofouling on vessels is the primary pathway for the introduction of non-indigenous marine species into New Zealand. These introductions threaten the marine environment and its economic, environmental, social and cultural values. With marine biosecurity in particular, the best line of defense is prevention, as once a marine pest gets here, it is extremely difficult and costly to eradicate. To manage the biosecurity risks associated with vessel biofouling, New Zealand's Ministry for Primary Industries (MPI) has issued the Craft Risk Management Standard (CRMS) for Biofouling on Vessels. The CRMS aims to reduce vessel biofouling by requiring vessels to take out preventative measures and maintain a clean hull before they arrive into NZ. Compliance with the CRMS can be achieved in several ways, including cleaning the vessel hull less than 30 days before arrival in New Zealand; carrying out continual maintenance of the hull using best practice, or applying MPI-approved treatments to the hull. This presentation gives an update on the regulatory tools and processes MPI is using to risk profile vessels arriving into New Zealand, and direct border management for vessels with respect to hull biofouling.

1B – ORAL 2

The past, present, and future of biofouling management in California

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The California Legislature placed a mandate on the California State Lands Commission (Commission) in 2007 to develop and adopt biofouling management regulations for vessels arriving at California ports. These regulations were adopted and implemented in 2017. During the decade between mandate and adoption, Commission staff engaged in a lengthy, transparent, science-based, stakeholder-involved process to craft a set of regulations that are protective, practical, and that align with international efforts. The regulations became effective on October 1, 2017. As vessels incrementally fall under the jurisdiction of these regulations based on each vessel's dry-docking schedule, Commission staff will continue to provide outreach and education to ease the transition to this new regulatory landscape. Commission staff will also evaluate responses to mandatory reporting forms and inspect arriving vessels to assess compliance with the new regulations with an eye towards identifying successful biofouling management strategies and opportunities to improve the regulations in the future. Over the next decade, Commission staff will continue to collect and analyze data and collaborate with international regulatory, industry, and scientific partners to refine and align international biofouling management regulations.

1B – ORAL 3

Australia's approach to managing biofouling risk

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In 2015 the Australian government introduced new legislation to manage biosecurity risk. Significantly, the new legislation changed the way biofouling risk can be managed, and as such, the Australian government has been developing new policies to manage this important pathway. Australia's biofouling policy aims to remain consistent with the IMO guidelines and is under development in collaboration with like-minded jurisdiction, New Zealand, Hawaii and California, as well as various industry stakeholders. A series of projects are being undertaken to provide the data necessary to develop informed, effective and risk based policies, these include: • Analysis of historic international biofouling data; • Estimating the non-market value of reducing the risk of marine pest incursions in Australian waters; • Surveying recreational boaters to gain an understanding of their current awareness and practices with respect to biofouling management; • Review and testing of available systems to treat internal niche areas of commercial vessels. Acknowledgements: The work presented in this study has been undertaken by the following service providers: A nationwide project to assess the non-market value to the community from avoiding marine pest incursions into Australia's waters - Australian Bureau of Agricultural and Resource Economics and Sciences. A nationwide project to improve understanding of biofouling risk and domestic recreational vessels - Australian Bureau of Agricultural and Resource Economics and Sciences. Efficacy of in-water treatment systems (Internal niches) - Biofouling Solutions Pty Ltd; Cawthron Institute

1B – ORAL 4

Risky is as risky does: Profiling vessel biofouling in a biosecurity context

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The Ministry for Primary Industries (MPI) has issued the Craft Risk Management Standard (CRMS) for Biofouling on Vessels Arriving to New Zealand, scheduled to come into force in mid-2018. The ability to recognise vessels that have potentially risky levels of biofouling is critical for the successful implementation of the CRMS, therefore MPI has developed a set of risk indicators which are being used at the border for clearance of international vessels. These risk indicators have been informative for identifying high-risk vessels, but quantitative evaluation is needed to assess indicator utility and robustness for determining compliance with biosecurity thresholds. To assess the performance of these indicators, MPI commissioned field surveys of international commercial vessels arriving to New Zealand. Over a 16-month period, 40 vessels were inspected and assessed for compliance with the CRMS short-stay biofouling thresholds. Biofouling was present on 39 of 40 vessels, occurring primarily in niche areas, and 16 vessels (40%) had substantial macrofouling (~20% cover in individual niche areas). With respect to predicting compliance with the CRMS, the initial risk indicator thresholds performed poorly - this was expected given the values were set to target heavily-fouled vessels, and not intended to flag the levels of fouling associated with CRMS non-compliance. Signal Detection Theory analyses were used to refine the high-risk indicator thresholds, which resulted in a statistically significant improvement in performance (93% correct prediction). These new thresholds and risk indicators are being further tested and trialled by MPI. (Work commissioned for this study was undertaken by Cawthron Institute.)

1B – ORAL 5

Hull Invasive Species (HIS) risk assessment tool: Big data assessment of global shipping to provide port specific actionable insight to reduce the risk of transport of invasive species

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AkzoNobel and Safinah are jointly developing a pioneering global assessment system to evaluate the relative risk of a vessel entering a port authorities waters - the Hull Invasive species (HIS) risk assessment. By combining AkzoNobel's proprietary global Fouling Challenge data and Safinah's extensive, independent knowledge of the marine coating landscape, we were able to create a dynamic, near real-time dashboard to provide early warning alerts to conscientious port authorities in order to reduce the risk of invasion by non-native species. Not intended to replace high resolution dive inspections, the Hull Invasive species (HIS) provides a port authority with a prioritized list of at-risk vessels, based on: • Vessel operation, • Environment experienced • Fouling control strategy This presentation will detail the background and methodology of this novel approach to early warning non-native species transportation, and potential applications for ports and the wider community.

1B – ORAL 6

An evaluation of small commercially available remote operated vehicles (ROV)
for undertaking surveys for invasive marine species

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Biofouling Solutions Pty Ltd. were commissioned by the Australian government's Department of Agriculture and Water Resources (DAWR) to undertake an evaluation of small commercially available ROV and drones for undertaking surveys for invasive marine species (IMS). The evaluation criteria included: 1). Retail price (must be less than aud\$80,000); 2). Capability of ROVs in challenging currents and sea conditions; 3). Ability of ROVs to detect IMS; 4). Size, weight, ease of deployment and power source; 5). Durability and serviceability; 6) ROVs must have a distributor (physical presence) within Australia. The evaluation comprised of two main components: 1) undertaking an initial desktop review according to the evaluation criteria, followed by 2) field testing the most promising ROVs. A total of 15 different ROVs were evaluated including: *seamor marine's steelhead*, *teledyne seabotix lbv150-4*, *videoray's pro 4* (standard base), and *deep trekker's dtx2* (standard package), *sealion-2*, *endura wi*, *rovee*, *videoray voyager*, *bluerov2*, *deep trekker dtg2 smart*, *videoray scout x3*, *hydroview sport*, *blueye*, *trident* and the *openrov 2.8 explorer bundle*. Seven of the 15 rovs were eliminated during the desktop review because they lacked a physical presence in Australia (i.e. *Sealion-2*, *endura wi*, *rovee*, *hydroview sport*, *blueye*, *trident* and *openrov 2.8 explorer*). Of the remaining eight, the most promising and available ROVs were tested in the field. Results of these field tests will be revealed during the presentation.

MONDAY 25TH JUNE 2018: TRACK B ICE PHOBIC COATINGS

1B – KEYNOTE 3

Designing durable icephobic coatings

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Ice accretion has a negative impact on critical infrastructure, as well as a range of commercial and residential activities. Icephobic surfaces are defined by an ice adhesion strength $\tau_{ice} < 100$ kPa. However, the passive removal of ice requires much lower values of τ_{ice} , such as on airplane wings or power lines ($\tau_{ice} < 20$ kPa). Such low τ_{ice} values are scarcely reported, and robust coatings that maintain these low values have not been reported previously. Here we show that, irrespective of material chemistry, by tailoring the crosslink density of different elastomeric coatings, and by enabling interfacial slippage, it is possible to systematically design coatings with extremely low ice-adhesion ($\tau_{ice} < 0.2$ kPa). These newfound mechanisms allow for the rational design of icephobic coatings with virtually any desired ice adhesion strength. By utilizing these mechanisms, we fabricate extremely durable coatings that maintain $\tau_{ice} < 10$ kPa after severe mechanical abrasion, acid/base exposure, 100 icing/de-icing cycles, thermal cycling, accelerated corrosion, and exposure to Michigan wintery conditions over several months. Finally, we will also discuss if it's possible to design fouling release coatings using similar principles.

1B – ORAL 7

Certain criteria for easy release

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Soft elastomeric films supported on a solid substrate are widely used in various applications related to the easy release of hard or soft materials adhering to it. These applications range from paper release coating, release of hard foulants, and, in recent years, the release of ice. While the fundamental principle underlying all release mechanisms is founded upon the science of fracture mechanics, there are important details that are also important in enhancing its performance. In real situations, it is often observed that manifestation of stress at the interface is more complex than that embodied in elementary fracture mechanics. For example, when a significant interfacial shear accompanies the pull off processes, the interfacial friction plays an important role, in which an interfacial slippage reduces the net stress needed to cause release. While surface energy provides the first landmark in selecting an easy release coating, this criterion, per se, is not sufficient, as the areal density of the load bearing chains often becomes the deciding factor both in friction and pull-off strength. An elastomeric coating with a lower entanglement crosslink density could outperform one with a high crosslink density, as the former would afford a lower density of load bearing sites. For the related reason, if a polymer is to be modified by infusing it with oily additives, a counter intuitive paradigm is that a higher molecular weight additive could outperform that of lower molecular weight additives at times, a gummy additive could be better than oil. In the backdrop, all these criteria highlight the importance of the elastic modulus of a coating that directly affects the pull off stress as it enters in the scene via Griffith equation.

1B – ORAL 8

Experimental variables, analysis, and considerations in ice adhesion testing and analysis

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Despite decades of research and the development of numerous low ice adhesion coatings, universal methods for adhesion testing and analysis are nonexistent. The materials properties of the coatings themselves influence the force required to delaminate ice from a surface, but so does the temperature, ice type, and fracture mode/geometry. Further, the analysis of the data is out of line with the physics of the tests. Without a consistent approach to ice adhesion testing and analysis, it will be impossible to reach the full potential that advanced coatings promise. Leveraging our historical role in ice adhesion testing and evaluation, the US Army Corps of Engineer's Cold Regions Research and Engineering Laboratory (CRREL) is performing research on ice adhesion testing to identify the important parameters needed to develop a rigorous quantitative analysis of ice adhesion tests. Progress towards unifying ice adhesion testing methods will be presented beginning with a discussion of the variables present during ice adhesion testing. The effect of ice microstructure, type, and temperature will be discussed; geometric aspects of testing will be emphasized. System validation and correction factors will also be addressed. With a baseline understanding of the testing variables and potential pitfalls, data analysis will be explained for ice adhesion as a materials property derived both as an adhesive strength and an adhesive fracture energy.

1B – ORAL 9

Towards the design of multifunctional icephobic slippery surfaces

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Multifunctional surfaces that possess both drag reducing and icephobic functions are rare. State-of-the-art superhydrophobic surfaces have demonstrated excellent drag reduction performance but these surfaces are rarely icephobic particularly under high humidity freezing conditions. Under these conditions, water droplets will rapidly nucleate onto the superhydrophobic surface textures, resulting in Wenzel state droplets that are strongly pinned onto the surface. Freezing of these droplets will lead to high ice adhesion owing to the enhanced solid-ice interfacial area. To resolve these issues, we report our latest development of directional slippery rough surface (SRS), which is inspired by the unique surface architectures of multiple biological plant species. Specifically, our directional SRS consists of nanotextured directional grooves in which the nanotextures alone are infused with a hydrophobic liquid lubricant. Owing to the hydrophobic slippery interface, we have demonstrated that the directional SRS is capable of rapidly removing Wenzel state droplets and significantly reducing droplet nucleation under freezing conditions & two important characteristics that underpin icephobicity of engineered surfaces. References: 1. Xianming Dai, Birgitt Boschitsch Stogin, Shikuan Yang, and Tak-Sing Wong, "Slippery Wenzel State", ACS Nano, vol. 9, pp. 9260 - 9267 (2015). 2. Philseok Kim, Tak-Sing Wong, Jack Alvarenga, Wilmer Adorno, and Joanna Aizenberg, "Liquid-Infused Nanostructured Surfaces with Extreme Anti-Ice and Anti-Frost Performance", ACS Nano, vol. 6, pp. 6569 - 6577 (2012). 3. Tak-Sing Wong, Sung Hoon Kang, Sindy K. Y. Tang, Elizabeth J. Smythe, Benjamin D. Hatton, Alison Grinthal, and Joanna Aizenberg, Bioinspired Self-Repairing Slippery Surfaces with Pressure-stable Omniphobicity. Nature, vol. 477, pp. 443 - 447 (2011).

1B – ORAL 10

Amphiphilic siloxane-polyurethane coatings for low fouling and ice adhesion

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In order to reduce the adhesion of marine fouling organisms on immersed surfaces, the concept of amphiphilic coatings is being explored. Amphiphilic surfaces have a mixture of hydrophobic and hydrophilic components and it is believed that having the right combination of multiple surface energies at the right length scale limits the ability of marine organisms to develop strong adhesive bonds to the surface. While silicone elastomers have been commercialized for fouling-release ship hull applications, and amphiphilic versions of these coatings have also been commercialized, it is of interest to develop more mechanically robust types of coatings. To address this, prior research has resulted in the development of a self-stratified siloxane-polyurethane (SiPU) coating system that has good adhesion to marine primers, is mechanically robust, and has reasonable fouling-release performance. An amphiphilic variation on the SiPU coating system was investigated that created amphiphilic coating surfaces through combining hydrophobic siloxane and hydrophilic poly(ethylene glycol) (PEG) components into the coating. Laboratory fouling-release studies showed systematic trends in bio-adhesion as a function of coating composition. This same set of coatings was subjected to ice adhesion measurements and a number of the coatings had very low ice adhesion values. Remarkably, the trends in ice adhesion as a function of coating composition paralleled the trends in barnacle adhesion, indicating that the underlying coating design concepts for marine coatings and ice phobic coatings are similar. The Office of Naval Research supported this research under grants N00014-12- 1-0482, N00014-13-1-0633, N00014-13-1-0634, and N00014-16-1-3064.

1B – ORAL 11

Phase change materials for ice mitigation

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Novel ice-phobic coatings were developed that employ phase change materials (PCMs). PCMs exist in a passive or dormant state under most environmental conditions, but PCMs undergo solid-solid phase changes over a narrow temperature range slightly below the temperature at which ice formation occurs. As ice forms on the surface, some of the latent heat of freezing passes to PCMs. This heat is absorbed by the PCMs and causes local strain on the coating surface and results in removal of the ice. Minimal force (<1psi) is required to remove ice from test surfaces treated with PCM ice-phobic coating technology.

1B – ORAL 12

Exploring a connection between marine biofouling and ice adhesion

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Minimizing adhesion of unwanted adherents has been the subject of a great deal of research and development because “self-cleaning” would be of great value for marine and aerospace applications. Unwanted adherents run the gamut from shipboard ice forming under arctic-like conditions to fouling by soft (seaweed) and hard (barnacles) marine organisms. Polymeric systems including fluoropolymers, silicones and polyurethanes have shown great potential for fouling release. For example, Ober has found that surface active PDMS systems modified with PEG and fluoroalkyl side-chain groups are effective for soft fouling release. Fundamentals of adhesion for rigid adherents are better understood than soft adherents where adhesion is typically evaluated using a water jet system. For hard adherents including ice and barnacle-like epoxy, the Wynne laboratory developed a method to determine quantitatively adhesion using a commercially available instrument. Variables affecting adhesion were coating thickness, stiffness, surface free energy and morphology. Considering rigid adherents, the Kendall model was adapted to relate peak removal force (P_c) with work of adhesion (w_a), modulus (K), thickness (t), and radius (a): $P_c \propto \pi a^2 ((2w_a K)/t)^{1/2}$. On the other hand, laboratory methods and theory for the study of soft adherents are not well developed. This presentation provides an overview of these research studies in the Wynne lab that involve both ice release and removal of barnacle like epoxy simulants. Preliminary studies of a laboratory method for adhesion of soft fouling is described along with preliminary results of adhesion of ice for an unconventional and economical nanostructured coating. (KJW gratefully acknowledges funding provided by the National Science Foundation, the Office of Naval Research and the VCU School of Engineering Foundation.)

1B – ORAL 13

SLIPS Coating on aluminum heat exchangers for energy-efficient refrigeration systems

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SLIPS creates a stable and immobilized liquid lubricant overlayer (LOL) and this "liquid surface" provides extremely slippery (low contact angle hysteresis) and non-sticky surfaces against a wide range of viscous contaminants, biofouling, ice and frost. Refrigeration systems typically require frequent defrost cycles to remove frost and ice that naturally forms on the surfaces of evaporator coils that quickly compromises the efficiency of a heat exchanger. We will present a scalable SLIPS application method developed for an aluminum evaporator coil commonly used in refrigerator systems, and demonstrate how SLIPS coated-heat exchanger can delay ice nucleation, decrease overall accumulation of ice by fast shedding of condensed droplets, and accelerate defrosting on heat exchanger surfaces. We have observed reduction of the total energy consumption close to 30% in a single cycle defrosting and in a subsequent cooling cycle in a residential refrigerator unit, while simultaneously providing less temperature fluctuation to result in higher quality of refrigeration for high value products (e.g. fresh produce and meat, expensive drugs, ice creams). This project was funded by ARPA-E (Contract no. 0670-7096, Oct. 2013 - Apr. 2015).

TUESDAY 26TH JUNE 2018

PLENARY 2

Antifouling & fouling release coatings: Towards more environmentally friendly
& long-term efficiency strategies

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Marine biofouling is a worldwide problem, costing billions of dollars per year in numerous civil or military marine applications. For the marine shipping industry, Self-Polishing Coatings (SPC) and Fouling Release Coatings (FRC) are current strategies used to prevent and control the natural process of colonization of ship hulls. On the one hand, SPCs are mainly composed of polymers bearing seawater hydrolyzable side groups leading to the renewal of the coating surface by an erosion process and to the control of the release rate of active molecules. Their antifouling efficiency depends on the diffusion of water into the coating, the swelling/dissolution of the hydrolyzed polymer chains and the diffusion of the dissolved active compounds to the coating surface. On the other hand, FRCs are mainly composed of a poly(dimethylsiloxane) (PDMS) elastomer matrix. Their specific fouling release property has been related to the hydrophobicity and low surface energy of PDMS, also influenced by parameters including surface roughness, elastic modulus and thickness of the coating. Over the recent past, research into novel antifouling and fouling release strategies with lower environmental impact and higher performances has gained significant attention. In this lecture, the present state of knowledge in this area will be summarized. Basic and applied research advances in coatings will be presented. Particularly, a review of the strategies developed at MAPIEM laboratory will be discussed. Ambiguous surfaces will be considered through the design of block copolymers to provide access to a wide variety of materials with tunable hydrophobicity, water resistance and mechanical properties. Several approaches under development will be presented including the use of hybrid surfaces displaying SP and FR properties, bio-inspired polymers, and micro-structured redox addressable polymers.

TUESDAY 26TH JUNE 2018: TRACK A HYDRODYNAMICS & DYNAMIC TESTING

2A – KEYNOTE 1

A rational approach to predicting the effect of antifouling systems on “in-service” ship performance

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Based on past and current research within his groups in Newcastle and Strathclyde Universities, the author presents a rational approach, which is based on the combination of an experimental and a computational procedure, to predict the effects of modern-day antifouling systems on “in-service” ship performance. This is further supported by a validation approach that involves the development of a dedicated performance monitoring and analysis systems on-board a full-scale research vessel which is currently underway. Here the word “rational” reflects ship hull (and propeller) conditions as well as the approach to predicting the effect of the hull coating systems under such conditions. The proposed approach arguably provides a full solution to the complex ship performance problem. It is “rational” in terms of tackling the main features of modern-day hull coating systems with the aid of bespoke experimental testing facilities and state-of-the-art computational methods. The proposed approach is generic and can be applied to any ship type and hull coating system in the presence of biofouling and it may even be combined with passive drag reduction systems. This approach involves both the combination of experimental data from flat test panels treated with representative surface finishes and extrapolation of this data to full-scale. However, for more accurate and direct estimation of performance prediction at full-scale, the extrapolation procedure needs to be replaced with Computational Fluid Dynamics (CFD) methods, especially for deteriorated hull surfaces due to fouling; at present, such experimental data are still required. The rational nature and hence strength of the proposed approach is to represent the effect of the actual hull surfaces “in-service” by using state-of-the-art experimental methods and data. This provides the option of an extrapolation procedure for practical performance estimations and also enables the use of CFD methods by avoiding the most difficult barrier of describing the actual hull surface numerically in CFD. Validation of the proposed approach requires full-scale data to be collected using a bespoke ship performance monitoring and analysis system which is dedicated to assessing the effect of coating systems in the presence of fouling. Such a system is under development as detailed in an accompanying presentation.

2A – ORAL 1

An assessment of skin-friction drag over a recently cleaned ship hull
under steady cruising via in-situ laser based measurement

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A recent study on assessing the drag penalty due to hull roughness from a recently cleaned and painted ship hull is reported. The experiment is conducted on an operating ship (Roll-on/roll-off ferry) under steady cruising by measuring the velocity profile directly over the hull using a Laser Doppler Anemometer (LDA). The use of LDA allows a non-intrusive measurement without perturbing the flow over the ship hull. Here a window was installed on the underside of the hull, located approximately 25.5 m downstream of the bow of the ship during its annual dry-docking and hull cleaning (Rex around 80,000,000). The window is enclosed within a water-tight enclosure that is constructed between the double bottom hulls which also houses the LDA and computer controlled traversing rail. The set-up allows the outward-looking LDA to measure the velocity gradient in the turbulent boundary layer formed over the hull (during steady sailing) across some traversable distance from close to the hull surface, to at least the end of the logarithmic region. Initial results show that there is a substantial increase in skin-friction drag for a recently cleaned ship-hull compared to the hydrodynamically smooth surface.

2A – ORAL 2

Joint testing to fast-track antifouling innovation into hull efficiency

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CMA CGM group is committed to minimize its environmental footprint by incorporating innovative technologies into its global fleet. In addition to its recent order of large LNG fueled containership together with a global emission improvement plan, the group is also investigating efficient fouling control solutions. Selection of an effective fouling control coating is extremely complex. The fouling ecosystems are moving targets whose strength fluctuate with sailing route (season, water temperature, nutrients, light) and operational conditions of the vessel (speed, activity, draught). To better tackle this complexity it is vital to reduce the gap between the testing facilities and real conditions. Therefore the evaluation of antifouling paints in real conditions becomes necessary to develop and improve the antifouling paints. Considering the aforementioned, antifouling paints supplied by HEMPEL were tested on CMA CGM large container ships (almost 400 meters long) operating between Asia and North Europe. Real life performance of these paints revealed by the diving inspection provided insights on the mechanism of the same under specific sailing conditions. The results to be presented show that these not only helps CMA CGM to improve the selection of the antifouling paint to be applied on CMA CGM fleet, but also accelerates HEMPEL capacity to translate innovative technologies into proven solutions for fouling control.

2A – ORAL 3

Experimental quantification of drag change of commercial coatings under the effect of surface roughness and soft fouling

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Chalmers Univ. of Technology, Dept. of Mechanics and Maritime Sciences,

The performance of ships will be adversely affected by the excessive hull roughness to an extent where financial penalties will be incurred. It is beyond the bounds of possibility to achieve a perfectly smooth hull, as the ship building process and paint application will leave their “fingerprint” on the surface. The roughness of the hull may vary from fine to coarse according to the substrate finish, the coating application methods used and further driven due to exposure to aggressive sea environment. The drag performance data of newly-applied and clean coatings is not sufficient to fully reflect the drag characteristics and efficacy of marine coatings over a typical period between dry-docking. Usually during this period, the increase in surface roughness and development of different fouling stages on marine coatings occur. Therefore, the study focuses on comparison of drag characteristics of hull coatings with relatively smooth, coarse roughness finishes and fouling conditions using time- and cost-efficient approach. The study describes experimental tests carried out to quantify the drag change of commercial coatings due to the presence of physical and biological roughness. Firstly, biocidal and non-biocidal coatings with relatively smooth and coarse roughness finishes are tested. Secondly, mentioned coating types and roughness ranges are exposed to fouling growth to explore the extent of algae fouling and its effect on drag characteristics. The results of the study may be useful to estimate the added drag and overall fuel penalty for ships with various coating roughness ranges and soft fouling. Moreover, the study also aims to suggest the shear forces required to remove algal fouling from different coating types with various roughness ranges.

2A – ORAL 4

An investigation of marine biofilm effects on the roughness and drag characteristics of surfaces coated with different sized cuprous oxide particles

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In this paper, pressure drop measurements were conducted to evaluate the effect of biofilm on the drag characteristics of the surfaces coated with different size cuprous oxide particles as antifouling. Four different sizes of cuprous oxide (D50 ranging from 12 μ m to 60 μ m) were applied on Newcastle University flat test panels (600mm x 210mm in size L x B) by spray application using a suitable binder. To achieve biofilm growth naturally under “in-service” conditions, these test panels were assembled on the research vessel, Princess Royal, for six months dynamic/static deployment in six weeks increments. The friction drag penalties on these panels, caused by biofilm, were evaluated by pressure drop measurements in the Newcastle University turbulent flow channel under dynamic flow conditions at different speeds. The test section of the turbulent flow channel was 10 x 180 x 2700 mm in height, width and length respectively. The roughness characteristics of all the test panels were analysed by an optical roughness profilometer to assess the detailed roughness statistics of the surfaces. Based on the analysis results of the systematic roughness and pressure drop measurements, a correlation was established between the relevant roughness parameters and the drag of the tested surfaces. This provides further insight into the effect of the biofilm on the drag characteristics of antifouling surfaces coated with varied size of cuprous oxide particles as well as an opportunity to predict the effect of the different size of cuprous oxide particles on the drag of ship hulls in the presence of biofilm.

2A – ORAL 5

Effect of barnacle density on hydrodynamic drag

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An experimental study was conducted on rough-wall, turbulent boundary layer flow. Varying planform densities of idealized, model barnacles (i.e. truncated cones) were investigated. Element densities studied ranged from 10% to 79%. Detailed turbulent boundary layer velocity statistics were recorded with a two-component LDV system on a three-axis traverse. The equivalent sand roughness height and skin-friction coefficient were determined and compared with the estimates from existing roughness element drag prediction models including Macdonald et al. (1998) and other recent models. Implications of these data for ship powering and in-water hull cleaning are considered. (Funding provided by the U.S. Office of Naval Research and the National Defense Science and Engineering Graduate Fellowship).

2A – ORAL 6

Dynamic assays to assess the accumulation of biofilm formers on coating chemistry candidates in the lab and in the field

A. ROSENHAHN (1), K. NOLTE (1), J. KOC (1), J. SCHWARZE (1), R. WANKA (1), W. YU (1),
A. ANUTHALINGAM (1), H. GARDNER (2), K.Z. HUNSUCKER (2), and G. SWAIN (2)

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When new Materials are developed to control marine fouling, their ability to weaken the attachment of biofilm forming organisms is one of the key properties to be tested. Several techniques have been developed in the past to probe attachment strength of cells [1]. Especially microfluidic test systems [2] offer several advantages, such as small sample area, small amounts of target species, and high throughput. We developed a microfluidic platform to test bacterial and diatom adhesion on coatings [3,4]. Cells are driven through a microchannel at a precisely controlled flow rate and at a constant concentration and both, accumulation and detachment can be monitored by video microscopy. As the assay is multiplexed and multiple channels can in parallel be exposed to the same diatom or bacterial suspension, surfaces can be directly compared. The shear ranges identified in the microfluidic experiments were used to develop a dynamic field test based on a rotating disk setup that allow s to compare the lab results against the development of early fouling communities in the field. Research funded by ONR N00014-16-12979, Mercur Pr-2015-0018, DFG RO2524/4-1 [1] L. Marcotte, M. Tabrizian, ITBM-RBM 2008, 29, 77 [2] D.P. Bakker, A. van der Plaats, G.J. Verkerke, H.J. Busscher, H.C. van der Mei, Appl. Envir. Microbiol. 2003, 69(10), 6280 [3] M. Alles, A. Rosenhahn, Biofouling. 2015, 31, 469-480. [4] K. Nolte, J. Schwarze, A. Rosenhahn, Biofouling 2017, 33(7), 531.

2A – ORAL 7

Measurements of biofouling drag using a 2-D channel flow apparatus with models of bio-fouled panels

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A 2-sided flow channel is used to measure the drag of model bio-fouled panels printed from laser scans of fouled ship hull sections. The panels include models of barnacles, oysters, and tubeworms with variations in fouler spatial density and size scales. Skin friction coefficients derived from the channel pressure gradient are measured for a range of Reynolds numbers and compared to smooth-wall values measured with polycarbonate plates. The differences are converted to values of equivalent sand grain roughness using analytic log-law wall boundary layer models. The roughness values are then compared to other published data.

2A – ORAL 8

Using CFD to predict ship resistance due to biofouling

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We have been using a computational fluid dynamics (CFD) approach to examine, for a typical US Navy destroyer hull, the impact of biofouling roughness on resistance. We implemented a roughness wall model, based on the equivalent sandgrain roughness (k_s) approach that accounts for the log-law solution for a turbulent boundary layer over biofouled surfaces, into a viscous flow solver called NavyFOAM. Two-phase, unsteady Reynolds Averaged Navier-Stokes (RANS) roughness simulations, previously validated against existing flat plate data from towing and channel tests, were used to examine the impacts of varying levels of biofouling homogeneously and heterogeneously distributed across the hull. The hull was divided into sections - bow, sides, bottom, stern, and transom - defined by Navy technical documents. Resistance was first evaluated for five values of k_s each distributed homogeneously across the hull, and changes in skin friction quantified both for the entire hull and for each section. The results compared well with previously-published estimates for known values of k_s . The divided hull was then used to explore the effects of heterogeneous biofouling by assigning different k_s values to the various hull sections. In addition, we quantified the effect of biofouling along the waterline on total resistance. These simulations can be used to study the effects of heterogeneous accumulation of biofouling as is regularly observed in the field, or the benefits of targeted hull cleaning efforts. This research was funded by the Naval Surface Warfare Center Carderock Division as part of the Naval Innovative Science and Engineering (NISE) program under the direction of Dr. J. Price.

2A – ORAL 9

Dolphin-inspired compliant coatings for drag reduction of ships

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Surface friction is responsible for 50-80% of the total drag of a ship. The flow condition over the bow region is laminar but it quickly turns into the turbulent regime as the water travels along the hull. The turbulent flow regime causes approx. 10 times higher friction compared to laminar flow. By postponing the transition from laminar to turbulent flow and thus increasing the ratio of laminar flow, a significant reduction of drag could be achieved. The best example for transition delay from nature is the dolphin, that reaches high underwater speeds and the flow around the body is predominantly laminar. It was assumed that special mechanical properties of the dolphin skin play a key role by damping the formation and development of Tollmien-Schlichting waves via energy absorption thereby delaying the transition. This effect could however not be reproduced in later studies. In the recently accomplished cooperative research Project Flipper the combination of numerical simulations, coating material development and hydrodynamic experiments lead to the first successful demonstration of a passive coating that reduces the drag of a ship model significantly. The coating consists of two layers, each with very specific mechanical properties. One layer with a thickness of several millimeters mimics the dolphin blubber and the outer more rigid layer reflects the dermis. The way from numerical simulation of hydrodynamics over simulation of material parameters, material development and successful demonstration in a water tunnel will be presented. (Funding provided by the German Federal Ministry for Economic Affairs and Energy).

2A – ORAL 10

Selecting a field test for differentiating the performance of fouling control coating prototypes:
Static vs dynamic

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As the list of restricted biocides in antifouling coatings continue to grow, there is an ever increasing need to develop fouling control coatings (FCC's) that utilize fouling release properties to provide an effective solution against the accumulation of biofouling. One of the challenges in developing these novel coatings is selecting a field test that can sufficiently differentiate coating performance over a short-term testing interval. There are currently two basic types of field tests used to screen prototype coatings: 1) static immersion and 2) dynamic immersion. While static tests can be relatively simple to perform, the immersed coatings are only exposed to hydrodynamic shear induced by tidal and wave/wind generated currents. The shear stress from these currents are typically an order of magnitude less than what the coating would experience on a moving ship and may not induce any fouling to release. Conversely, dynamic tests can be designed to expose the coating to a variety of hydrodynamic shear stress similar to what would be experienced on a moving ship. These tests, however, are more complex to implement and operate. Both types of tests are compared across multiple field studies to explore if the complexity of dynamic testing provides sufficiently more resolution in differentiating the performance of prototype FCC's with fouling release properties. The theoretical hydrodynamic considerations in the design of a dynamic test and the application of results in predicting FCC performance at full-scale are also discussed. This study aims to assist the applied researcher designing an accelerated field testing plan for the development of an FCC based on fouling release properties. This work is in part funded by ARPA-E (Contract no. DE-AR0000759) and completed with generous support of Office of Naval Research.

2A – ORAL 11

Static/dynamic test method to evaluate idle day's tolerance of hull coatings

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Antifouling performance of hull coatings is often (strongly) reduced when ships are laying idle for periods longer than a few weeks. Both self-polishing coatings (SPC) as well as fouling release coatings (FRC) are developed for optimal performance when the ship is actively sailing. In order to see how hull coatings perform after idle times of several weeks a dedicated test protocol was set up in which coated panels were exposed to a combination of dynamic and static ageing regimes. Dynamic ageing was done at a rotor drum system in natural seawater and static ageing (i.e. simulated idle time) was performed in raft exposure tests. Performance of hull coatings was assessed on two aspects: how much fouling develops on the panels after different idle times and at what (sailing) speed such fouling releases. Nine hull coating systems were investigated. The test protocol involved 2 dynamic ageing times, 2 static raft exposure periods, 2 immersion depths and 4 different rotation times at 2 speeds at a rotor system in fouling release tests. Longer idle times gave more severe slime and algal fouling on a number of paints, especially on panels exposed at 30 cm depth. Two other paint systems, however, collected very little fouling even after 10 weeks raft exposure. Except for the latter two paints, fouling release could not be accomplished by rotation at 8 knots. At 15 knots rotation speed four paint systems got almost clean after 5 minutes of rotation already. The presentation will illustrate further details on this methodology to investigate the idle day's tolerance time of ship hull coatings.

2A – ORAL 12

Can the screening process for fouling-release coatings be improved to better predict ship-scale performance?

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Fouling-release (FR) coatings typically represent a biocide-free approach to fouling control for ship hulls. Rather than prevent the attachment of organisms, the coatings reduce adhesion such that fouling is shed while making way. Over the last 20 years the U.S. Navy has installed FR coatings on a small number of ships, but has seldom observed reliable performance despite favorable results from screening tests. These results appear to be linked to aspects of ship operational tempo and speed-time profile. As new FR coating technologies are introduced, the U.S. Navy needs improved screening tests that accurately predict performance for its ships' particular operational profile. An evaluation was completed of several different screening tests for FR coatings including observing the release of biofouling when subjected to flow and measuring the adhesion strength of recruited hard fouling. The goal was to make data-driven recommendations to improve the ability of panel testing to predict coating performance at ship-scale. When hard fouling became established on the tested commercial FR coatings, there was limited release when subjected to flow at 10, 20 and 30 knots. Coatings which were able to effectively reduce the rate of hard fouling accumulation performed better during both panel testing and larger scale applications.

2A – ORAL 13

Comparative analysis of antifouling coatings on ship's hull

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Protection of steel structures is a major concern of ship owners and commercial operators due to responsive behavior of metals in a marine environment. Uncoated metals are generally more vulnerable to such environment. This research attempts to determine the efficacy of anti-fouling coatings when applied to ship's hull. Corrosion and Biofouling are the two main aspects that have a profound effect on the structural properties of metal and hull efficiency. All products claim to be the very best, however, every product differs from others in their technical aspects such as material composition, percentage of volume of solids, DFT, durability, adhesion, color, ease of application, resistance to fouling and service periods. Hence, field tests are necessary to evaluate the performance of the coatings in different flow field conditions. The use of artificial panels to study biofouling in natural environments is important for evaluation of antifouling systems and to test the efficacy of different coatings. The panels from different manufacturers should be tested alongside each other in marine environments that are reflective of the actual environments where the coating systems are to be used for comparative analysis. It is suggested to conduct the panel testing at least for a period of 6 months before drawing to any conclusive arguments, as this would be the minimum amount of data required to be able to assess real-world condition testing and to verify different outcomes from different areas of the world.

TUESDAY 26TH JUNE 2018: TRACK B POLICY & REGULATIONS

2B – KEYNOTE 1

Chemical regulation: The need for a holistic approach

G. PROWSE

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The presentation explores the relationship between different regulatory frameworks and their impact on industrial coatings use. How competing regulations can block the development of effective solutions to support the established protection goals and ambitions of policy makers and how conflicting regulatory approaches can work against achieving those environmental ambitions. The maritime industry faces a rapidly expanding regulatory regime with increasingly sophisticated regulatory requirements and variation at local, regional and global levels. The need for smarter solutions to fouling and corrosion control that maximise asset protection whilst minimising environmental impacts has never been clearer.

2B – ORAL 1

US-FIFRA versus EU-BPR: An incomplete comparison

L. JONES

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An early version of FIFRA (1947), requiring pesticides registration for interstate commerce, also established a rudimentary set of labelling provisions. Concerns regarding toxicity later prompted significant changes leading to the current Federal Insecticides, Fungicides and Rodenticides Act (7 U.S.C. §136 et seq.). The Biocidal Products Regulation ((EU) No. 528/2012) is a relative newcomer, yet with a broad history starting with separate country laws, followed by the Biocidal Products Directive (98/8/EC) requiring transposition into national legislation, which finally evolved into a Regulation, directly applicable to all EU countries. Comparing a metaphorical senior citizen with a 5-year old toddler seems quite a challenge, but an interesting exercise. With dossier evaluation now ongoing for many antifouling paints containing existing active substances under the BPR there is some basis for comparison with FIFRA in terms of procedures and requirements. As is always the case with comparisons, it will be enlightening to point out specific differences between the two regimes, or, different approaches by which each system aims to achieve the same overall goals. The presentation will focus on items either pertaining to antifouling, impacting on procedures or affecting market access and on items which may appear counterintuitive, unexpected, illogical, unreasonable, or even absurd when looking from the other side. Amongst the covered subjects: main application categories, guidance, mutually unknown concepts such as inert ingredients, substances of concern, biocidal product families, exclusive use and exclusion criteria. The presentation includes a mini-dictionary of biocides/pesticides terminology to help people heavily rooted on one or the other side to still understand each other. Not a luxury, imagining that even something simple like a 'new active substance' (or should I say new active ingredient) does not mean the same across the Atlantic.

2B – ORAL 2

Understanding your role in the regulatory process as an expert, advocate, and stakeholder

K.S. GOETZ

Washington State Department of Ecology, Hazardous Waste and Toxics Reduction Program
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The regulatory process does not exist in a vacuum. Lawmakers and regulatory agencies depend on input from industry and subject matter experts, environmental and business advocates, and the general public. In order to effectively participate in and contribute to this process, you must understand how it works. This presentation will introduce the audience to the regulator's perspective on adoption of laws governing antifouling coatings. It addresses three important areas for participants to consider: (1) the regulatory framework and authority involved; (2) the applicable regulatory process and relevant procedures; and (3) the associated regulatory context, including relevant stakeholder interests and historical information. The presentation discusses each of these concepts using recent Washington State legislation as a case study and provides guidance to participants on how to develop and respond to regulatory proposals on antifouling coatings.

2B – ORAL 3

Modelling the real world

K. LONG

RCL, Loanhead, U.K.

As part of the policy ambitions of the BPR the risk assessment should define a reasonable worst case determination of the PEC value. A number of potential marina scenarios have been proposed and significant debate continues regarding whether these scenarios reflect a reasonable worst case, or are excessively conservative in their approximations of the PEC value compared with the real world situation. This paper sets out to review and collate existing monitoring data for key antifouling active ingredients determined for European marinas and to use that data as a bench mark to validate the PEC values determined using the marina scenarios that are available for use in regulatory decision making as part of the approval process for antifouling paints. Currently there have been few attempts to carry out this exercise for the newest models; this paper will provide a valuable insight into the validity of the models for judging the potential environmental impact of antifouling paint active ingredients.

2B – ORAL 4

Regulating coatings

N. BLOSSOM

American Chemet Corporation, East Helena, MT, USA

Regulations covering traditional antifouling coatings and their active ingredients are being developed by many national/regional Authorities, in many cases mindful of the balance between the need to control biofouling and the sustainability of the aquaculture, pleasure craft and commercial shipping industries. This presentation will provide a summary of the key regional management approaches and proposed regulations, with an overview of the interrelationships between of them. Conclusions on recent assessments, and their implications for the global industry will be addressed.

2B – ORAL 5

Three and half decades of experience on ecological issues near cooling water discharge area of a nuclear power plant

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One of the major environmental concerns of power plants is the discharge of heated water along with biocides, when discharged into the nearby aquatic system is bound to have adverse effect on the flora and fauna present in the receiving water body. Madras Atomic Power Station (MAPS), a Pressurized Heavy Water Reactor (PHWR), of 470 MW (e), capacity, located at Kalpakkam, south east coast of India has been operating since 1984. Seawater at a rate of 35 m³/sec is used for cooling the condenser and process water heat exchanger. The coastal water supports significant amount of biofouling in the cooling water systems of MAPS. Low dose continuous chlorination is practiced for biofouling control. The author has been carrying out researches on various ecological aspects such as; impact of power plant discharges on the coastal water quality, distribution of thermal effluents in the coastal waters, phytoplankton recovery in the discharge area, estimation of chlorine demand, residual oxidant & chlorination byproducts in the discharge area, challenges in the measurement of water temperature in the mixing zone of outfall, assessment of heat impacted zone and impingement of marine organisms while passing through the cooling water system, since 1984. The talk will revolve around the extensive research work not only carried out by him on the above topics but also work available from India focusing on ecological & legal issues in tropical power plant discharge area. The talk will also touch upon areas of research needed to strike a balance between the operational need and ecological cum environmental concern.

TUESDAY 26TH JUNE 2018: TRACK B
 MACRO & INTEGRATIVE BIOLOGY: SESSION 2

2B – ORAL 6

Temporal variation in the recruitment and growth of biofouling organisms
 at Port Canaveral, Florida

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Understanding the early stages of biofouling and the relationship to ambient conditions will help in the development of targeted antifouling solutions. A study was designed to investigate the relationship between recruitment and growth of fouling organisms to changes in salinity and temperature at Port Canaveral, FL. Every month, six optically clear, polycarbonate panels (20 x 10 x 0.15 cm) were immersed for a period of three months to observe how the community changed through time. Each week, panels were photographed and the backs of the panels scanned on a desktop scanner. Panel scans enable the base of the organisms to be observed through the clear polycarbonate allowing for identification of new recruits and tracking their rate of growth. The panels were weighed and visually assessed for percent cover by macrofouling organisms. Temperature and salinity were recorded by a water quality sensor every half hour. Statistical analyses utilizing multivariate statistics, repeated measures ANOVA and correlation analysis were used to describe the differences in community structure, fouling pressure, growth rates and relationships to the seawater temperature and salinity. The data demonstrated that changes in biomass were related to the community structure and environmental conditions. (Research funded by ONR Grant N00014-16-1-3123 and the ASTM Student Project Grant Program)

2B – ORAL 7

Biofouling by sessile macro-organisms on offshore buoys
 east of the Leizhou Peninsula, in northern South China Sea

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An investigation on marine fouling on offshore buoys east of the Leizhou Peninsula, the northern South China Sea was conducted in late August 2016. A total of 35 sessile species were identified and the dominant species were *Anthopleura* spp., *Brachidontes variabilis*, *Balanus reticulatus*, *Perna viridis*, *Megabalanus volcano*, and *Megabalanus tintinnabulum*. The biomass ranged from 3994.2~8641.72 g/m² and there was no significant difference among groups. Meanwhile, the Shannon-Wiener diversity index (H'), Margalef's species richness index (d), and Pielou's evenness index (J') of the community structure ranged from 1.49~2.99, 1.34~2.68, and 0.38~0.64, respectively. A little bit of the pedunculate barnacles *Lepas anatifera* and *L. anserifera* were collected in Buoy 1 deployed 42 km offshore. However, the sessile fouling communities on Buoys 4 and 7 (35 km and 30 km offshore, respectively) were composed of littoral species. In general, the fouling characteristics of sessile macro-organisms are closely related to the factors such as distance from shore, sampling season, water depth, light, local current conditions and open extent of waters.

2B – ORAL 8

Multivariate analysis of attachment of biofouling organisms in response to material surface characteristics-field experiment

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Non-toxic non-fouling coatings offer an environmentally-friendly alternative to biocide-containing antifouling paints and utilize properties such as surface chemistry or topography to provide an unfavorable surface for organismal attachment. Previous laboratory assays with several species of biofouling organisms were used to identify key surface characteristics (surface energy, surface charge, and the dispersive component of surface energy) determining attachment patterns. We have now extended these investigations to the field. In nature, substrates become fouled with a conditioning film or biofilms almost immediately upon immersion which may alter the surface characteristics of the substrate and thus change the pattern of organismal attachment. We examined the attachment of biofouling organisms on coated glass rods at differing durations of immersion in order to determine if/how the effect on attachment of particular surface characteristics changed over time. Coatings that were submerged for 1, 3, or 5 days recruited five larval groups: barnacles, hydrozoans, bryozoans, bivalves and tubeworms. The number of larvae attached to the coated glass surfaces increased over time, but multivariate analysis of larval attachment indicated that the coatings had a significant effect on attachment at all immersion durations. The surface energy and the dispersive component of surface energy became more influential over time. Negatively charged surfaces were distinguishable from neutral surfaces throughout the course of the experiment, while positively charged surfaces were not as easily distinguishable from neutral surfaces. This research was funded by the Office of Naval Research and the Navy Undersea Research Program.

2B – ORAL 9

Comparing critical removal stress of bryozoans and barnacles at two static-immersion test sites

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Biofouling is spatially and temporally variable resulting in impacts to man-made structures based on geographic location. Coatings which are commonly used to prevent fouling vary in performance due to the specific adhesion mechanism of different fouling species. The development of effective foul-release coatings that function well across variable marine systems requires examination of multiple fouling species at different geographic locations. To date, most screening of coatings in the field occurs by measuring the critical removal stress of hard-fouling organisms such as barnacles, tubeworms, and bivalves. Here we report on the use of encrusting bryozoans as a new species for evaluation of coatings at field sites. Specifically, we tested whether there were differences in adhesion strength between barnacles and encrusting bryozoans from two field sites, one in Florida and one in California, using commercially available silicone-based foul-release coatings. Encrusting bryozoans had lower adhesion strength than barnacles at both static immersion test sites. Additionally, while the overall trend between barnacles and bryozoans was the same at both test sites, the magnitude of critical removal stress was different, suggesting that different species within the same taxonomic group could possess different adhesive properties. Lastly, adhesion strength was significantly different between two commonly tested encrusting bryozoan species in California. Our study suggests that encrusting bryozoans are another good model organism for testing the efficacy of coatings. Understanding how foul-release coatings perform across a broad spectrum of fouling organisms is necessary to developing coatings that perform well in naturally dynamic systems.

A keystone enzyme in estuaries: Trypsin and its roles at a variety of scales

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Trypsin, an endopeptidase, is an ancient and ubiquitous enzyme. Trypsin and its peptide products are central in physiological cascades including blood clotting, and the innate immune response. Trypsin and its products arginine and lysine carboxyl-terminal peptides are important in signaling. Roles range from signaling and communication in marine animals to in organizing breeding aggregations and organizing estuarine communities. Examples include predator attractants, shell cues for anemones and hermit crabs, larval settlement cues and pheromones for gregarious animals like barnacles and oysters, crustacean larval release pheromones, curing and signals in biological glues, biofouling management by crustaceans, feeding stimulants and mechanism in deposit feeding and body odors. Trypsin is a keystone enzyme because it and its products are central to the functioning of estuarine ecosystems. (Funded in part by the US Office of Naval Research, Sea Grant, NSF, and DR.).

TUESDAY 26TH JUNE 2018: TRACK B MANAGEMENT OF VESSEL FOULING (GROOMING & PREVENTATIVE TECHNOLOGY)

2B – ORAL 11

Advantages of proactive ship hull grooming from a biologist's perspective

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Ships will foul regardless of duty cycle. Most in-service ships develop biofilms and if they remain idle for long periods of time they will typically accumulate significant amounts of hard fouling. The accumulation of fouling creates both hydrodynamic penalties and increases the risks for invasive species. Biofouling that develops on ship hulls is typically managed by a reactive underwater cleaning program. These are often aggressive, can damage the coating and only occur after the ship is already operating under a fouling penalty. Grooming has been defined as the proactive, gentle, habitual and frequent mechanical maintenance of a ship hull to keep it in a fouling free condition. Over the past decade, the U.S Office of Naval Research, has provided funding for the development of “grooming” as a method to control fouling. This talk will focus on understanding the ecology of the fouling community to guide the development of grooming technology, specifically: what are the forces required to groom, what frequency of grooming is required to prevent settlement, how does the growth vary with spatial and temporal variations, how does grooming interact with different classes of fouling control coatings and ship operational schedules, what are the implications for invasive species transport, and how does grooming affect coating roughness and drag? This work was funded by the Office of Naval Research (Grants # N00014-16-1-3123 and N00014-16-1-3050).

2B – ORAL 12

Investigation of two ship hull coatings subjected to grooming
under static and dynamic immersion

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Cruise ships operating in warm waters typically develop biofilm and algae fouling despite regular steaming intervals at high speeds. Two ship hull coating types (a smooth hard coating and a silicone fouling release coating), as well as an epoxy control, were subjected to static and dynamic immersion at Port Canaveral, Florida for a period of 5 weeks. The dynamic immersion facility included both a sunlit and a shaded portion, and was operated with two daytime stops per week to represent a cruise ship schedule. A portion of both static and dynamic immersion surfaces were subjected to weekly grooming as a method to aid in the control of fouling without damaging the coating. Results showed all ungroomed surfaces subjected to both static and dynamic immersion experienced fouling, and groomed surfaces had reduced or no fouling. The groomed silicone fouling release coating exposed to dynamic immersion, and the smooth hard coating exposed to dynamic immersion in the shade were free of fouling.

2B – ORAL 13

Controlled shock waves for underwater hull grooming: A feasibility study

X. SUN and K. WANG

Kevin T. Crofton Department of Aerospace and Ocean Engineering, Virginia Tech, Blacksburg, VA 24061, USA

This talk presents a theoretical and computational study on the use of controlled shock waves for hull grooming, focusing on the feasibility of removing hard and soft fouling organisms settled on silicone-based fouling release (FR) coatings or copper-based anti-fouling (AF) coatings. The basic hypothesis is that given the drastically different acoustic and mechanical properties of fouling materials and the coatings, repeated pulses of shock waves may lead to the vibration, fracture, and detachment of biofouling, without damaging the coating. Different mechanisms for generating shock waves in water, including electrohydraulic, electromagnetic, and piezoelectric methods, will be introduced. The wave profiles obtained from these mechanisms will be compared. The transient responses of different materials to shock loading, in terms of elastic waves and deformation, are predicted using both a linear acoustics model, and a novel, three-dimensional CFD (computational fluid dynamics) CSD (computational solid dynamics) coupled simulation framework recently developed by the authors and collaborators. The resulting fatigue and fracture in fouling materials are estimated basing on existing theories and parameters for similar engineering materials. The effects of shock magnitude, duration, and frequency are predicted through a computational parameter study. The possibility of inducing cavitation will also be discussed, together with its potential meritorious effect in facilitating fouling release and deleterious effect in damaging coatings. [Acknowledgement: The authors gratefully acknowledge the support of the Office of Naval Research (ONR) under award N00014-17-1-2831, and the support of the National Science Foundation (NSF) under awards CBET-1751487 and CBET-1706003.]

2B – ORAL 14

ROV technology for hull cleanliness

T. DYRBYE

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The ROV technology has been developed for the oil & gas sector to support deep water operations and to reduce the risk of having divers in the water. It is also being used by the defense industry for various advanced tasks including mine laying and mine sweeping. The introduction into the maritime industry is fairly new and is led by 3-4 companies. The presentation will give some examples of the application in general and illustrate how it is used to perform vessel cleanings. It will also give some examples on how the digital technology support the precise navigation on the hull, delivering a cleaning at high consistent quality and with much improved documentation. Other features with the ROV technology, including possible future developments, will also be shared. The technology is supporting the shipping industry's needs to reduce the fuel consumption and the regulators need to reduce emissions and the transfer of invasive species.

2B – ORAL 15

Testing the efficacy of underwater hull grooming tools

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Hull grooming has been proven to work synergistically with fouling control coatings to maintain the surface free of biofouling. The Center for Corrosion and Biofouling Control has worked since 2005 to develop the concept of hull grooming: the gentle and frequent cleaning by a remotely operated or autonomous underwater vehicle using soft rotating brushes. A large-scale test facility as well as experimental procedures and apparatuses have been developed at Port Canaveral for testing the efficacy of grooming technology. Two grooming tools have been mounted to a Seabotix vLBC300 ROV and tested on an antifouling and a fouling release coating in long-term weekly grooming experiments. The tools' ability to control biofouling has been quantified using the Coral Point Count software from monthly underwater photographs. The tools impact on the coatings ablation rate and roughness have been measured with an Elcometer DFT gauge and TQC Hull Roughness Analyzer respectively. The resultant fouling, thickness and roughness of the groomed coatings have been compared to ungroomed controls and show improved fouling control without increased ablation rates or roughness. Funding Provided by ONR Grant Number N00014-16-1-3050.

2B – ORAL 16

Bursting the iodine vapor bubble: Iodine infused aeration for biofouling prevention

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Aeration, directed continuous streams of air bubbles applied to submerged surfaces, is one environmentally-friendly method for deterring the settlement of fouling organisms. The inclusion of iodine vapor (I₂) within air bubbles may provide additional fouling prevention by reducing microbial counts and formation of biofilms. Testing in 2016 in Port Canaveral, Florida examined the efficacy of a full-scale aeration system deployed on a small vessel with sections coated with two types of antifoulant coatings, Intersleek® 1100 (fouling-release) and Interspeed® BRA-640 (ablative copper biocide), as well as an inert epoxy barrier coating to assess the interaction between I₂-infused aeration and commonly used marine antifoulant coatings. I₂-infused aeration resulted in consistent reductions of 80-90% in hard fouling across all three coatings. Additionally, aeration reduced the soft fouling rate by 45-70% when used in conjunction with both Intersleek® and Interspeed® BRA versus those coatings alone, though aeration did not significantly reduce soft fouling relative to control on the inert epoxy surface. The results of this study highlight the contribution of I₂-infused aeration as a standalone mechanism for fouling prevention in situations where antifoulant coatings are not feasible (e.g., sea chests), or as a complement to traditional antifouling coatings on hull surfaces. Additional testing is needed to determine whether I₂-infused aeration yields sufficient additional benefit relative to standard aeration in preventing fouling to justify logistical and financial complexities of large scale implementation. (Funding received from the Naval Undersea Warfare Center Division Newport).

2B – ORAL 17

Aeration can prevent biofouling growth provided wall shear stress exceeds a threshold value

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Significant shear stresses are needed to remove established biofouling organisms from the hull of a ship. Given that there is a link between the amount of time that fouling accumulates and the stress required to remove it, it is not surprising that more frequent grooming requires less shear stress. Indeed, one environmentally-friendly approach to mitigate marine biofouling is to continuously introduce a curtain of air bubbles under a submerged surface; it is believed that this aeration exploits the small stresses induced by rising bubbles to continuously prevent accumulation along a submerged structure. Although curtains of rising bubbles have successfully prevented biofouling accumulation, it is unclear if a single stream of bubbles could maintain a clean surface, even locally. Furthermore, the magnitude of the induced stresses by any aeration system is unknown. These points raise the more general question: in the limit of any continuous grooming scheme, is there a critical stress that must be exceeded to prevent longer-term fouling? Here we show that single bubble stream aeration can prevent biofouling accumulation on an epoxy surface in regions where the average wall stress exceeds approximately 0.01 Pa. We arrive at this value by comparing observations of biofouling growth and prevention from field studies with complementary laboratory measurements that probe the associated flow fields. Finally, we relate the spatial and temporal characteristic of the flow to the size and frequency of the rising bubbles, which informs the basic operating conditions required for aeration to continuously prevent biofouling accumulation.

THURSDAY 28TH JUNE 2018

PLENARY 3

Considerations for marine corrosion experiments

B.J. LITTLE

Artificial seawaters and simple sodium chloride solutions do not replicate the corrosivity of natural seawaters. Most researchers attribute the differences in corrosivity to the presence and activities of microorganisms in natural seawater. Acknowledging the necessity to include microorganisms in marine corrosion testing, natural and artificial seawaters are frequently augmented with nutrients and/or microorganisms to evaluate specific mechanisms for marine corrosion. Other manipulations can include addition of oxygen scavengers and deoxygenation by gas replacement to provide anaerobic environments. Each manipulation can have unintended consequences for marine corrosion. For example, oxyanions, e.g., nitrates, phosphates and sulfates, routinely added as nutrients, can act as corrosion inhibitors. Chloride, an aggressive anion, must be present in a concentration at least comparable to that of all corrosion-inhibiting anions combined; otherwise, localized corrosion is inhibited. Oxyanions, added to stimulate bacterial growth, can inhibit corrosion by adding too many non-chloride ions. Furthermore, a chloride-containing medium becomes more corrosive as microorganisms consume oxyanions. Yeast extract (YE), rich in nitrogen-containing compounds and carbohydrates, is often added to seawater to stimulate growth of microorganisms. However, YE can be inhibitory to some microorganisms. YE contains B vitamins, e.g., riboflavin and nicotinamide, known redox mediators. Redox mediators increase the rate of electron transfer between microorganisms and electrodes, sorb to surfaces and chelate metal ions. The pH of carbonate-buffered seawater is controlled (buffered) by carbon dioxide (CO₂). As CO₂(aq) is removed from seawater during nitrogen gas purging (i.e., deoxygenation) pH increases and the microflora is altered. Addition of YE decreases the pH of natural seawater. Manipulations to optimize growth of microorganisms in seawater has produced data sets that are contradictory, cannot be replicated and are not useful in predicting material lifetimes in the marine environment.

THURSDAY 28TH JUNE 2018: TRACK A MANAGEMENT OF VESSEL FOULING (REGULATIONS & EFFICACY TESTING)

3A – KEYNOTE 1

Cleaning up the clutter: How is in-water cleaning regulated in California?

C. SCIANNI

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The motivations for, and regulation of, in-water cleaning (IWC) of vessels in California have evolved considerably since 2008. Operational efficiency was the primary driver for IWC activities prior to 2008. These activities were largely unregulated because vessel discharges were exempted from the federal Clean Water Act. A new paradigm focused on IWC for efficiency and environmental protection emerged in 2008 as biofouling management and IWC became elevated as regulatory priorities for federal, state, and local agencies. The regulatory environment went from minimal to a complex, intertwined web of interjurisdictional oversight over the course of a year. The regulatory landscape has become even more complex in the decade since, as IWC service providers now must obtain a state or local permit in addition to receiving further oversight at the federal, state, and local levels for nonindigenous species purposes. To improve clarity and address the complexity surrounding the current regulation of in-water cleaning in California, State Lands Commission staff are pursuing the following three related actions: 1. Engagement with state and local water quality agency partners to ensure that concerns about nonindigenous species introductions are a part of their permit application review. 2. Working cooperatively with regional partners through the Coastal Committee of the Western Regional Panel on Aquatic Nuisance Species to develop a regional IWC regulatory framework to standardize requirements across the U.S. Pacific states. 3. Participation in a collaborative program to independently test IWC systems under the leadership of the Alliance for Coastal Technologies to ensure that robust, independent data are available to demonstrate the level of effectiveness for IWC service providers applying to operate in different waterways.

3A – ORAL 1

Hawaii Invasive Species Council resolution on vessel in-water cleaning operations

J. KUO

Hawaii Department of Land and Natural Resources

In the State of Hawaii, in-water vessel hull husbandry is not allowed in commercial harbors due to the State's Department of Health Water Quality Standards. While there are obvious biosecurity and water quality concerns associated with vessel in-water cleaning (IWC) operations, "no management" of biofouling between commercial vessel dry-dockings will exacerbate biosecurity and environmental concerns. Alternative locations and methods used for managing biofouling, like cleaning offshore or dry-docking for routine grooming, are either significantly more dangerous and/or economically unfeasible; in addition, coral reef habitats nearby may be affected by the potential release of paint contaminants and aquatic aliens. Therefore, the Hawaii Invasive Species Council (HISC) Resolution on IWC operations was introduced and adopted on, January 18, 2018, by department heads, with overlapping jurisdictions on the issue, including the Department of Land and Natural Resources (DLNR), Department of Transportation (DOT), and Department of Health (DOH). The Resolution requires adopting agencies to 1) formally recognize the overlapping jurisdictions on IWC activities and the environmental benefits of allowing IWC, 2) collaborate on developing conditions for allowing IWC, and 3) support data collection during the leg of Alliance for Coastal Technologies IWC capture technology testing in Hawaii. This presentation will summarize current and future actions for implementing the HISC Resolution on IWC operations in commercial harbors.

3A – ORAL 2

Evaluations of ship in-water cleaning and capture technologies

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- (1) Alliance for Coastal Technologies and Maritime Environmental Resource Center
- (2) U.S. Naval Research Laboratory
- (3) Smithsonian Environmental Research Center
- (4) California State Lands Commission
- (5) Hawaii Department of Land and Natural Resources
- (6) Maritime Administration

Ship biofouling presents notable problems for the maritime industry by increasing drag and concomitant fuel consumption and exhaust emissions, as well as facilitating coating breakdown and subsequent vessel corrosion. Ship biofouling is also a notable vector for the global-scale transfer and introduction of non-native aquatic species, which can have enormous ecological and economic impacts on coastal environments. A number of in-water cleaning and capture (IWCC) systems have been developed in recent years, focused mostly on hull husbandry. To facilitate further innovations that address these critical maritime and environmental issues, and to help transition IWCC technologies into widespread operation, a collaboration of third-party testing programs, researchers, and agencies has established a ship in-water biofouling cleaning and grooming evaluation initiative. The goal of this program is to independently quantify system efficacy and reliability in removing fouling organisms-and capturing debris and potential contaminants-from complex vessel structures. Currently, seven companies have applied to take part in a series of IWCC evaluations in 2018-19 with the specific goals of (1) refining and standardizing methods and procedures for testing IWCC technologies, and (2) providing rigorous, independent data on the performance of in-water cleaning systems that can be used to apply for permitted, commercial use in ports around the world. This presentation will discuss the initiative's structure and function, summarize results to date, and describe future efforts in this area.

3A – ORAL 3

Testing the efficacy of under-water cleaning

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We propose to manage biofouling according to similar principles as those for ballast water, and the benefits, risks and consequences for management policies. We focus on the possibilities to test the impact of under-water cleaning by currently available hull-cleaning methods on ambient waters. Under-water cleaning may contaminate ambient waters with non-native species and coating particles. A study by the Netherlands Government Institute for Water Research, showed that it was impossible to fully contain particles within an enclosing structure (1999). We propose to test waters in which a ships' hull has been cleaned according to the testing principles for ballast water management systems (BWMS) on the transfer of species according to the standard of Regulation D-2 of the Ballast Water Management Convention (BWMC, IMO, 2004). The equipment employed at our and other BWMS test facilities may serve as a guidance. The BWMC the standard of D-2 is geared to test for the presence of viable organisms $\geq 50 \mu\text{m}$ and between 10-50 μm . The methodologies testing BWMS offer a framework to develop tests to detect an increase in presence of organisms after hull cleaning. we will discuss the consequences of applying the BWM discharge standard for testing the efficacy of hull-cleaning methods, which entail: (1) Feasibility, validation of sampling and analysis technologies for hull fouling, (2) Potential to develop valid management tools and guidance fit for implementation, (3) Responses of the natural environment to hull-cleaning run off. (4) Indicators to check if such testing offers a sound way to bar hull-fouling particles from entering ambient waters.

3A – ORAL 4

Technical solutions to solve problem fouling down under

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Vessel biofouling is the major pathway for the introduction of non-indigenous species into New Zealand's marine environment. These introductions can have significant environmental and economic impacts. The most effective method for removal of biofouling from a vessel is via dry-docking or slipping. However, availability, practicality and feasibility issues regarding management of fouled vessels has led to reactive in-water systems being proposed as a management tool. Continuing New Zealand's ongoing commitment to address the biofouling problem, the Ministry for Primary Industries (MPI) has funded or is providing key technical support on research initiatives addressing the efficacy of in-water cleaning or treatment systems. Three projects testing the efficacy of in-water systems are described based on proposed standards and procedures that aim to minimize biosecurity risk. Laboratory and field testing of systems is being undertaken to strengthen the proposed standards and procedures as required. Acknowledgements: The work presented in this study has been undertaken by the following service providers: Efficacy of in-water cleaning systems (External hull) - Ramboll New Zealand Ltd. Efficacy of in-water treatment systems (Internal niches) - Biofouling Solutions Pty Ltd; Cawthron Institute Treatment of recreational vessel pipework - Cawthron Institute; National Institute of Water and Atmospheric Research; Biofouling Solutions Pty Ltd.

3A – ORAL 5

Evaluation of reactive in-water hull cleaning systems for biofouling management

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New Zealand has one of the most mature systems for biosecurity protection in the world, and an ability to respond to biosecurity risks at the border is essential for protecting native biodiversity. The Craft Risk Management Standard (CRMS), to be implemented in May 2018, focuses on managing the risk of marine pest incursions via the vessel biofouling pathway. Given the ever-increasing levels of marine traffic to New Zealand, demonstrably effective, environmentally "friendly" incursion response tools for minimizing vessel biofouling risk are urgently required. The Ministry for Primary Industries (MPI) has provided a draft framework and proposed a set of performance standards for testing the efficacy of reactive in-water systems for cleaning vessel hulls. The current project, funded by MPI's Operational Research Team, uses the proposed framework to identify and test different, commercially provided, in-water cleaning systems with potential to manage the biosecurity risk associated with fouled large vessels. Systems will be evaluated primarily for their ability to retain particulate material greater than 12.5 µm in average diameter. Dispersion modelling will also be used to determine the fate of copper and zinc loads released to the environment. A key component of the evaluation will be an assessment of the efficacy of the testing framework in determining system suitability. At this early (implementation) stage of the project, we are identifying the types of systems that are commercially available for testing, with a view to beginning testing in 2018/2019.

THURSDAY 28TH JUNE 2018: TRACK A BEYOND SHIPS

3A – ORAL 6

Foul release and integrated solutions for instrument protection

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One of the incorrect approaches for biofouling control for oceanographic instruments to date is the notion that there is a one size fits all biofouling control method. The more refined strategy is the use of specific biofouling control methods for specific instruments, mission types and sensor types. Biofouling control for oceanographic instruments is best achieved through a multi-tiered integrated approach. Specifically, the selected use of foul release coatings, ultraviolet (UV) sterilization, mechanical cleaning, and chemical immersion offer greater effectiveness for controlling biofouling on many instruments. Another paramount consideration is the hydrodynamic streamlining of instruments and their associated platforms. The recent advances in biofouling control methods for oceanographic instruments and related platforms represent a significant improvement over the historic practices noted. One of the most effective biofouling solutions over the last 10 years is the use of non-stick or “foul release” coatings that have been formulated specifically for use on oceanographic instruments. Foul release coatings rely on the surface properties of the material itself to significantly reduce biofouling settlement. They also greatly reduce the work required to clean an instrument or platform. These coatings are particularly effective on instrument housings, acoustic transducers and host platforms such as surface and subsurface gliders. Foul release coatings can be self-cleaning in high-energy environments such as moving platforms or wave environments. These coatings are designed to last the lifetime of the instrument, thereby making them cost effective solutions for many applications. While the foul release coating system is effective on instrument housings and acoustic transducers it is in many cases not a suitable biofouling control system for non-acoustic sensor elements.

3A – ORAL 7

Thermal control of biofouling

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Biofouling of immersed surfaces is a problem whose current solutions are expensive, impermanent and often toxic. Where heat is a by-product, such as in power generation, thermal control of biofouling is one of the most “environmentally acceptable control methods available” (3). Thermal methods have been shown to eliminate biofouling on submerged surfaces, but their application has been limited because of power costs and impracticability (1,2,3,4). This presentation provides initial results on an alternative method for thermal control of biofouling. 1. Biofouling prevention by induction heating. 2011. Patent application US20110117294. Nevid and Swain et al. 2. Marine Fouling and Its Prevention. 1952. US. Naval Inst., Woods Hole #580. 3. Marine Biodeterioration. 1984. Naval Institute Press. pp. 261-299 4. Sensor fouling on deep-submergence vehicles. 1968. Mar. Sci Sym. Vol 4. Plotner et al.

3A – ORAL 8

Materials and coatings needs for marine & hydrokinetic technology

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To provide affordable and sustainable energy to coastal regions, the kinetic energy of waves, tides, and ocean currents are being harnessed through the development of Marine & Hydrokinetic (MHK) technology. Early open water testing of MHK devices showed materials and coatings related issues that are being addressed by DOE's MHK Advanced Materials Program. The team assembled conducts applied research and provides guidance to accelerate the commercialization of MHK technology. Currently, we are focused on developing material design tools to enable the use of composite materials. Composites are promising materials that could provide lightweight marine durable structures. However, composites are expensive and are unproven under MHK performance conditions. To reduce uncertainty in using composites, we are investigating their performance, potential for manufacture, and providing validated resources to industry. Sandia National Laboratories (lead), along with Pacific North west National Laboratories, National Renewable Energy Laboratory, Montana State University, and Florida Atlantic University have partnered to investigate carbon and glass reinforced composites. We are evaluating environmental effects (biofouling, salt water, corrosion) on performance using materials provided by industry and supply chain vendors. Preparation for substructure testing and understanding MHK load challenges are upcoming tasks in which MHK developers will direct. This talk will focus on our understanding of MHK materials issues and share with the audience what data will be housed in the open source U.S. DOE MHK Materials & Structures Database. Sandia National Laboratories is a multitechnology laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

3A – ORAL 9

Adhesion strategies of cyanobacteria on photobioreactor materials

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Photosynthetic cyanobacteria (blue-green algae) are considered as an attractive third generation renewable biomass source mainly due to their ability to produce fuels directly from CO₂ and sunlight. In spite of growing demand and valuable biofuels being already produced from cyanobacteria, their cultivation in photobioreactors (PBRs) is challenging due to their tendency to cause rapid biofouling on inner walls of the PBRs. Fouling interferes with the light transmission efficiency of the photobioreactor materials and reduce the overall cyanobacteria biomass generation and biofuel productivities. Despite the fact that they are well known fouling organisms, studies focused on their fouling prevention are scarce. Therefore, as a prerequisite to a successful design of an antifouling surface to prevent cyanobacteria fouling, we have investigated the preliminary adhesion processes of a selected cyanobacterium (genetically engineered to enhance biofuel production) on a range of existing or potential PBR materials. This was done by evaluating the physicochemical changes occurring during the initial adhesion of engineered cyanobacteria on PBR materials through experimental techniques such as surface contact angle measurements, bright field microscopy, attenuated total reflectance-Fourier transform infrared (ATR-FTIR) spectroscopy and atomic force microscopy (AFM). From the surface contact angle measurements, the formation of conditioning film on PBR materials was evident within 12h of immersion of the materials in engineered cyanobacteria suspension. ATR-FTIR spectroscopy revealed the proteins and polysaccharides as dominant groups involved in initial adhesion of engineered cyanobacteria. Changes in roughness, height and thickness of the conditioning biofilm on PBR materials during the initial adhesion of engineered cyanobacteria were found to be substrate specific as determined by AFM.

Fouling control for acoustic sensors

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As surfaces in the marine environment become fouled there is often a significant adverse effect on their operational functionalities. For sensors this can include a camera becoming obstructed or an acoustic signal being muffled and degraded before it reaches an acoustic sensor. For acoustic sensors it is also possible that the application of various antifouling coatings could change interfacial properties of a surface and affect its acoustic characteristics, however actual investigations into the characterization of this are rare. In this study, neoprene coated with four marine antifouling coatings (a cuprous oxide based self-polishing coating; a hydrogel foul release coating; a hybrid biocidal-foul release coating and uncoated neoprene doped with the biocide DCOIT during the curing process) were used to evaluate effects of the coating, biocidal components and fouling on the acoustic signal of a sensor. A simple insertion loss test was completed for each panel to ascertain the transmission loss. These samples were deployed in temperate waters to gauge the effectiveness of the antifouling technologies. The samples were removed and bagged in-situ. The insertion loss tests were repeated for each of the bagged samples to elucidate the effects of various fouling stages on transmission loss. Results indicate that the application of fouling control coatings, including those containing biocides, had little influence on transmission loss and that the largest effects occurred due to calcareous fouling. The results will inform industry on the most appropriate measures to protect acoustic sensors and signals from the rigors of the marine environment.

THURSDAY 28TH JUNE 2018: TRACK A BIOMIMICRY, BIOINSPIRATION & NATURAL ANTIFOULANTS

3A – KEYNOTE 2

Amphiphilic silicones with broad-spectrum anti-fouling behavior

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Silicone foul-release (FR) coatings represent a non-toxic alternative to ablative marine coatings. However, the efficacy of silicones to broadly control biofouling is limited such that amphiphilic anti-fouling (AF) coating systems have emerged as a potentially effective alternative. The poor anti-fouling behavior of silicones is attributed to their extreme hydrophobicity. Although poly(ethylene oxide) (PEO) is known to be exceptionally anti-fouling (e.g. protein resistant), these observations have been largely made when PEO is grafted to a physically stable substrate (e.g. gold and silicon wafer). In this way, migration of the PEO to the water-surface interface, where biological adhesion occurs, is not required. In this work, we sought to enhance the water-driven surface-migration of PEO incorporated into silicones in order to achieve superior anti-fouling behavior. Conventional PEO-silanes consist of a PEO segment separated from the reactive crosslinkable group by a short alkane spacer. In contrast, we prepared PEO-silane amphiphiles with siloxane tethers of varying lengths and as well as variable PEO segment lengths. Amphiphilic silicone coatings were prepared by blending a silicone with the PEO-silane amphiphiles at different concentrations. The impact of amphiphile architecture as well as level of silica reinforcing filler on water-driven surface restructuring was assessed. The resistance of these amphiphilic silicone coatings to diverse marine biofoulers was evaluated.

3A – ORAL 11

Environmentally friendly anti-fouling coatings constructed by biodegradable polymer and natural antifoulant

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Marine biofouling causes huge economic loss and serious problems to maritime industries. There is a great demand for environmentally friendly anti-biofouling technology. Marine natural products have been considered as a promising source of antifoulants. However, we still face practical challenges, such as mass production of compounds at cost-effective means, biosafety, and antifouling mechanisms. Furthermore, how to incorporate antifouling compounds into polymers and how to solve the compatibility and the controlled release of natural antifoulant from coating are equally important issues to be addressed. In the present study, we have developed novel anti fouling coatings by incorporating butenolide derived from marine bacteria into biodegradable poly(ϵ -caprolactone) based polyurethane, where the degradation of the polymer provides a self-renewing surface and serves as both carrier and release system of butenolide. Measurements of mass loss indicated that the polymer was degraded in seawater and that the degradation rate increased in the presence of marine organisms or enzymes. Moreover, measured release rates indicated that butenolide could be released from the biodegradable polymer for at least 3 months and the release rate depended on both the concentration of butenolide and the temperature. Incorporating a naturally occurring resin (rosin) into the biodegradable polymer increased the self-renewal rate and improved the later release rate of butenolide. The field test indicated that the system had excellent antifouling properties (Funding provided by the Hong Kong Scholars Program and National Natural Science Foundation of China).

3A – ORAL 12

Probing the natural allelopathic dihydrostilbene scaffold to generate powerful marine antifoulants

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The current presentation reports the results from the first comprehensive evaluation of a class of allelopathic terrestrial natural products as antifoulants in a marine setting. To investigate the antifouling potential of the natural dihydrostilbene scaffold, a library of 22 synthetic dihydrostilbenes with varying substitution patterns, many of which occur naturally in terrestrial plants, were prepared and assessed for their antifouling capacity. The dihydrostilbene scaffold was shown to possess powerful general antifouling effects against both marine microfoulers and macrofoulers with inhibitory activities at low concentrations. The species of microalgae examined displayed a particular sensitivity towards the evaluated compounds at low ng/mL concentrations. It was shown that several of the natural and synthetic compounds exerted their repelling activities via non-toxic and reversible mechanisms. The activities of the most active compounds were comparable to the commercial antifouling booster biocide Sea-nine®. In further optimization experiments 9 synthetic dihydrostilbene-oxime hybrids were also prepared and evaluated in an attempt to additionally improve the antifouling properties of the native scaffold. The investigation of terrestrial allelopathic natural products as antifoulants represents a novel strategy.

3A – ORAL 13

A new biological antifoulant for marine paints

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Biofouling increases surface resistance to vessel movement, reducing the speed of the vessel and increasing fuel consumption. After the ban on tin-based antifouling, most suppliers started to use copper-based coatings. However, dissolved copper from these coatings systems has been identified in certain poorly flushed basins and in crowded marinas where these metals may accumulate and exceed the Clean Water Act standard for copper, which is 3.1 µg/L in marine waters. Significant R&D resources have been allocated for the development of copper-free antifouling coatings in anticipation of increasing restrictions, which may be leveled against the yacht market before reaching the broader marine/shipping sectors. Biomimetx SA a Portuguese start-up developed a mixture of compounds - BMX-11 - produced by proprietary bacteria, that are biodegradable, cost effective and broad spectrum. We are presenting for the first time this biological biocide, capable of being incorporated in marine paints, envisioning replacing current booster biocides or eventually to become, after further development, a full replacement for current antifouling biocides BMX-11 proved in the laboratory to be active against a wide range of organisms and after incorporated in paint showed in raft tests that is still active against soft and hard fouling. Raft test took place in several locations, namely in Portugal and Italy (done by Boero Yacht Coatings). BMX-11 production, by bacterial fermentation reached industrial scale, showing that can be deliver to industrial customers cost effectively. BMX-11 was already considered a Biochemical pesticide by US EPA.

3A – ORAL 14

Development and testing of a riblet-textured fouling-release coating with drag reducing properties

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The laboratory and in-field testing of a drag-reducing riblet texture with fouling-control properties is presented. A riblet-textured coating based on a modified version of the commercial fouling-release product Intersleek® 1100SR has been successfully prepared. Taylor-Couette measurements have shown that the Modified Intersleek® Riblets reduce drag by up to 6% as compared to a smooth reference. Fouling control laboratory assays including barnacle settlement demonstrate that the riblet pattern does not substantially reduce the ability of Intersleek® 1100SR to prevent fouling by *Balanus amphitrite* cyprids. Ongoing performance assessment including the results of in-field fouling settlement testing will be presented and future plans for scale-up and practical realisation discussed. The authors of the work presented gratefully acknowledge funding received from the European Union Seventh Framework Programme in the SEAFRONT project under grant agreement 614034.

3A – ORAL 15

Antifouling efficacy of 3D-printed microstructured surfaces

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Many marine organisms are surprisingly free of biofouling although lacking chemical defense. Instead surface microstructures have been suggested to have a deteriorative effect on organism settling and adhesion. The concept of surface microstructuring for biofouling control have been explored but the potential suite of surfaces to be mimicked or adapted has not been fully utilized, mainly due to limitations of the manufacturing techniques. In this study we exploit the versatility of the 3D-printing technique to produce complex bioinspired microstructured surfaces against biofouling. The aim was to evaluate the effect of adding structures on a different length scale creating an oscillation in height compared to sharkskin microstructured surface (Magin, 2010). By the use of scanning electron microscopy (SEM), optical profilometry and light microscopy minor deviations between the CAD-model and the final morphology of the printed surfaces were observed. The antifouling efficacy was assessed in a field study at the west coast of Sweden. At the first inspection both the classical sharkskin and the oscillated sharkskin showed significantly lower barnacle settling compared with a smooth reference (t-test, $p=0.006$ and $p=0.002$ respectively). At this inspection the oscillated sharkskin showed significantly lower degree of barnacle settling compared to the classical sharkskin (t-test, $p=0.04$). The difference between the smooth reference and the microstructured surfaces regarding barnacle settling prevailed at the following inspections but the difference between the classical and oscillated sharkskin diminished. Notably was the lower barnacle growth rate observed on the microstructured surfaces indicating problems bridging holes or protrusions during organism growth. With time all surfaces became seriously fouled but we observed differences in biofouling community between the smooth reference and the microstructured surfaces. (Funding provided by FORMAS).

From intertidal organisms to biomimetic antifouling metals:
The development of antifouling patterns using laser micro-machining

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Biofouling is the unwanted colonisation of organisms on a living or artificial surface. Convergent evolution has led to the development of antifouling textures on many marine species. The aim of this study was to determine the effect of biomimetic surface textures on biofilm using laser micro machining (SPI Lasers G3 Infrared nanosecond pulsed fibre laser) directly onto metal surfaces for the first time. A fringe projection microscope (GFM) was used to produce 3D scans of the surface topography of shells of bivalve and crab species. For the first time, laser processing was used to transfer the selected micro-topography patterns onto marine grade stainless steel (316L). Samples (n=5) were deployed in the field (Liverpool South Docks, UK) for 7 days. Abundance of biofilm was assessed using random systematic sampling. Biofilm was significantly less abundant on crab and shell biomimetic surfaces than the smooth control ($\chi^2_{(4)}=18.8$, $p=0.001$; $\chi^2_{(4)}=12.432$, $p=0.014$). The micro-topography pattern limits the attachment of the biofilm to the surface. This study shows that biomimetic surfaces have the potential to be a non-toxic, eco-friendly antifouling technology that work directly on marine metal structures without the need for further coatings or chemicals. (The research was funded by LJMU).

THURSDAY 28TH JUNE 2018: TRACK B CORROSION

3B – KEYNOTE 1

Implementation of corrosion control technologies within the U.S. Department of Defense

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The annual cost of corrosion to the U.S. Department of Defense is approximately \$20B USD and represents between 15% of 25% of all maintenance performed on systems and facilities. Corrosion also negatively impacts system availability. For example, corrosion prevention and control was responsible for 23% of all non-availability days for Navy and Marine Corps aviation systems in 2014¹. In an attempt to reduce these impacts, the Corrosion Policy and Oversight (CPO) Office in the Office of the Under Secretary of Defense (Acquisition and Sustainment) has partnered with the Military Departments to fund over 300 projects focused on developing, adapting, and implementing corrosion prevention and control technologies between 2005 and the present. Summaries of selected projects related to marine corrosion will be presented and the challenges associated with implementing new technologies in defense systems will be discussed. While some of these challenges are technical in nature such as extending the results of accelerated testing to systems in service, many of the most difficult challenges are administrative in nature such as meeting qualification requirements, changing specifications and drawings, and ensuring logistics support for new technologies.

3B – ORAL 1

A history of accelerated life testing for cathodic debonding: 1978 to 2018

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The US Navy first began to develop experimental protocols for accelerated life testing (ALT) of outboard electrical cables in 1978 after a rash of debonding failures of unknown cause were reported by the Fleet. The early protocols established the use of Arrhenius kinetics as the backbone for such ALTs, but used generic values of 30 kcal/mol and 10 kcal/mol for the Arrhenius activation energy for accelerating “corrosion” and “water diffusion through the encapsulant”, respectively. By the mid-1980s it was generally understood that the cause of the cable connector debonds was a process called “cathodic debonding”. This process occurred because the hulls of Navy vessels were cathodically polarized to prevent corrosion. A byproduct of that process was the generation of a very high local pH environment that debonded polymers from metal surfaces. This realization led to improvements in the ALT experimental protocols including the use of sacrificial anodes attached to samples to supply the required cathodic polarization, and control of environmental conditions (e.g., dissolved oxygen levels) to maintain conditions optimum for cathodic delamination. Renewed interest in cathodic debonding, during the last decade, triggered by another rise in connector failures, has led to the more realistic Arrhenius activation energy values being measured and used in ALT experimental protocols. These new methods, involving direct measurement of the rate of cathodic debonding on samples and via the use of a potentiostat to measure the current density between the sample metal and a sacrificial anode, are just now being incorporated into ALT protocols and should lead to more realistic predictions of cathodic debonding resistance of coatings and materials in the future.

3B – ORAL 2

Corrosion inhibition of Martensitic stainless steel in acid medium by ammonium benzoate:
Solanum tuberosum extract as surfactant

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Surface deterioration by corrosion is one of the complications associated with ageing facilities and components especially under some service environments. Studies involving performance of corrosion inhibitors had been identified as one of the critical research needs for improving the durability of martensitic stainless steel used in various industrial applications. This paper investigates the inhibiting effect of Ammonium benzoate against the corrosion of martensitic stainless steel in 0.5M HCl solution. The steel samples were cut to corrosion coupons, and immersed into 0.5M HCl medium at 300C using gravimetric and electrochemical techniques. The microstructures of the developed thin films and uncoated samples were characterized by optical (OM) and scanning electron microscope (SEM/EDS). Moreover, X-ray diffractometer (XRD) was used to identify the phases present. Results obtained reveal that the compound (Ammonium benzoate) performed effectively giving a maximum inhibition efficiency of 79% of 2% v/v concentration from weight loss analysis and 80.9% at 2% v/v concentration from polarization test. Moreover, the results obtained from potentiodynamics polarization had good correlation with those of the gravimetric method. The adsorption of the inhibitor on the martensitic stainless steel surface from the acid was found to obey Temkin's adsorption isotherm. Scanning electron microscopy (SEM/EDX) observation confirmed the existence of an absorbed protective film on the metal surface. In addendum, combination of ammonium benzoate and *Solanum tuberosum* extract greatly reduced the corrosion rate with ~ 90% efficiency compared to ordinary ammonium benzoate.

3B – ORAL 3

Encapsulated cerium salt for enhancing corrosion properties of PU coating

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Polyurethane (PU) coatings are widely used to protect metals and avoid corrosion problems. Owing to restrictions on using toxic chromate scientists are attempting to develop new, more environmentally-friendly coatings that maintain their performance over extended periods. Unfortunately, these coatings are inadequate to prevent metal corrosion for prolonged periods or under adverse conditions. Therefore, the anti-corrosive properties of PU coatings have been improved using different inhibitors which are usually mixed directly in the parent coating. However, if an inhibitor is directly added in to a coating, it may show negative impact on the coating properties. Moreover, solubility of many inhibitors in coating media is a serious concern and affects inhibitor efficiency. The direct addition of an inhibitor to a coating can result in the interaction between the two materials leading to deactivation of the inhibitor. Microencapsulation is an efficient way by which this problem can be overcome without sacrificing the properties. In this study, cerium encapsulated inhibitors were mixed with parent PU coating to enhance the corrosion resistance. A slow release of encapsulated inhibitor was also recorded.

3B – ORAL 4

Tuning transport properties in epoxy barrier membranes

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The silver-silver chloride electrode is a widely used reference system for various electrochemical applications. Silver-silver chloride reference electrodes that are boldly exposed to seawater are commonly used to monitor potential for cathodic protection applications. This setup is beneficial in that there is no need for an internal filling solution, and therefore no junction potential formed at the interface between the filling solution and the environment. However, the measured potential is dependent on the local chloride ion concentration and will fluctuate if the chloride concentration changes. It is subject to contamination, such as by bromide, which can also shift the potential. The addition of a membrane separating the sensing element from the environment would limit these effects. The membrane should have a minimal flow between the filling solution and the sensing environment so that the long-term stability is not compromised, but have a low enough resistance to avoid a substantial potential drop across the membrane. Different epoxy membrane candidates were formulated and cured under different conditions. Electrochemical impedance measurements were used to assess the barrier properties for the various epoxies after immersion in water, with significant decreases in impedance with water uptake. (Funding provided by the U.S. Naval Research Laboratory.)

3B – ORAL 5

Numerical modelling and influence of Cu addition at high-temperature on the surface characteristics and electrochemical properties of icosahedral Al-Cu-Fe coatings on Ti-6Al-4V alloy

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Modern industrial applications require materials with special surface properties such as high hardness, wear and corrosion resistance. The performance of material surface under wear and corrosion environments cannot be fulfilled by the conventional surface modifications and coatings. Therefore, different industrial sectors need an alternative technique for enhanced surface properties. This paper focuses on the numerical modelling and influence of copper addition on the hybrid coatings Al-Cu-Fe on a grade five titanium alloy using laser metal deposition (LMD) process. A 3kW continuous wave ytterbium laser system (YLS) attached to a KUKA robot which controls the movement of the cladding process was utilized for the fabrication of the coatings. The titanium clad surfaces were investigated for its corrosion and other surface properties at different laser processing conditions. The samples were cut to corrosion coupons and immersed into 3.5M NaCl solution at 28°C using Potentiodynamic Polarization and Electrochemical Impedance Spectroscopy (EMS). It was found that the geometrical properties of the coatings and the Heat Affected Zone (HAZ) of each sample remarkably depended on the optimization of Cu addition and the laser process parameters due to the laser-material interaction. It was observed that there are higher number of aluminium and titanium intermetallics presented in the coatings which variably enhanced the surface properties. The enhanced micro-hardness and corrosion properties were attributed to the formation of hard intermetallic compounds (TiCu, Ti₂Cu, Ti₃Al, Al₃Ti) produced through the in situ metallurgical reactions during the LMD process. COMSOL Multiphysics was used to validate the corrosion properties of the coatings.

3B – ORAL 6

The roles of Al and Sn alloying on corrosion of antifouling/antimicrobial Cu-Al-Sn alloys

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Corroding Cu-based alloys have demonstrated antifouling and antimicrobial function through the release of Cu ions and are efficacious enough to kill even antibiotic-resistant and epidemic strains of bacteria such as MRSA. However, alloying elements have a strong influence on antifouling/antimicrobial efficacy by affecting tarnishing (corrosion product formation), passivity, and preferential alloy solute release (dealloying). A continuously antifouling/antimicrobial surface may be attainable through alloying by restricting corrosion through a regulating non-tarnishing oxide layer while simultaneously permitting enough corrosion for continuous soluble Cu release. In this work, the roles of Al and Sn in FCC Cu on dissolution and oxide formation were evaluated with binary (Cu-Al, Cu-Sn) and ternary (Cu-Al-Sn) alloys in a simulated artificial perspiration with in situ electrochemical methods, and ex situ characterization of soluble and insoluble corrosion products and surface damage. The influence of alloying elements on dissolution mechanisms and surface films were evaluated with electrochemical experiments in diagnostic acidic, basic, and chelating chemical environments combined with ab initio atomistic simulations of solute-doped surfaces of Cu “alloy” slabs using Density-Functional Theory (DFT). Ternary alloying with low amounts (<10 at %) is anticipated to endue the properties of both Al and Sn in synergistic combination where the fraction of protective (Al-) oxide coverage increases at lower Al contents than the binary Cu-Al system due to the greater dissolution rate of Cu-Sn. Functional roles on corrosion and cation release including synergisms of these alloying elements will be highlighted. Furthermore, implications of alloying effects on antifouling/antimicrobial function of a Cu-based alloy will be discussed. (Work funded by the National Science Foundation: DMR 1309999).

3B – ORAL 7

Cathodic protection performance of Al-Zn-In-Mg-Ti sacrificial anodes for steel piles in ocean

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Cathodic protection performance of Al-6Zn-0.02In-1Mg-0.03Ti sacrificial anodes for steel piles was characterized by mass loss, optical and electronic microscopy analyses. The electrochemical behavior was conducted by open circuit potential, potentiodynamic and potentiostatic polarizations. The results showed that cathodic protection potential was in the range of -0.960 and -1.103 V(SCE). The corrosion type and consumption rate of the anode were related with the output current. In harsh corrosion environment, the anode showed uniform corrosion and lost more mass to output more current to fulfill cathodic protection. Otherwise, localized corrosion and less mass loss were observed. The anodes were covered by marine creatures and corrosion product. The corrosion product contained amorphous $\text{Al}(\text{OH})_3$, $\text{MgAl}_2(\text{CO}_3)(\text{OH})_x\text{H}_2\text{O}$, which became more crystalline from outside to inside of the anode. A transparent corrosion product was firstly found on the anode surface, which contained amorphous $\text{Al}(\text{OH})_3 \cdot x\text{H}_2\text{O}$ with S and $\text{Al}_x\text{Cl}_y(\text{OH})_z\text{mH}_2\text{O}$. The electrochemical performance of the anode was strongly reduced by the coverage of corrosion product. Open circuit potential of the anode increased and the output current dropped. The effect of corrosion product thicknesses on the anodic activation was not obvious.

3B – ORAL 8

Investigating microbial communities involved in accelerated low water corrosion from sediment and sheet piling samples

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Accelerated Low Water Corrosion (ALWC) is a form of biocorrosion of metal structures in the marine environment at around the low tide water level. In order to understand the causes of ALWC, research to ascertain the microbial communities involved in the process is required. In this work, traditional culture-based isolation and modern microbiological methods, (i.e. Sanger sequencing and metabarcoding of the 16S rRNA genes), were used to study the microbial communities of sediment and steel sheet piling obtained from a tidal river location close to major maritime industry. Isolation of pure cultures of microbes from the sediment sample employed marine simulation agar media (e.g., R2A and Marine Agar) and both aerobic and anaerobic incubation conditions. A total of 43 isolates were cultured from the sediment and their identities compared favourably with the results from metabarcoding of the e-DNA extracted from both the sediment and tubercle. However, relative abundances of the bacterial groups did differ, and metabarcoding of the corrosion biomass, but not pure culturing, highlighted the bacterial phylum Deltaproteobacteria, which is where many sulfate reducing bacteria (SRB) are found. SRB are frequently reported to be relevant to ALWC. Some of our sediment isolates and groups from metabarcoding have been previously reported as surface colonisers or biofilm formers in corrosion. The surface growth mode of sediment attached microbes is consistent with the growth mode of microbes on sheet piling. The next stage of the research will be to use a selected suite of the isolates along with a commercial strain of SRB (*Desulfovibrio desulfuricans*) in laboratory scale corrosion studies.

3B – ORAL 9

Crevice corrosion of stainless steel in tropical seas

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Stainless steels are widely used in seawater for different applications in the oil and gas and desalination industry. In natural seawater, all surfaces will be rapidly covered by microorganisms with the formation of a biofilm, inducing a significant shift in corrosion potential for stainless steel in the noble direction. The other significant effect of the biofilm on stainless steel is the significant increase of the cathodic efficiency (e.g. the cathodic reduction of dissolved oxygen), increasing the rate of propagation of localized corrosion such as pitting and crevice corrosion. Although this phenomenon has been widely studied at temperate and cold seawaters, very little is known in tropical seawater in which bioactivity is expected to be different. Open-circuit potential measurements and measurements of the cathodic efficiency have been performed at different temperatures in temperate and in tropical seas. The study aimed at defining the differences between temperate and tropical sites in terms of electrochemical behavior (e.g. open-circuit potential and cathodic current for oxygen reduction). One of the main differences was found to be the critical temperature for biofilm ennoblement which was different for temperate and tropical seawaters. The results are discussed in terms of risk for crevice corrosion for stainless steels in tropical seas.

3B – ORAL 10

Electrochemical corrosion behaviors and mechanism of carbon steel
in the presence of acid producing bacteria

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In the marine environment, it is acknowledged that more than 20% of the overall corrosion is associated with microbiologically influenced corrosion (MIC). MIC is usually induced through important changes in the variables like ions, pH values, and oxygen level in localized regions. Acid producing bacteria, which can induce variation of pH by producing amounts of acids, occupy a particular position in MIC. Here, the corrosion behavior of Q235 carbon steel in the presence of *Citrobacter sp.* was investigated by surface analysis, weight loss and electrochemical measurements. The attachment and subsequent biofilm formation of *Citrobacter sp.* were obviously observed on carbon steel. The colonized bacteria accelerate the corrosion of the steel plates, compared with the samples in sterilized artificial seawater. Meanwhile, the flake-like corrosion products in sterilized artificial seawater were observed while hydrangea-like corrosion products occurred on carbon steel incubated in *Citrobacter sp.* solution. Moreover, the compositions of corrosion products varied in response to without/with bacteria which indicated the complex corrosion process. Further investigation showed that the corrosion mechanism of steel incubated in *Citrobacter sp.* solution was closely related to its acid-producing activity.

3B – ORAL 11

Spatial distribution of electric field strength in a rectangular electrochemical cell using a
2-dimensional reference cell tip array in an applied AC potential field

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Experimental data show the non-uniformity of current distribution leaving plate electrodes in a well-constructed, rectangular prism-shaped, 200 Gallon tank containing 1/40th scale artificial seawater. The tank was utilized for the purpose of creating a nearly uniform 2-dimensional electrical field resulting from passing AC current electrochemically from one platinum-coated titanium electrode to another using a potentiostat. The tank was also outfitted with a positioning system and a four-probe cruciform sensing arm. The research in this study incorporated a four electrode setup to determine the field strength (measured via impedance between two of the four sensing tips) resulting from applied AC current density. Apparent impedances were measured by performing galvanostatic electrochemical impedance spectroscopy (EIS) with a potentiostat applying a global current density applied to the electrodes in units of Ω/in . Field strengths (in units of V/in) were calculated by multiplying apparent impedances by a global applied current density. Tank maps of the electrical field in terms of Z_{mod} have been constructed by measuring the Z_{mod} response at various locations in the tank, in both perpendicular and parallel modes. The Z_{mod} distribution has been found to be remarkably uniform across the tank. The effect of a relatively small (6" x 6") patch of electroplaters' tape on the working electrode was evaluated by measuring both perpendicular and parallel components of the Z_{mod} EIS response. At distances of 1.5" from the patch on the working electrode, the perpendicular component of Z_{mod} decreased to about 70% of its value in the absence of the patch, whereas the parallel component increased approximately tenfold from its otherwise very small value. At distances of 6" and farther from the working electrode, very little effect from the patch was observed. These results have been ascribed to a re-directing of the electrical field near the patch on the working electrode.

THURSDAY 28TH JUNE 2018: TRACK B NEW ANALYTICAL METHODS

3B – ORAL 12

Optimization of non-purgeable organic carbon (NPOC) analysis as a quantitative method to assess biofouling

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A method of using non-purgeable organic carbon (NPOC) analysis was developed to provide a quantitative and accurate means of measuring fouling accumulation on any surface type. The process for extracting total organic carbon was optimized to prevent damage to delicate coatings while maximizing the recovery of fouling material. Several solvents and extraction protocols were developed and compared with published methods to identify a procedure that provides 1) excellent surface cleaning, 2) minimal damage to antifouling coatings, 3) little loss of organic material due to mineralization, and 4) provides low-cost and rapid analysis for large numbers of samples. The resulting approach uses a 3% H₂O₂ solution to recover organic matter from surfaces. An optional sonication step may be used to enhance recovery when analyzing porous or highly structured surfaces, but it is typically not necessary. The potential for damage to coatings was assessed by measuring NPOC extraction from clean (non-fouled surfaces), pigment transfer to the extraction solution, and changes in surface energy. Potential mineralization of organic matter was assessed by applying the extraction protocols to known concentrations of organic carbon standards. This approach has since been used for the high-throughput analysis of 100's of diverse coatings samples and compared with other methodologies. (Funding provided by the US Department of Energy, Office of Energy Efficiency and Renewable Energy and by the Pacific Northwest National Laboratory's Chemical Imaging Initiative).

3B – ORAL 13

Determining reliable release estimates for antifouling coatings

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Antifouling coatings (AFC) play an important role in the control of biofouling. Whilst the economic and environmental benefits are recognized, active substances contained in AFC can potentially pose a risk to the environment. The US Federal Insecticide, Fungicide, and Rodenticide Act require the Environmental Protection Agency (EPA) to consider the benefits of these products along with its hazard and exposure in a risk/benefit decision. One of the most critical parameters for determining the environmental profile for AFC is the active substance release or leaching rate. Technically the type and properties of the paint film rather than the active substance properties control release. Thus, accurate and representative estimations of leaching rates are prerequisite for generating reliable environmental risk profiles for AFC products. Currently, the preferred EPA method to determining active substance leaching is the modified ASTM method. However, primarily developed to guide product development processes the method itself explicitly states that results do not to provide reliable in-service release estimates for use in environmental risk assessments. Whilst this discrepancy is recognized, EPA still considers it the best available method. Although several alternatives to the ASTM method exist and new methods are being developed, the US Navy “dome method” generates most reliable results. The dome method measures in situ active substance release rates under environmentally relevant conditions while in-service. However, high cost as well as practical and logistical challenges currently limit the applicability of the method. The presented work describes adaptations to the dome method to improve its applicability. Further, options for refining available ASTM data for overcoming existing limitations are outlined. Together, highly reliable in-service release estimates for use in environmental risk assessments and adequate for regulatory purposes can be determined.

3B – ORAL 14

Molecular mechanisms of antifouling polymers studied by submonolayer surface sensitive nonlinear optical spectroscopy in situ at buried solid/liquid interfaces

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Sum frequency generation (SFG) vibrational spectroscopy is a submonolayer surface sensitive nonlinear optical spectroscopy. It can provide vibrational spectra of surfaces and interfaces in situ, which can be used to determine the presence, coverage, orientation, and orientation distribution of various functional groups on surfaces and at interfaces. In this paper, SFG has been applied to investigate molecular structures of interfaces of antifouling polymers and water, protein solution, or bioadhesives generated by marine organisms. A variety of polymers such as zwitterionic polymers, polymers containing polyethylene glycol, silicones with incorporated biocides, as well as some control polymers were investigated. In addition to polymer structures, interfacial water structures were also examined using SFG. It was found that strongly hydrogen bonded water dominated the zwitterionic and polyethylene containing polymer surfaces in water, preventing other molecules from adsorption. Interestingly, protein molecules could not disturb the water molecules on zwitterionic polymer surfaces. Oppositely, protein molecules could disturb the water structure on polyethylene containing polymers, but could not deposit on the surface. For silicones with biocides, long chain biocide molecules stick out to the aqueous phase to prevent fouling to occur. This study demonstrated that SFG is a powerful analytical technique to probe the molecular structures of buried solid/liquid interfaces in situ in real time, providing important knowledge on antibiofouling mechanisms of polymer materials. (Research funded by Office of Naval Research).

3B – ORAL 15

Meta-analysis and effect sizes for antifouling research

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It is widely recognized in many scientific fields that single studies cannot be relied upon to give definitive answers to research questions, and that findings must be replicated to give confidence in scientific conclusions. In research areas as diverse as medicine, social policy, and environmental science, synthesis of research findings from multiple studies is carried out via systematic review and meta-analysis, which aim to combine results in carefully designed and repeatable ways. Some research fields are also moving away from Null Hypothesis Significance Testing (NHST), which focuses on using p-values to determine whether effects are “significant” or “non-significant”, towards an estimation approach which focuses on effect sizes and confidence intervals. These approaches have been underused in antifouling research and this presentation discusses three main ways in which they could be beneficial for the field. Firstly, they allow comparison of different surfaces or technology types even when these are not tested simultaneously. Secondly, they provide a standardised means of combining results from repeated tests on the same surfaces. Finally, they provide methods for exploring the effects of different variables on antifouling performance, using data from previously published studies. Example analyses will be presented using real data from laboratory antifouling assays and published literature. Antifouling researchers should consider making use of these approaches and reporting their results in ways that facilitate future meta-analyses and research syntheses.

3B – ORAL 16

Friction related leveling study of antifouling coatings using a 3D measurement system

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Improving leveling of antifouling (AF) coatings will diminish the outermost surface unevenness, which therefore reduces skin friction and sites of weakness, i.e. starting points for coating breakdown and biofouling. Consequently, it is important to improve leveling to enhance the overall performance of AF coatings, though the benefits will be meaningful only before biofouling develops. Leveling of coatings has not been widely studied, which is attributed to not only the complexity of the phenomenon but also the lack of appropriate approaches. In this work, an approach combining a 3D measurement system and a refitted automatic coating film application system was originally developed for leveling study. Although spray application produces a distribution of waviness on ship hulls, we strive to obtain representative waviness and it was found that a special made spiral applicator provided surface patterns similar to that. Using this approach, effects of coating ingredients (additives and solvents) on leveling of traditional AF coatings were studied. One wetting agent and one less volatile solvent were found to be very effective. Silicone oil showed more effects on waviness than roughness. Importantly, three leveling stages were found for low viscosity AF coatings whereas only the last stage was available for high viscosity ones, which was also well-supported by evaporation tests. (Funding provided by Blue INNOShip, CoaST and Hempel Foundation.)

3B – ORAL 17

An integrated approach for accelerated marine coating development

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Coatings are the primary method of defense against the persistent problem of biofouling for vessels, structures, and equipment in contact with marine environments. Despite the best coatings on the market today, the problem of biofouling is responsible for over \$15 billion in additional fuel costs to vessel operators, as well as costly cleaning, downtime, and loss of maneuverability for marine equipment. The need for coatings with improved fouling control performance is growing while the cost of developing new solutions is also growing with the estimated cost and time to bring a new biocide-containing product to market to exceed \$10M and >5 years. Adaptive Surface Technologies has developed an integrated approach that can effectively reduce the time and cost to bring a new marine coatings product to the market. We will present an accelerated development approach based on a non-toxic technology utilizing a liquid over-layer called SLIPS®. The demonstrated approach leverages the following factors 1) rapid synthesis of surface active components (an alternative to relying on external suppliers whose interests are dominated by other industries) 2) high-throughput surface wetting analysis, allowing for effective hypothesis development 3) development of new field testing instrumentation allowing for improved resolution of foul release performance of formulations at a faster timescale. The established relationships between composition, wetting properties and performance enable a hypothesis-driven rapid prototyping of coatings for effective fouling control in a fast, systematic and cost-sensitive manner to address the performance and environmental restrictions of current products. This work is in part funded by ARPA-E (Contract no. DE-AR0000759) and completed with generous support of Office of Naval Research.

3B – ORAL 18

Copper extraction by Glutaraldehyde-crosslinked Polyethyleneimine antibiofouling nano-coatings from model seawater system with adsorbing polysaccharides and competing ligands**S. KAUR, I. KEMPSON, J.B. LINDEN, M. LARSSON, and M. NYDEN**

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Copper release is central in today's marine antibiofouling coatings for its biocidal effect at the coating-water interface of ship's exteriors. However, copper release and accumulation causes pollution of marinas and harbours and deterioration to marine life. Our interest is to develop an environmentally friendly green coating technology involving a never-ending cyclic uptake-release of copper naturally present in the sea. Such coatings with no net release of copper can also remediate copper-contaminated marinas and harbours. Our newly developed glutaraldehyde-crosslinked polyethyleneimine (GA-PEI) coating shows a high affinity and selectivity for copper, demonstrating potential for solving the first step towards such a technology i.e. the uptake in artificial and real seawater. Any material submerged in seawater will be rapidly conditioned by a polysaccharide film. Copper binding will compete with organic ligands which may limit performance of the coatings. In this study the effect of adsorbed seawater-relevant polysaccharides and competing ligand EDTA on copper binding performance of our polymer films was investigated in an artificial-seawater model system (Kaur, 2017). Advanced analytical techniques were used, including grazing incidence X-ray absorption near edge spectroscopy, Time-of-flight secondary ion mass spectroscopy, X-ray photoelectron spectroscopy and quartz crystal microbalance with dissipation monitoring. Results revealed that in seawater a swollen polysaccharide layer allowed unhindered transport of copper into the PEI layer. Our coating outcompeted EDTA and the spatial distribution of copper species was determined with nanometre precision. The results are highly relevant for copper extraction at low concentrations in complex natural environments. S. Kaur, I. M. Kempson, J. B. Lindén, M. Larsson and M. Nydén, *Biofouling*, 2017, 1-11.

FRIDAY 29TH JUNE 2018

PLENARY 4

From ocean reef to operating room: Marine sandcastle worm-inspired medical adhesives

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Sandcastle worms are tube-dwelling marine polychaetes that use minute dabs of a multi-part, self-initiating glue, on a massive scale, to geoengineer the world's coastlines by building large reef-like structures. The sandcastle worm glue comprises distinct sets of condensed, oppositely charged polyelectrolytic components polyphosphates, polysulfates, and polyamines that are granulated and stored at high concentration in separate cell types. The pre-organized adhesive granules are secreted separately and intact, but rapidly fuse and expand into a crack-penetrating complex fluid. Within 30s of secretion into seawater, the fluid adhesive transitions (sets) into a porous solid adhesive. The nano- and microstructures of the foamy adhesive likely contribute to the strength and toughness of the adhesive joint through several mechanisms. Catechol oxidase, co-packaged into both types of adhesive granules, acts as a curing agent to covalently crosslink the adhesive, and becomes a structural component of the final adhesive joint. Three key features of the natural sandcastle glue were reproduced to create synthetic bioadhesives: i) the oppositely charged polyelectrolytic nature of the adhesive components, ii) the condensed liquid (complex coacervate) delivery form of the adhesive, and iii) the liquid to solid setting mechanism - a phase inversion triggered by environmental conditions. The biomimetic adhesive is in pre-clinical testing as an in situ setting liquid embolic agent that is deliverable through transarterial microcatheters to selectively block blood flow. (Research was funded by the Office of Naval Research (N000141612538), the National Institutes of Health (R01HD075863), and Fluidx Medical Technology, Inc.)

FRIDAY 29TH JUNE 2018: TRACK A NEW ANTIFOULING TECHNOLOGY: SESSION 2

4A – KEYNOTE 1

Meeting an emerging US Navy fleet need: Effective biofouling control coating systems for aluminum-hulled vessels

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For decades now, the underwater hulls of United States (US) Navy ships have been protected from biofouling with cuprous-oxide ablative coating systems combined with in-water cleaning. The ebb and flow of an array of naval fleet priorities - primarily rooted in readiness, military effectiveness, economics, and air/water quality - have shaped the search for advanced biofouling control technologies including biocide-based and biocide-free coating systems combined with maintenance approaches/tools. The recent introduction of aluminum-hulled ships to the Navy fleet has provided a new driver since the application of cuprous-oxide based coatings on aluminum-hulled vessels presents an unacceptable galvanic corrosion risk. Copper-free underwater hull coating systems could both mitigate this risk as well as lingering concerns over copper emissions both in terms of drydock waste streams and harbor inputs. We will present results from a series of studies rooted in traditional panel and ship patch/hull testing methods, but with purposeful modifications designed to fill key data gaps. We made changes to existing protocols used to quantify ablation rate, established new protocols to measure the response of coatings to cleaning tools, and considered the interplay between coating performance and ship activity level and the timing and frequency of inspections and maintenance events. Based on this effort, two test coatings have now been qualified for 7 years or less of service which allows them to be moved out the aluminum-hulled fleet. Additional in-service observations are planned which may lead to qualification for use on ships with substantially longer drydocking cycles.

4A – ORAL 1

Mitigate heat exchanger bio-fouling with iodine vapor infusion: The results of a two-year Navy study

M. RADICONE

I₂ Air Fluid Innovation, Inc., USA

This presentation summarizes the results of a two-year project led by the Naval Facilities Engineering and Expeditionary Warfare Center to demonstrate the potential for the patented I₂ infusion system to reduce the rate of foul within Department of Defense shipboard heat exchangers. Fouling of DoD shipboard heat exchangers is a chronic and costly operating problem that requires significant maintenance. The heat transfer performance and efficiency decrease due to the fouling of the heat exchanger plates and tubes resulting in additional fuel consumption and increased greenhouse gases. Costly and labor consuming, remedial chemical cleaning protocols currently used, produce considerable hazardous waste. Through the infusion of air containing elemental iodine vapor into the heat exchanger, this demonstration has shown that the formation of biological foul has been reduced and the period between physical cleanings extended while maintaining acceptable system parameters.

4A – ORAL 2

Novel nontoxic antifouling coatings with enhanced flexibility and durability

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We will present a study on the comparative performance of new nontoxic antifouling coatings designed to protect flexible surfaces and coatings that provide improved durability. Biomimetic surfaces have been shown to provide interesting antifouling mechanisms that potential provide nontoxic alternatives to existing paints that rely upon copper and other toxic antifouling materials. Unfortunately, many manmade biomimetic coatings are fragile making them unsuited for marine applications. We will show initial studies on nontoxic biomimetic coatings with enhanced durability as well as coatings that are effective on flexible surfaces. Testing methods and results demonstrating the low toxicity, durability, and antifouling properties of the coatings will be reported. The work presented in this study was supported by the Laboratory Research and Development Program at the Pacific Northwest National Laboratory (PNNL) and the U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy).

4A – ORAL 3

Utilizing zwitterion functionalised silica nanoparticles to fabricate biofouling resistant coatings for marine applications

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Critical to the development of antifouling coatings technologies for aquatic applications is the coupling of effective materials and chemistries with coating fabrication techniques, providing a clear avenue for the application of these coatings to industrially relevant processes. One approach that is gaining increasing interest is the application of nanomaterials to generate antimicrobial interfaces. Nanomaterials can be employed to provide specific functionality to the coating interface (i.e. catalytic interfaces), they can be modified to present appropriate surface chemistries at the material interface, and the coating fabrication method may be tailored to generate specific interfacial topographies and surface morphologies. Herein we utilize silica nanoparticles modified with zwitterionic chemistries to fabricate surface coatings using spin coating and spray coating techniques. The organisation of the surface chemistries on the silica nanoparticles can be controlled by varying the reaction conditions during particle functionalisation. We show the surfaces to be highly effective at preventing the adhesion of marine bacteria and diatom fouling species, providing a facile approach to the development of biofouling resistant surfaces.

4A – ORAL 4

Photocrosslinked polyzwitterionic polymers as ultralow fouling coatings

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The development of materials with the capability to resist the accumulation of biomass on surfaces in contact with seawater is both, economically and ecologically desired. Zwitterionic polymers show high resistance against differently charged proteins, bacteria [1], and marine organisms [2]. Various methods were used to obtain zwitterionic coatings [1-4]. While self-assembled monolayers enabled us to understand the relevance of charge neutrality and to reveal the effect of different anionic and cationic groups [5,6], the zwitterionic functionality has ultimately to be embedded into polymers for technical applications [7]. Here we present a new method to obtain photocrosslinkable zwitterionic coatings. Zwitterionic methacrylates were co-polymerized with benzophenonemethacrylates to obtain a photocrosslinkable polymer. We applied the polymers by spin-coating and subsequent photocrosslinking. The obtained coatings were characterized by AFM, IR, and XPS prior to biological testing. To test the impact of the molecular architecture, the charge arrangement of cationic and anionic groups was altered. All surfaces were characterized with respect to protein resistance by SPR, exposed to microfluidic diatom tests and tested against colonization of zoospores of the green alga *Ulva linza*. On the basis of the obtained data, design criteria for optimized zwitterionic components for fouling-release technologies will be discussed. Research funded by ONR N00014-16-12979, DFG RO2524/4-1. (1) Cheng et al., Biomaterials 2009, 30, 5234-5240. (2) Yang et al., ACS applied materials & interfaces 2017, 9, 18295-18304. (3) Lange et al., Langmuir 2016, 32, 10199-10205. (4) Colak., Biomacromolecules 2012, 13, 1233-1239. (5) Bauer., Langmuir 2016, 32 (22), 5663-5671. (6) Chen., Langmuir 2006, 22, 8186-8191. (7) Jiang., Adv. Mater. 2009, 21, 1-13.

4A – ORAL 5

UVC anti-fouling solution: device design simulation and experimental verification

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AkzoNobel and Philips are jointly developing a fouling prevention solution based on UV-LEDs. The innovative concept is based on the transport of UVC light, which is generated by LEDs embedded inside a multilayer film system. The device is designed such that the outer surface of the film is irradiated with the UVC light, thus preventing fouling settlement. The design of the device is informed by optical simulation based on input of optical material and LED properties, device geometry and knowledge on the minimum UVC threshold intensity required for fouling prevention. In this presentation, we will provide experimental data from lab patch studies, together with successful in-field fouling prevention tests ranging those conducted in collaboration with DST Group and FIT to the first in-service trials of the concept on ocean going vessels. The most recent insights and advances relating to the technology enablers of the device concept, e.g. the optics approach, the UVC LED technology, the powering solutions, and the mechanical design will also be discussed.

4A – ORAL 6

Functionalized siloxane-based surface active block copolymers:
Controlling surface chemistry and antifouling performance

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Marine biofouling is a major problem affecting naval operations and aquatic industries, leading to increased drag, additional fuel consumption, hull damage, and/or added maintenance costs. With increased scrutiny on biocidal coatings, environmentally benign alternatives must be explored. This requires greater understanding of how surface chemistry and surface structure affect antifouling performance. This work seeks to do this through the use of a system of di- and triblock copolymers of polystyrene-poly(methyl vinylsiloxane-random-dimethylsiloxane) (PS-b-P(MVS-ran-DMS) and PS-b-P(MVS-ran-DMS)-b-PS) that were designed as a non-toxic hydrophobic, low surface energy backbone material with a vinyl moiety capable of being functionalized via thiol-ene “click” chemistry. This backbone provides a customizable platform for screening a wide array of functional groups to systematically explore their effect on antifouling and fouling release characteristics. Attachment of hydrophilic side groups creates an amphiphilic surface capable of reducing settlement and increasing release of three model marine species. Redox active stable radical groups attached to the backbone disrupt settlement and adhesion of barnacles which use oxidative adhesive curing. The antifouling performance of these materials was investigated through collaborative study of settlement, attachment, and removal of fouling organisms and correlated to polymer structure and surface chemistry. (Funding provided by the Office of Naval Research).

4A – ORAL 7

Comparative antifouling efficacy of hydrophilic chemical species presented
as polymer brushes and bulk polymer systems

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The aim of this study was to compare antifouling efficacy of well-defined hydrophilic polymer brushes with more industrially relevant bulk polymers. These two distinct polymer systems were produced by random co-polymerization of butyl methacrylate with the same range of hydrophilic co-monomers, including zwitterionic sulfobetaine methacrylate, ionic sulfopropyl methacrylate potassium salt, methacryloxyethyltrimethyl ammonium chloride salt and non-ionic methyl-terminated polyethylene glycol 350 methacrylate. Polymer brushes were 'grafted-from' glass using Reversible Addition-Fragmentation chain Transfer polymerization and characterized using X-Ray Reflectivity and X-Ray Photoelectron Spectroscopy. Surface energies of both systems were also calculated in the hydrated state. Finally, the brush and bulk systems were tested for settlement of barnacle cyprids, *Balanus improvisus*, and the attachment strength of settled barnacle juveniles and cells of *Navicula incerta* using a turbulent flow-cell. The laboratory-based assays were accompanied by in-field tests conducted in temperate and tropical waters. The data obtained suggest that antifouling performance was significantly better in the bulk systems compared to the polymer brush systems. The study revealed that the best fouling-resistant chemistries comprised ionic functionalities, with zwitterionic sulfobetaine being most effective in suppressing marine biomass attachment and growth. (Research funded by AkzoNobel/International Paint and COST Action CA15216).

4A – ORAL 8

Novel technologies for the dynamic removal of fouling from submerged surfaces

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The build-up of fouling organisms is a challenge faced by nearly all submerged surfaces, with even modern fouling-release coatings experiencing biomass accumulations over time under static conditions. This becomes especially problematic in complex and hard to reach corners of marine structures and equipment, such as the interior of pipes, leading to blockages and the need for extensive maintenance operations. Looking into novel ways to address this challenge we are investigating dynamic cleaning techniques that allow for the remotely removal of attached biomass by exploiting the interplay between fouling organisms and fundamental material properties of both passive substrates and novel fouling-release technology. One such experimental technique involves the “bulldozing” of adhered biofilms using ferrofluid droplets remotely controlled by magnetic fields, while another is the incorporation of a vascularized network into a slippery FR surface allowing both for aeration treatment and lubricant replenishment, making use of the natural affinity of slippery coatings for air bubbles to enhance potential cleaning effects. The potential advantages, applications and limitations of these novel cleaning techniques will be discussed.

FRIDAY 29TH JUNE 2018: TRACK A
 NEW ANTIFOULING TECHNOLOGY: SESSION 3

4A – KEYNOTE 2

SPC Technology: What lessons can we learn from the pioneers?

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The early development of SPC technology gives a useful insight into the challenges faced by anyone wishing to bring new fouling prevention technology to the Marine and Yacht market. Colin Anderson started his career in antifoulings just after the first SPC was launched more than 40 years ago, and in this presentation shares some stories of the people, products and problems that had to be overcome to achieve success.

4A – ORAL 9

The development of a UV-C fouling prevention system for ship hulls

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AkzoNobel and Philips are jointly developing a pioneering fouling prevention system based on UV-LED technology; by combining AkzoNobel's coating formulation, surface protection and adhesion know-how with Philips' capability in UV-LED lighting and electronics, the two companies are aiming to develop an economically viable solution for the prevention of fouling settlement. The approach is based on the use of ultraviolet (UV) light which is known to have an effect on biological organisms, the severity of this effect is dependent on the target species, dose and wavelength of the UV light. This technology concept integrates low intensity UV light emitting diodes (LEDS) in a protective film scheme which is designed to allow the UV light to be emitted from the surface, thus providing the total prevention of biofouling accumulation on the protected area. This presentation details both the laboratory and in-field fouling prevention testing of the latest prototype devices and outlines the forthcoming stages of product development including technology sourcing, materials selection, scale-up, test patching and vessel trials.

4A – ORAL 10

Selektepe in non-traditional marine paint matrixes

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Common marine paints today are usually either Controlled Depletion Coatings (CDP), Self Polishing Coatings (SPC) or Foul Release Coatings (FRC). Even though these coatings systems performance improve continuously they occasionally get fouled and the hull needs to be cleaned. Unfortunately, these coatings, especially FRC, are not very resistant towards impact and abrasion. Cleaning/grooming can reduce the lifetime of the coating surface or, in worst case, can destroy the surface completely. Cleaning activities will most likely increase in frequency as regulatory demands for a clean hull free of fouling when entering certain ports/harbours or countries are increasing. Hence, more cleaning will likely damage softer coating systems. In this presentation, addition of Selektepe to matrixes which are more resistant towards cleaning, while still offering good antifouling properties will be discussed. The presentation will also discuss material that can be used for other marine applications, where traditionally it has been hard to protect against fouling.

4A – ORAL 11

SEANINE® R397: New generation marine antifouling agent

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Marine biofouling is challenging for the ship industry. Fouling of the ship's hull will result in speed reduction, increased fuel consumption, and a higher frequency of dry-dockings. Currently, copper based self polishing paints, e.g., cuprous oxide, along with booster biocides, are the dominant products in the anti-fouling paint market. Ideally, self-polishing paint systems prevent fouling through the slow and steady exposure of anti-fouling actives at the surface of the paint film. However, in some paint systems, an inconsistent biocide release has been observed, which results in fouling performance deterioration at an early stage. Based on the US EPA Green Chemistry Award Winning Technology SEANINE® 211N Marine Antifouling Agent, Dow Microbial Control has developed SEANINE® R397 Marine Antifouling Agent, a highly effective, rapidly biodegradable marine antifouling agent, developed for use in the new generation of environmentally preferred marine antifouling paints for ships and marine structures. SEANINE® R397 Marine Antifouling Agent introduces a state-of-the-art, proprietary micro-encapsulation technology to control the release of the active ingredient. This new technology provides higher formulation flexibility, as it allows the marine antifouling agent to be used as a co-biocide to prevent soft fouling organisms or to extend it to prevent hard fouling. We will demonstrate the advantages of SEANINE® R397 Marine Antifouling Agent through a combination of field testing and laboratory data.

4A – ORAL 12

On the way to biocide free foul release coatings

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Starting out from an established product class, an amphiphilic silicone-hybrid resin was developed, which can be used as a binder for foul-release coatings. A hydrophobic silicone-epoxy resin, with its strong anti-adhesive properties, was combined with a hydrophilic polymer. On contact with water, the hydrophilic moieties will develop a hydrate layer around the polymer, and therewith create a film of water on top of the surface. This layer will mask the ship's hull from surrounding organisms and they will refrain from settling on the solid surface. Furthermore, the hydrophobic silicone backbone adds an easy-to-clean effect to the coating. The foul release properties of this binder were tested in newly developed laboratory tests. In one method, a mesocosm was created in a special aquarium. Over a period of six weeks, the coated panels were exposed to conditions comparable to an algal bloom under static conditions. This was followed by one week of rotation, simulating a moving vessel and releasing loosely attached organisms. In addition, a microcosm test was carried out, employing co-cultures of diatoms and bacteria. The results from both tests were in accordance with the results from seawater exposures, indicating that the amphiphilic silicone-hybrid polymer can serve as a binder or co-binder for foul-release coatings.

4A – ORAL 13

Gel encapsulated biocide in anti-fouling paints for large vessels and ships

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EnCoat has shown that silica aerogel encapsulated zinc pyrithione is effective in controlling leaching in an anti-fouling yacht paint without cuprous oxide or zinc oxide and without losing technical properties relative to commercial solvent-based anti-fouling paint. During 2017 focus has primarily been on a different pyrithione in encapsulated form to prove similar anti-fouling efficacy on rafts compared to a commercial product. The raft tests took place in several locations with varying water quality (salinity and temperature). The general outcome was favourable, but we want to optimize the performance of the technological platform further. In these endeavours, the influence of temperature on water absorption was investigated for the formulated and tested paint. Aiming at a better understanding on how the encapsulated material interacts with other materials in the paint formulation, a test setup was carried out whereby a selection of paint formulation parameters and their interactions were analyzed. The paints formulated were tested as dry films with regard to water absorption and polishing. Leaching was investigated for the most interesting samples. The water absorption of the dry film was found to depend on a couple of paint formulation parameters, and in some cases in a non-linear fashion. The overall aim is to be able to adjust water absorption, leaching and polishing rate in the antifouling paint to be acceptable for larger vessels and ships durability according to state of the art. Today, anti-fouling paints for larger vessels or ships contains large amounts of cuprous oxide. A substantial reduction of this biocide without loss of efficiency made possible by the encapsulation technology, will significantly reduce the raw material cost as well as the environmental impact of an anti-fouling paint.

4A – ORAL 14

SLIPS amphiphilic hybrids as promising environmental fouling control coatings

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Non-toxic fouling control solutions are highly desirable given the uncertainty of regulatory restriction on anti-fouling coatings with active biocides. Slippery Liquid Infused Porous Surfaces (SLIPS) are a commercially viable non-toxic material solution for biofouling control. Unlike traditional fouling release coatings, SLIPS® present a slippery surface which results in self-cleaning properties. We report combining SLIPS® materials with surface active amphiphilic compounds also known to have fouling control properties. The resulting SLIPS® amphiphilic hybrid surfaces show a synergistic combination of surface behavior associated with effective incorporation of both technologies into a fouling control surface. The surfaces maintain low sliding angle associated with SLIPS, and also displaying dynamic wetting behavior associated with the presence of amphiphilic surface. Laboratory and field test results suggest that SLIPS® amphiphilic hybrids demonstrate a new and promising combination of technologies with effective fouling release performance. This work is in part funded by ARPA-E (Contract no. DE-AR0000759) and completed with generous support of Office of Naval Research.

4A – ORAL 15

Non-leachable hydrophilic additive for amphiphilic fouling release coatings

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Amphiphilic surfaces are particularly effective in inhibiting the development of biofouling and are a very good alternative to existing commercial biocidal coatings. However, although performing well under certain conditions of use, fouling release coatings (FRC) have a very low efficiency in static exposure and require improvements. In addition, toxic paints based on the release of biocides tend to have their use prohibited or restricted. Obtaining the amphiphilic character is achieved by the addition of a hydrophilic moiety to a hydrophobic silicone matrix. Nevertheless, their chemical incompatibility leads to a release of these compounds (polymers, additives, oils, uncross-linked materials) and their persistence in water system is a potential threat to marine environments. The aim of this study is to determine how to increase bonding capability between the hydrophilic and hydrophobic part. This bonding should prevent release of compounds in seawater and increase amphiphilic character sustainability. Poly(ethylene glycol) (PEG) has been used as hydrophilic part with different parameters (molecular weight, kind of linkers and terminal functions). Poly(dimethylsiloxane) (PDMS) of two different molecular weight have been used as hydrophobic matrix. The efficiency of the cross-linking, the ability of PEG functions to access to the coatings surface and the film homogeneity have been evaluated by different technics. Results have shown that use of PDMS copolymers allows the best retention and furthermore prevent release of silicon oils in seawater. PDMS acts as linker to increase the compatibilization during the cross-linking. This structure comprising a cross-linking function attached to the PDMS/hydrophilic copolymer has therefore a high potential as non-releasable additive for amphiphilic FRC applications. Acknowledgments for financial support: French National Research Agency, University South Brittany.

Self-cleaning polydimethyl siloxane/metal alloy nanocomposites with marine antifouling property

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Biofilm formation on the surface of sensor housing has posed a potential threat to long time use of sensor. In addition, fouling of this area can also lead to inaccurate measurement due to sensor drifts. This paper developed a facile method to synthesize a series of polydimethyl siloxane(PDMS)/metal alloy nanocomposites, which have been coated on sensor housing. It proved that the coating layer has both self-cleaning property and marine antifouling property, while PDMS contributes to self-cleaning property due to low surface energy and low roughness, and metal alloy nanoparticles contribute to antifouling property. Moreover, the addition of metal alloy nanoparticles increased mechanical property of PDMS, which can overcome the easily damaged problem of PDMS in practical use. The antifouling, wettability, morphology and composition of coating materials were studied by confocal laser scanning microscopy (CLSM), water contact angle (WCA), scanning electron microscopy (SEM) and fourier-transform infrared spectroscopy (FTIR) separately.

FRIDAY 29TH JUNE 2018: TRACK B

BIOADHESION: NATURAL & BIOMIMETIC ADHESIVES

4B – KEYNOTE 1

Local environmental conditions affect the adhesive strength of benthic marine organisms

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Marine organisms that form secure attachments to hard substrates, especially mussels and barnacles, have long served as inspiration for the development of man-made underwater adhesives. Key advances have emerged from detailed laboratory analyses of the molecular composition, structure and mechanics of the adhesives and their components, under a range of conditions that are typically static. Coastal ocean environments, however, are notoriously dynamic in time and space and are subject to local scale (on the order of mm to m) modification by the aggregate metabolic activity and structure of the organisms themselves (= ecosystem engineering). Several recent studies by our research group and others, largely motivated by an interest in understanding the effects of changing ocean climate on the ecology of marine organisms (e.g., mussels, macroalgae), will be presented to illustrate how environmental conditions alter bioadhesive maturation and strength, in some cases reversibly. These studies underscore the value of using an ecological perspective in evaluating structure-function relationships of biological materials, which can in turn inform the bioinspired design of novel adhesives and new strategies to manage the biofouling activities of marine organisms. (Funding provided by National Science Foundation, Washington SeaGrant and University of Washington)

4B – ORAL 1

In vivo confocal microscopy reveals phase-separating secretion clears the way for barnacle adhesion

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Marine macro-foulers (e.g, barnacles, tubeworms, mussels) create robust underwater adhesives capable of attaching themselves to almost any material. While proteomic analysis has provided insight into the chemical composition of these natural adhesives, developing synthetic analogs that mimic their performance remains a challenge due to an incomplete understanding of adhesion processes. Through the use of in vivo confocal microscopy with multiple fluorescent probes, we have identified that acorn barnacles (*Amphibalanus* (= *Balanus*) *amphitrite*) secrete a phase-separating surfactant mixture to clean and protect the surface ahead of growth and cement deposition. This mixture consists of a phenolic laden gelatinous phase that holds a phase rich in lipids and reactive oxygen species at the seawater interface. This secretion oxidizes and lifts off adhered biofilms surrounding the barnacle base as it expands. These findings show barnacles repurpose phenolic chemistries ubiquitous to adhesives and cuticles as part of their own antifouling strategy. The discovery of this critical step in underwater adhesion represents a missing link between natural and synthetic adhesives, and provides new directions for the development of environmentally-friendly biofouling solutions.

4B – ORAL 2

Exploring the cyprid “footprint” proteins:
Adhesion behavior by AFM-based force spectroscopy using trace amounts of sample

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The cyprid, the penultimate stage of the barnacle, explores substrates for sites of settlement and secretes temporary adhesive proteins deposited as footprints during surface selection. The footprint proteins not only serve as the temporary adhesive proteins, but also function as conspecific pheromone for other cyprids. Understanding the footprint proteins' nano-mechanic property and adhesion behavior can help design effective antifouling coatings. The atomic force microscopy (AFM) was used to study the parameters as surface charge and wettability on the footprint protein morphology in seawater conditions. To further explore the nano-mechanical property of the footprint proteins, the colloidal AFM based force spectroscopy method was firstly developed. The footprint proteins were immobilized on AFM colloidal probes and the adhesion force between footprint proteins and surfaces were studied. The effect of surface charge and wettability on the footprint proteins' adhesion behavior was systematically studied. By using the AFM based force spectroscopy method, we for the first time obtained the isoelectric point of the footprint proteins of barnacle cyprids in the range of 9.6 - 9.7.

4B – ORAL 3

Sticking like barnacles: Unraveling and mimicking a natural adhesive

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Barnacles produce a micron-thick layer of ordered amyloid-like nanofibers from proteins that function as a permanent wet adhesive. Recent proteomic work from our lab shows that barnacles achieve this largely through display of complex charged chemistries using small and flexible side-chains, folded in a manner similar to adhesive silks used by spiders and insects. Their well-defined, modular, nature result in novel biomaterials that serve many purposes: adhesion, durability, bacterial resistance, and even potent enzymatic activity. Fibers are shaped by a highly conserved domain alternating between short 20-residue low complexity sequences (Gly/Ser/Thr/Ala residues) and regions with charged and aromatic side chains, with more than 80 such domains in just five proteins. The adhesive properties of these unique sequences and their function in an amyloid-like structure remain unclear. To study this, we produce miniaturized synthetic peptides from consensus barnacle cement sequences and also insert sequences into a host amyloid system of bacterial fimbriae to produce abundant and engineered wet adhesive mimics. Short synthetic peptides demonstrate that certain cement sequences specifically recognize and activate cement polymerization to form bioinspired nanomaterials. Further, bacterial biofilms are demonstrated to be a viable route for the growth of recombinant cement fibrils. These materials are characterized by AFM-based nanomechanical measurements and compared to the Wild-Type barnacle adhesive. Synthetic and recombinant adhesive materials provide a route to scale up and study a scarce but potent class of multifunctional adhesive nanostructures produced by one of the most tenacious marine fouling organisms in the ocean.

4B – ORAL 4

Dopa-incorporated bioengineered mussel adhesive proteins and their use in adhesion mechanism study

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Marine mussels secrete mussel adhesive proteins (MAPs) for their adhesion with fascinating properties such as strong adhesion to various material substrates, water displacement, biocompatibility, and controlled biodegradability. Investigation of mussel adhesion mechanism is regarded to be very important to understand mussel's underwater adhesion and to develop various mussel-inspired functional materials for a wide range of applications as underwater bioadhesives. Due to difficult natural extraction and limited availability of MAPs, recombinant protein expression was expected to contribute not only to replace natural extraction as an alternative strategy with sufficient productivity applicable for developing underwater bioadhesives but also to investigate mussel adhesion mechanism. Here, we present production of 3,4-dihydroxyphenylalanine (Dopa)-incorporated recombinant interfacial MAP type 3 fast variant (fp-3F) and type 5 (fp-5) which is similar with natural MAPs, and investigation on Dopa-Fe³⁺ complexation and its role at the substrate-plaque interface. We successfully produced Dopa-incorporated recombinant interfacial MAPs containing a large amount of Dopa using in vivo residue-specific unnatural amino acid incorporation method. The Dopa incorporation yield was over 90% which is similar with natural interfacial MAPs and Dopa-incorporated recombinant MAPs showed greatly enhanced surface adhesion in dry and underwater environments and strong water resistance. Also, Dopa-Fe³⁺ complexations of Dopa-incorporated recombinant fp-3F and fp-5 were observed suggesting the possibility of Dopa-Fe³⁺ complexations at the plaque-substrate interface by natural fp-3F and fp-5. The force measurements using surface forces apparatus analysis were performed with regard to Dopa-Fe³⁺ complexation and finally the potential role of Dopa-Fe³⁺ complexation was suggested as a regulator of Dopa functionality switching from surface adhesion to cohesion, in response to the microenvironment.

4B – ORAL 5

Biophysical characterization and three dimensional structure studies of
Megabalanus rosa (Acorn barnacle) cement protein - Mrpc20

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Biofouling poses serious challenges to the maritime industry, and the development of antifouling coatings requires in-depth understanding of molecular mechanisms by which fouling organisms are able to tightly adhere to solid substrates. Barnacles are one of such aggressive marine macrofoulers. These organisms secrete "cement proteins" to adhere to solid surfaces and the cement has been proposed to be a complex of at least 5 proteins (Mrpc 100, Mrpc 68, Mrpc 52, Mrpc 20 and Mrpc 19). However our understanding behind the mechanisms of adhesion of these proteins at the molecular level remain sparse. Quartz Crystal Microbalance with Dissipation (QCM-D) studies of recombinant Mrpc20 proteins on metal oxides like TiO₂ and SiO₂ suggest strong and irreversible protein adsorption on these surfaces. Circular Dichroism (CD) studies indicate that in solution, the protein adopts a mixture of helices and β -sheets (60%) and the remaining 40% is dynamic. With these preliminary data, we have proceeded to determine the 3D structure of this protein in solution. Nuclear Magnetic Resonance spectroscopy (NMR) is a powerful tool that we are using to determine the structure and fold of Mrpc20 at the molecular level. In particular, our recent 2D NMR studies shedding light on the 3D structure of Mrpc20 will be presented. Once the 3D structure of the adhesive protein is determined, studying and understanding the adhesion mechanisms and the conformational changes upon binding to substrates is greatly facilitated.

4B – ORAL 6

Adhesive proteins from synthetic biology

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Nature has evolved a handful of adhesive proteins with attractive underwater-adhesion properties. Recent studies on these natural adhesive proteins have largely advanced our understanding of their structures and adhesive mechanism. However, very few have been used for human applications due to limitations in harvesting these natural adhesives in large amounts. To overcome this limitation, we harnessed the biosynthetic power of microbes and developed a strategy to overproduce natural adhesive proteins using engineered *Escherichia coli*, yielding grams of recombinant mussel adhesive proteins (mfps). We further developed a native chemical ligation method to synthesize high molecular weight mfp oligomers. We demonstrated that recombinant mfps with higher molecular weights displaying stronger underwater adhesivities than the recombinant mfp with natural size. Thus, our work has provided a method for the facial synthesis of recombinant adhesive proteins with better properties in large quantities.

4B – ORAL 7

Mussel-inspired polyesters with aliphatic pendant groups demonstrate the importance of hydrophobicity in wet adhesion

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Mussel adhesion has fascinated scientists for their ability to adhere to underwater substrates. They do this by the secretion of adhesive proteins underwater in a temporal fashion. The mixture of proteins secreted by mussels are tuned to provide both adhesive and cohesive interactions with the substrate. Synthetic adhesives in comparison are for the most part are compromised in an aqueous environment due to their inability to prevent water penetration into the adhesive interface. We will present our work on the design and evaluation of synthetic polyesters that demonstrate strong underwater adhesion. The polyester is designed to flow at room temperature that enables application without any solvent. Catechol units of the polymer provide adhesive contacts with the substrate. The applied polymer is subsequently cured to a crosslinked polymer providing cohesive interactions. Lapshear measurements show strong adhesion even when the polymer is applied underwater and cured. Our current results indicate that the hydroxyl groups of catechol play a role in adhesion and that a hydrophobic environment is necessary for synthetic adhesives to show good performance in wet environments. We will also describe fundamental studies regarding the nature of the adhesive interface as revealed by sum frequency generation spectroscopy and JKR measurements.

Control of surface adhesion and cohesion is dictated by lysine in
underwater adhesion system of marine mussel

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Mussel adhesion is the most well-known system for underwater adhesion, and 3,4-dihydroxyphenylalanine (Dopa) has been considered as the key molecule in underwater adhesion from the intensive studies. Although many secrets of mussel have been unveiled, we still have a little understanding about how mussel controls the balance between surface adhesion and cohesion which is critical feature for successful adhesion. In this work, we focused on lysine (Lys) which is also a major building block of interfacial mussel proteins, but has acquired less attention compared to Dopa. We first designed peptides inspired by foot protein type 3 fast variant of *Mytilus californianus* (Mcfp-3F) to investigate how Lys affects underwater adhesion of Dopa with respect to the distance between Dopa and Lys. Nano-scale surface adhesion and cohesion forces were measured using surface forces apparatus (SFA) with the designed peptides, and NMR analysis was performed to explain its phenomenon. We also re-designed two biased proteins from Mcfp-3F and biosynthesized in bacterial expression system. Sequentially, same nanomechanic measurements were performed to confirm our findings from the peptide study. We expect this study could explain how nature assigns the roles of Dopa in underwater adhesion of marine mussel, and could also give insights in designing biomaterials for underwater adhesion.

FRIDAY 29TH JUNE 2018: TRACK B MARINE BIOFILMS ON NATURAL & ARTIFICIAL SURFACES

4B – KEYNOTE 2

The biofilm as efficient, adaptive and structured systems on surfaces

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Under the fluctuating environmental conditions that characterize oceans, the preferred mode of microbial life is the “biofilm” - a collection of cells and extracellular organics usually attached to a surface. The biofilm, when viewed up close, begins to reveal specific structures, properties and highly-organized features, which contribute to its unique properties and make it very different from those of planktonic cells. Biofilms will form on almost any surface placed in seawater. The biofilm, by its very design, strengthens attachment and enhances the adaptability and survival of the cells, making it difficult to control or remove from surfaces. The critical emergent property of biofilms is their secretion of extracellular polymer secretions (EPS); which facilitate their diversity and unique adaptability. EPS form a 3-dimensional matrix from which cells localize extracellular activities and conduct cooperative interactions that cannot be accomplished efficiently by free-living cells. EPS occur in a range of molecular sizes and include polysaccharides, proteins, lipids, and nucleic acids as actively-secreted components. Many EPS are highly-sorptive and provide a diffusion-slowng microenvironment, which sharpen small-scale (μm) biogeochemical gradients. Together, these organized communities can engineer biogeochemical precipitation, resulting in construction of giant-microbial macrostructures. Conversely, coordination can facilitate microbially-mediated corrosion and mineral dissolution. Adaptability within biofilms is centered in the EPS matrix, which allows cell-cell chemical communication (i.e. quorum sensing), extracellular digestion of sorbed organics, and facilitates efficient horizontal-transfer of genes. These allow cells to persist even in the presence of toxic antimicrobial measures. Finally, biofilms are prominent in “extreme” environments ranging from sea-ice communities to hypersaline systems to the high-temperatures/pressures of hydrothermal-vent systems. This overview summarizes some of the most elusive properties of biofilms on natural and artificial surfaces in oceans.

4B – ORAL 9

Profiling the biofilm community composition of an important coral settlement substratum and its response to local and global stressors

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Crustose coralline algae (CCA) are vital to healthy coral reef ecosystems and provide settlement cues for a variety of invertebrate larvae including corals. For some corals, settlement, which is an integral part of the recruitment process, appears to be dependent on the presence of chemical cues produced by biofilm bacteria associated with CCA. The biofilm communities on CCA are species specific and may be related to preferences exhibited by some coral larvae during settlement. In choice assays, the threatened Caribbean elkhorn coral, *Acropora palmata*, prefers to settle on the CCA *Hydrolithon boergesenii* over a co-occurring CCA species, *Paragoniolithon solubile*. Even for less choosy coral species, *H. boergesenii* provides an adequate settlement substratum. As a result, this species of CCA has been used as a settlement substratum for a variety of experiments looking at the impacts of various stressors on coral settlement processes. Changes to the bacterial biofilms of *H. boergesenii* were monitored as part of these larger experiments. Analysis of these data demonstrates the impact of algal contact (*Styopodium zonale* or *Halimeda opuntia*), ocean acidification, and increased seawater temperature on the surface bacteria communities associated with *H. boergesenii*. Bacteria may be critical to the identification of appropriate settlement habitat by corals. Understanding how local and global stressors affect bacterial biofilm communities is a necessary and often overlooked part of the broader ecosystem impact.

4B – ORAL 10

Kinetics of multi-species biofilms on artificial surfaces in static and dynamic mode using a multi-omics approach

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Microbial biofilm formation in the marine environment can directly impact artificial surfaces and indirectly influence macro colonizers settlement. Experimental designs with different types of antifouling coatings (self-polishing coating, SPC and fouling release coating, FRC; polyvinyl chloride, PVC as control) immersed in the Toulon Bay (North-Western Mediterranean Sea) was developed under static or dynamic modes. Samples were evaluated from 24h to 1-year immersions, for cell count (flow cytometry), microbial taxonomy (16S rRNA metabarcoding) and LC-MS-based metabolomics. Microbial community successions were affected by both immersion mode and surface type. Although increasing with time, cell density was significantly affected in both FRC and SPC in comparison to PVC, with a significantly stronger impact of the dynamic mode. Copper-based SPC diminished significantly and lastingly the biofilm diversity, conversely to the FRC which effect was limited to first weeks. Multidimensional analyses also showed that, in both immersion mode, SPC exhibited specific communities whereas FRC and PVC ones tend to converge. The dynamic rotation promoted a strong selection on the community including on the PVC. In general, Flavobacteriaceae and Rhodobacteraceae were the most abundant families, but on SPC, the Alteromonadaceae were prevalent (>90%) in the static mode and Erythrobacteraceae (>50%) in the dynamic mode. Metabolomics and taxonomic analysis were correlated, and better values are obtained in more resolute taxonomic levels. Further analysis of metabolomics data and functional prediction from taxonomy can help to elucidate how the community established in the various experimental conditions.

4B – ORAL 11

Biofilm diversity on foul release coatings: a metagenomics approach

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Marine biofilms (mainly composed of bacteria, diatoms, spores/larvae of macro-organisms) constitute an important component of the overall biofouling process i.e. accumulation of marine macro-organisms (e.g. algae, barnacles, ascidians) on artificial surfaces. The maritime industry is largely affected by biofilms as they can increase roughness on ship hulls therefore impacting the ship's hydrodynamics, leading to higher CO₂ emissions and fuel consumption. Current antifouling (AF) coatings, mainly Foul Release Coatings (FRCs), inhibit colonization of macro-organisms, however biofilms remain an issue as they tenaciously adhere on FRCs. Very little is known about the overall biofilm species composition, especially when formed on FRCs, therefore it is crucial to gain knowledge on biofilm biodiversity. In the current work we investigated the biofilm community composition found on FRC coatings (plus controls) and exposed in two different sites, Southampton, UK and Genoa, Italy via Next Generation Sequencing targeting the 16s rRNA and 18s rRNA. Overall PCO analysis showed clear OUT clusters with site and surface properties. For the 16s rRNA analysis, Cyanobacteria were the main phylum in Southampton while for the Genoa site it was Proteobacteria and Bacteroidetes. On FRCs these main taxa were significantly reduced when compared to the controls. For eukaryotes, the FRCs significantly decreased crustacean presence in both sites, while the diatom genus *Navicula* was abundant in Southampton but not in the Genoa, however when compared to the controls, FRCs showed reduced abundance. We believe that data like the ones we present here, will aid the AF industry towards a more informed coating design.

4B – ORAL 12

Characterisation of marine biofilms: In search of robust predictors of drag

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Biofilms, characterised by their inherent persistence, present a universal fouling challenge. The resilience of biofilms to physical and chemical stresses, combined with the diversity of environmentally-responsive biological, chemical and physical properties, means that biofilms will eventually grow on all currently known marine coatings when exposed to real world operating conditions. The AkzoNobel Fouling Control R&D teams are incorporating investigatory methods from across the multi-disciplinary fields of biofilm science to better understand biofilms that form on all marine surfaces, whether coated or not, in an effort to improve our coating development processes. Hull surveys of newly dry-docked ships around the world, and analysis of coating panels that have been immersed in-field show that, even visually, not all marine biofilms are the same. Variance in biofilms, attributed to differences in both the composition and community, results in differences to the frictional drag. This presentation describes ongoing work aimed at fully characterising marine biofilms in order to define a biofilm metric that is a robust predictor of the associated drag penalty. The application of techniques which range from traditional imaging methods to Optical Coherence Tomography (OCT) and from HPLC pigment analysis to metagenomic sequencing will be presented and the relationship between biofilm physical properties and hydrodynamic drag discussed. The authors gratefully acknowledge funding received from the European Union Seventh Framework Programme in the SEAFRONT project (grant agreement 614034); the Royal Commission for the Exhibition of 1851; InnovateUK and BBSRC (Management and Use of Biofilms Programme).

4B – ORAL 13

Application of chitosan-ZnO nanocomposites in biofouling prevention

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Chitosan is a promising material possessing antimicrobial, antifungal and anti-algal properties which can be obtained from partial deacetylation of waste crustaceans' shells. In the current study, we fabricated a chitosan-ZnO nanocomposite coating and investigated its application to biofouling prevention and active food packaging. Antifouling properties of the chitosan-ZnO nanocomposite coatings were studied in both laboratory and mesocosm experiments using species of marine bacteria and diatoms, as well as larvae of the bryozoan *Bugula neritina*. The nanocomposite coating inhibited the growth of bacteria and diatoms in comparison with chitosan only coatings and unprotected controls. The chitosan-ZnO nanocomposite coating on polyethylene (PE) films was also used for active food packaging. The effect of this packaging on quality and shelf life of the vegetable okra *Abelmoschus esculentus* was evaluated. PE films coated with the nanocomposite prevented the growth of food pathogens, such as *Salmonella enterica*, *Escherichia coli* and *Staphylococcus aureus*, after 24-h incubation. Additionally, this nanocomposite coating helped in preserving the quality of okra samples by maintaining moisture content, total soluble solids and pH. These results demonstrate the promise of chitosan-ZnO nanocomposite coatings that can be utilized in diverse industrial applications in the future.

Photocatalytic nanocoatings for the mitigation of microbial biofouling

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Biofouling of aquaculture installations has heavy penalties. Usually, biofouling is prevented by application of antifouling coatings that contain toxic biocides, like copper. Due to high toxicity of such coatings, low toxic and non-toxic solutions are urgently needed. The natural antifouling defense mechanisms of some seaweeds inspired us to mimic this process by fabricating ZnO photocatalytic nanocoating. In this study, we investigated formation of biofilms on uncoated fishing nets (control), nets coated with copper-based antifouling coating and experimental photocatalytic nanocoating. Nanocoatings reduced 3-fold abundances of microorganisms and performed better than the commercial coating. MiSeq next generation sequencing of 16S and 18S DNA genes proved that nanocoatings compare to the commercial coating was not selectively enriching prokaryotic and eukaryotic communities with pathogens and the resistant species. Moreover, microbial communities developed on nanocoatings and control substrata showed some similarities and were very different from ones on the commercial coating. Our preliminary results suggested that the antifouling effect of experimental nanocoatings was localized and the toxicity to non-target species was minimal. In summary, we have successfully developed sunlight-responsive antifouling ZnO nanocoating for the mitigation of microbial biofilms in aquaculture. Acknowledgements: This work was funded by grants of the Research Council of Oman (TRC, RC/AGR/FISH/16/01) and SQU- South African National Research Foundation (CL/SQU-SA/18/01).

FRIDAY 29TH JUNE 2018: TRACK B MOLECULAR BIOLOGY & BIOINFORMATICS

4B – ORAL 15

Sample preparation optimization of marine biofouling communities for mass spectrometry analyses

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The frictional drag caused by marine biofouling communities on ship hulls can lead to millions of dollars of annual fuel and maintenance expenses (Schultz 2011) for the U.S. Navy. However, relatively little is known about the vast assortment of marine microorganisms that are responsible for the formation of these communities and even less is known about how these organisms maintain and function within these communities. Metaproteomics, when appropriately coupled with metagenomic DNA sequencing, can aid in filling these knowledge gaps. To effectively apply metaproteomics to marine biofouling communities, methods for efficient protein extraction must be developed. Methods have been established for the metaproteomic processing of biofilms (Leary 2012), but these currently require large quantities of biofilm. As culturing biofilms that mimic the complexity of environmental communities is difficult, we have developed a method for pressure-assisted lysis and digestion using a Barocycler (Pressure Biosciences Inc.) to minimize the amount of sample needed. Using pure culture marine bacteria *Vibrio natriegens* and *Marinobacter sp.* CP-1, we have demonstrated the ability of pressure lysis and digestion to prepare samples quickly and effectively for liquid chromatography-tandem mass spectrometry. This optimized method will then be applied to low complexity but electrically functional biofilms from biocathodes, and ultimately on highly complex ship hull biofouling communities to provide proteomic insights into the physiology and ecology of fouling communities formed in different geographic environments.

4B – ORAL 16

Using pressure cycling technology to examine the *Amphibalanus amphitrite* cement proteome:
Method development and the effect of extraction solvents

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Marine biofouling poses a substantial challenge to stationary submerged surfaces in the ocean, primarily affecting the military as well as power generation and shipping industries. Barnacles, a major biofouler, permanently attach to surfaces during their transition from a mobile stage as a cyprid to a sessile stage as an adult by producing a proteinaceous cement at the surface interface. Several cement proteins have been characterized via mass spectrometry, yet the existing sample processing methods are labor intensive and require large amounts of barnacle cement, hindering further progress in this field. To this end, we have developed faster methods that use smaller sample amounts by exploiting pressure cycling technology (PCT), aiding in protein extraction and digestion for proteomics studies. These new PCT methods produce comparable proteomics profiles to previous methods, and have allowed further examination of the effect of solvents used during the extraction phase on protein identification which were not possible before. As predicted, the various solvents used (hexafluoroisopropanol (HFIP), urea, methanol, and combinations thereof), resulted in the identification of different protein profiles with varying abundances. This information can now be used to further develop targeted mass spectrometry methods to perform quantitative analysis, enabling future research on the effects of environmental and surface substrate composition on barnacle cement, a critical step for the development of new coatings for submerged surfaces to combat hard biofoulers.

POSTER PRESENTATIONS BEYOND SHIPS

POSTER 1

Improving battery efficiency in hybrid drive systems and vessel power banks

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Battery performance is affected by high and low temperatures. Regulating the temperature can promote faster ion transfer between cells/plates and increase the efficiency of the system. Flooded battery systems ideally discharge in temperatures between 20-30°C. In arctic regions, pilot vessels, research vessels, and commercial carriers experience temperatures that cause electrolyte gelling in flooded lead-acid and absorbed glass mat batteries. Applying a thermal coating system to the battery surface or battery storage center would allow for a stable operating temperature for the battery and increased charge and discharge performance. This presentation illustrates the performance gains available at various temperature ranges.

POSTER 2

Predicting the impact of biofouling for heaving wave energy convertors using physical models

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Research into the effects of fouling on wave energy convertors (WEC's) is in its infancy. Previously, wave rider buoys have been used to estimate the impact of biofouling in heave (Langhamer, Wilhelmsson and Engström, 2009; Thomson et al, 2015; Want et al, 2017) using existing growth. Other pilot studies have adopted the use of representative biological samples where plastic strips are used to represent macro algae at scale on the Oyster 800 wave energy device (Tiron et al., 2013). Many of these studies have highlighted the need for further research in this area in order to develop the WEC industry. This work develops methodologies for reproducing man made physical models of fouling; hard fouling (*Chirona hamerii*) and soft fouling (*Laminaria digitata*). For soft fouling a series of mechanical testing is conducted in living samples and man-made materials in order to select a sample material based on Young's Modulus, density and flexibility. For hard fouling purely the geometry of the samples are considered using 3D scanning and printing methods. Fouling models are used to predict the effect of biofouling for heaving wave energy devices through calculation of damping coefficient and added mass using free decay tests and forced oscillation tests. Damping is found to increase with density of *Laminaria digitata* fouling up to oscillation periods of 2 seconds after which the relationship is less clear. (Funding provided by Plymouth University).

POSTER 3

Polyethylenimine functionalized polyacrylonitrile cloth for removal of copper ions from seawater

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Copper-based antifouling paints were widely utilized and investigated for decades. However, as one of the heavy metals, the release of copper ions from paints would also lead to heavy metal pollutions, which has become serious with the rapid increase in global industrial activities, simultaneously. The accumulating of heavy metal would cause various ailments such as dehydration, stomachache, nausea, dizziness, lack of coordination in muscles, destroying the nervous systems of young children, etc., which lead to considerable significance to remove copper ions from seawater. Polyethylenimine (PEI) functionalized polyacrylonitrile (PAN) fibers were prepared and woven into cloth, due to the high adsorption affinity for metal ions of PAN and PEI, and especially the hydrophilicity of PEI. Molecular structures were investigated using X-ray photoemission spectroscopy (XPS) and Fourier transform infrared spectroscopy (FT-IR). The micrographs of the cloth were analyzed by scanning electron microscope (SEM). Inductively coupled plasma mass spectroscopy (ICP-MS) was used for quantitative analysis after marine tests. The capacity of the cloth is 97.3 mg of copper/kg of adsorbent after 17 days of contact between the adsorbent and seawater in Rongcheng, China. However, the capacity of adsorbent was influenced by marine fouling, barnacle to be specific. For further study of marine adsorbent for copper, the antifouling property should be considered by functionalizing antifouling groups to the adsorbent, such as cationic polymers, antibiotics, antimicrobial peptides, antimicrobial enzymes, etc. (This paper is funded by the International Exchange Program of Harbin Engineering University for Innovation-oriented Talents Cultivation.)

POSTER 4

Investigation of fouling organisms on offshore natural and man-made structures and their possible control measurements in nuclear power plants in China

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In many countries including China, growing industrialization, lack of fossil energy and higher environmental protection pressure, nuclear energy has been developed in recent years. However, except for Jellyfish, algae and other marine organisms bloom, biofouling is becoming another limited factor influenced normal cooling seawater supplement in nuclear power plants. In this presentation, biofouling investigation was carried on the offshore natural and man-made structures near the nuclear power plants. Several classical macrofouling organisms were observed, such as barnacle (*Amphibalanus reticulatus*, *Fistulobalanus kondakovi*, *Tetraclita squamosa squamosa*, *Amphibalanus rhizophorae*, etc.), mussel (*Perna viridis* domained), oyster (*Crassostrea sikamea*, *Crassostrea angulata*), etc. Antifouling paints were tested by normal panel-immersion test program in the one of investigated sea area. An 18 months test showed a kind of silicon-based antifouling paints with biocide agents is effective to control the serious biofouling phenomena. Other antifouling measurement such as oxidizing (by direct chemicals or electrolysis) and non-oxidizing agents are also being carried out. The results of our study will be of benefit to the further studies of fouling rules and development of antifouling materials and technologies for costal nuclear power plants.

POSTER 5

Biofouling & marine renewable energy: Performance analysis of coatings & composite materials

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The US Department of Energy, Office of Energy Efficiency and Renewable Energy's Advanced Materials program was created to assist the MHK industry with materials and coatings selection. The effects of biofouling and corrosion present a key challenge to the components of marine hydrokinetic power (MHK) and offshore wind platforms that are fully or partially submerged. Consequences include diminished or interrupted power production and increased annual maintenance and operations costs. Many companies are also exploring the inclusion of composite materials into their designs, creating challenges with protecting joined mixed materials (e.g., alloy and composite) and the unknown long-term performance of many composites when submerged. Past and ongoing studies exploring the reliability of coatings, composites, and joined materials under relevant environment conditions will be described to provide a description of test methods. Results and analysis from the comparative performance studies will be provided to identify promising materials and strategies while conclusions drawn from the investigations will identify specific challenges remaining for substrate and systems protection. (Funding provided by the US Department of Energy, Office of Energy Efficiency and Renewable Energy).

BIOADHESION: NATURAL & BIOMIMETIC ADHESIVES

POSTER 6

Study of anti-bioadhesion activity of glass surfaces grafted with rare furanosidic carbohydrates

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Biofilm results of a bacterial development on live or artificial surface. This community is embedded and protected by an extracellular matrix composed of exopolymers, proteins, nucleic acids. This capacity creates real economic and environmental issues. In marine industry, biofilm is the first step of the macrofouling or biofouling development leading to an increase in transport delays, maintenance and cleaning. Currently, the better way to avoid this phenomenon is the use of biocide. Their release significantly impacts the marine environment. Thus, the research in anti-biofilm and/or anti-biofouling is to develop surface coupled with non-biocidal molecules to prevent the format ion. Furanosidic carbohydrates are natural hexoses with five-membered ring only found in microorganisms. However, in most of microorganisms, their biological roles are still to be elucidated giving an interest as potential anti-biofouling molecules. In this context, we have developed glass surfaces presenting furanosidic sugars grafted by Cu catalysed Huisgen cycloaddition to act on the bioadhesion step. For this purpose, we have synthesized furanosides of glucose, galactose and mannose with S-glycosidic linkage known to be more stable than O-glycosidic linkages. After grafted, glycosidic surfaces have been characterized by contact angles and XPS spectrometry. The bioadhesion studies on bacterium reference *Pseudomonas aeruginosa* have shown significant results with grafted surfaces and it appears that they reduce the bacterial binding force. (The authors are grateful to the GlycoOuest network supported by the Region Bretagne and the Région Pays de la Loire. We thank the Ministère de l'Enseignement Supérieur et de la Recherche, the CNRS for financial supports.)

POSTER 7

Expression of recombinant adhesive nanofibers from engineering *E. coli* biofilms

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Barnacles produce amyloid-like protein fibers that confer permanent surface attachment capable of withstanding harsh marine conditions. To harness barnacle glue properties at larger scales, we exploit genetically accessible bacterial biofilms with two aims: First, we engineer *E. coli* fimbriae protein CsgA to mimic barnacle adhesive chemistries. Second, we replace endogenous csgA nanofibers with recombinant *Balanus amphitrite* barnacle cement proteins (CP's) CP19, CP43 and CP48 using the csg *E. coli* secretion system and study them independently from the context of the natural adhesive. Congo red staining of Serine and Lysine modified CsgA mutants in *E. coli* indicate formation of amyloid fibers, an observation corroborated via Congo red depletion assays. In addition, atomic force microscopy (AFM) demonstrates formation of distinct CsgA fibers by these cells. Barnacle cement proteins also show distinct Congo red staining and the ability to deplete Congo red from solution. Further AFM imaging demonstrates that monomeric CP43 secreted by *E. coli* forms nanofibers in extracellular environments, similar to how the native adhesive fibers are thought to be formed. This result is the first demonstration that CP43 has a propensity to form nanofibers independent of all other barnacle glue components, shedding light on its function in the barnacle. We show that the *E. coli* biofilms are a viable system for heterologous expression and study of foreign amyloid-like materials and adhesion proteins.

POSTER 8

In-situ peel test of barnacle adhesion interface

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Barnacles adhere to a variety of surfaces by building a chemically complex, layered interface. Barnacle adhesion is further enhanced by unique geometrical features in the interface. The resulting interface is structured to promote adhesion by resisting crack opening. To separate the contributions of chemistry, mechanics and geometry, we have built a peel test apparatus to measure the physical properties of adhesion while simultaneously monitoring the barnacle detachment process. Adult *Balanus amphitrite* barnacles were reattached to and grown on flexible polydimethyl (siloxane) (PDMS) substrates. The PDMS substrate was peeled from the barnacle base plate with a 90 degree peel angle. The resulting adhesion force was recorded using a load cell and the peel front was monitored by a digital stereoscope, simultaneously. The force and displacement measurements were used to calculate the strain energy release rate (G) of the adhesion interface. Subtle changes in adhesion forces occurred when the peel front reaches “primary” (new growth) and “secondary” (reattached) cement regions, or defects such as patches of algae. The force measurements reveal that the adhesion force of primary cement is significantly higher than the secondary cement. Importantly, in situ monitoring of the peel front revealed the influence of the geometric features of interface on barnacle adhesion mechanics.

POSTER 9

Wet adhesive nanomaterials derived from the barnacle *Amphibalanus amphitrite* polymerize by molecular recognition of sequences

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Aquatic and marine arthropods produce fibrous, silk materials as underwater adhesives. Classified as arthropods, barnacles produce a micron-thick layer of proteinaceous glue with structure similar to amyloid nanofibers. This glue functions as a permanent wet adhesive. Adhesive fibers in barnacle glue are shaped by a highly conserved domain alternating between short 20-residue low complexity sequences and regions with charged and aromatic side chains. To recognize sequences critical to cement assembly, we derive seven synthetic peptides from consensus barnacle cement sequences of *Amphibalanus amphitrite* glue proteins. These barnacle cement derived peptides (BCDPs) have conserved low complexity segments comprised of Gly/Ser/Ala/Thr residues, the building blocks of silk associated materials. We hypothesize that each BCDP sequence yields unique aggregation kinetics and amyloid-like morphologies, providing a means for the organism to control polymerization rate and physical properties of wet adhesive biomaterials. To study cement protein assemblies, we used Thioflavin T polymerization assays to characterize the activity and interaction of BCDP sequences. Time-resolved fluorescence measurements demonstrate that polymerization is peptide sequence specific with varying activity, onset times, and distinct fibril formation. Active BCDPs undergo hydrogel formation and demonstrate specific sequence recognition. The ability to activate dormant BCDP sequences through molecular recognition mechanisms will be discussed. Synthetic BCDPs are shown to produce nanomaterials similar in morphology and molecular structure to complex proteinaceous barnacle glue while providing a means to scale up and additionally study native barnacle cement with marine biofouling.

BIOMIMICRY, BIOINSPIRATION & NATURAL ANTIFOULANTS

POSTER 10

Anti-biofouling efficacy of seaweed-mediated nanoparticles coatings

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In field experimental studies, biosynthesized bi-metallic (Ag/CuO, Ag/ZnO, Ag/TiO₂, CuO/ZnO, CuO/TiO₂ and ZnO/TiO₂) NPs (mixed with water based resins; phytigel and Revacryl 380) were coated on the surfaces of Fibre Reinforced Plastic (FRP), Stainless Steel (SS) and Wooden panels. These panels were immersed in the coastal waters (photic zone) about 4-12 weeks. Every week, all the rafts were checked for studying the attachment and growth of fouling organisms. The most effective concentrations (300-700 µg mL⁻¹; totally 10 mL was needed for each panels) were used to determine the antifouling efficacy of NPs. The above mentioned bi-metallic NPs registered maximum activity (50-65%) compared with mono-metallic NPs (20-45%) and marine plant extracts. However, Ag/CuO and CuO/TiO₂ NPs exhibited highest (up to 65%) inhibition of biofilm and biofouling formation followed by Ag/ZnO > Ag/TiO₂ > CuO/ZnO > ZnO/TiO₂ NPs. From this observation, NPs coated SS panels showed efficient antifouling potential compared with FRP and wooden panels, whereas all the control panels showed dense biofilm formation and attachment of biofouling organisms at 12th week. The overall results of the present study clearly emphasize the anti-biofouling potential of biosynthesized NPs against both micro and macrofouling organisms and substantiate their low toxic nature. Therefore, the present study suggests that seaweed-mediated clean, nontoxic and environmentally acceptable nanoparticles can be applied as coating materials on the surfaces of small wooden/fiber boats, mechanized boats, aquaculture installations and other marine systems to prevent the settlement and growth of fouling consortia. Furthermore, major studies (collaborate with antifouling paints industries) are necessary to validate the advantages of the seaweed-mediated bi-metallic NPs as an alternative anti-biofouling strategies.

POSTER 11

New bioinspired antifouling products:
Bio-guided activity from synthesis to the incorporation in paints

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Bioinspired antifouling (AF) compounds with potential to assure commercial supplies were synthesized and screened for AF effectiveness and environmental compatibility [1]. Two promising bioactive and non-toxic compounds, as well as the commercial biocide ECONEA® for comparative purposes, proceeded to incorporation in marine coatings in order to validate their potential AF effect in real protective antifouling systems. The first coating approach included direct incorporation in polyurethane (PU) and silicone (S) based marine coating formulations gently provided by Hempel AS. Bioactivity was guided by an *in vivo* anti-settlement bioassay using mussel adhesive larvae as target species [1]. This anti-settlement bioassay was adapted to permit the assessment of bioactivity in painted substrates in controlled lab conditions. Results show that S coatings formulations seems to present advantages relatively to PU coating and significant differences were also found among tested compounds, which corroborate with the different coating matrices inherent properties, as well as the chemical compatibility of AF compounds with the polymeric matrices. [1] Almeida et al. Sci. Rep. 2017, 7, 42424. (Funding provided by FCT and ERDF (UID/Multi/04423/2013) in the framework of the programme PT2020 under the project PTDC/AAGTEC/0739/2014-POCI-01-0145-FEDER-016793- RIDTI 9471).

POSTER 12

Antifouling potential of portoamides isolated from cyanobacteria

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Cyanobacteria produce a wide range of secondary metabolites that have the potential to be the next generation of environmental safe antifouling (AF) agents, being non-toxic and effective, and more easily ensuring product supplies renovation. In this work promising AF pure compounds previously isolated from cyanobacteria were screened for AF bioactivity. AF activity was tested against macrofouling community using an in vivo anti-settlement test with mussel adhesive larvae. Bioactive compounds were further tested for anti-microfouling activity, including biofilm-forming bacterial strains and diatom species. Biochemical modes of action by the modulation of AF biomarkers, acetylcholinesterases (AChE) and phenoloxidase (PhOx) were evaluated. Results showed that portoamides previously isolated from the cyanobacteria *Phormidium sp.* LEGE 05292 from the Blue Biotechnology and Ecotoxicology Culture Collection (LEGE CC), presented bioactivity against the settlement of mussel adhesive larvae ($EC_{50} = 4.862 \mu\text{g/ml}$). These compounds also showed low toxicity to target species (no mortality at 3-50 $\mu\text{g/ml}$) and non-target species *Artemia salina*. Portoamides presented effectiveness in preventing bacterial growth (EC_{30} ranging from 20,89 to 25,82 $\mu\text{g/ml}$), however no significant effect on diatoms growth was observed. No significant alterations were found in AChE and PhOx in vitro after exposure to portoamides. Further research efforts on portoamides AF targets in mussel adhesive larvae need to be conducted in the way to their incorporation in marine coatings. (Funding provided by FCT and ERDF (UID/Multi/04423/2013) by the project INNOVMAR (reference NORTE-01-0145-FEDER-000035, within Research Line NOVELMAR), supported by North Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, through the ERDF).

POSTER 13

Role of hydrogen bonding in peptoid- and peptide-based marine antifouling coatings

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Peptoids, biomimetic sequence-defined polyamides, enable fine control over both the monomer chemistry and the secondary structure that impact antifouling capabilities, and have shown success in fouling resistance and release when incorporated as polymer side chain substituents. Surprisingly, analogous peptides (which, unlike peptoids, contain hydrogen bond donor sites on the backbone) do not share the same antifouling properties. Coatings incorporating hydrogen-bonding peptides failed to reach the diatom fouling resistance and release of chemically similar non-hydrogen-bonding peptoids. In addition to hydrogen bonding donor sites, peptides also contain chiral carbon centers that enable secondary structure, while peptoids lack this center and are disordered. To verify whether the differences seen between peptide and peptoid samples were due to hydrogen bonding or secondary structure effects, and to more generally explore the role of hydrogen bonding in fouling performance, a new peptoid material was developed that contained hydrogen bonding donor sites while lacking secondary order. Fouling results for the new peptoid as well as the non-hydrogen-bonding peptoid indicate hydrogen bonding (rather than secondary structure) largely determines the differences seen between similar peptide and peptoid coating components.

POSTER 14

Chitosan derivatives working as natural antifoulants for marine antifouling coatings

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Chitosan is a kind of natural, biodegradable, non-toxic and multifunctional resource, which is the second most abundant biomass on earth after cellulose. In this study, we employed chitosan, the only kind of alkaline natural amino polysaccharide, and its derivatives as natural biocide in self-polishing coatings (SPCs). Chitosan derivatives include benzoylchitosan, quaternized chitosan, double antibacterial functional groups chitosan, N, O-carboxymethyl chitosan, chitosan coated iron oxide particle and their copper complexes were synthesized by reaction with C₂-NH₂ and C₆-OH active groups of chitosan. Their structures were characterized by X-ray diffraction, fourier transform infrared, and thermo gravimetric analysis. As compared to other samples, carboxymethyl chitosan copper complex showed much higher thermal stability. What's more, due to the effect of chelation and magnetic field, both carboxymethyl chitosan copper complex and magnetic chitosan copper complex particle are have slower Cu²⁺ release rate compared to the chitosan copper complex, respectively. The antibacterial property showed that all the chitosan derivatives exhibited higher inhibitory activity against *Escherichia coli* and *Staphylococcus aureus* bacteria. Different antifouling coatings were prepared by taking the homemade zinc acrylate copolymer as the matrix material and chitosan and synthetic products above as activity compounds. The panels were lowered into seawater at Rongcheng of Shandong Province and the panels with modified chitosan have fewer slime and plant foulings in comparison with the original chitosan after a 2-month field exposure. The study provides novel and environmentally friendly actively agent alternatives for marine antifouling application. (Research funded by the National Natural Science Foundation of China, 51603053).

POSTER 15

Bacterial exopolysaccharides as antibiofilm agents in natural flowing seawater

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The antibiofilm potential of three bacterial exopolysaccharides (EPS) produced under laboratory conditions by bacteria originating from microbial mats was investigated on titanium coupons. The coupons were placed in natural flowing seawater and monitored by open circuit potential measurements and direct microscopic analyses. A novel bacterial EPS comprised of uronic acid and N acetylated hexosamines was shown to inhibit bacterial adhesion at low concentrations (as low as 0.2 ppm). Such marine biopolymers could be an alternative route to prevent or limit biofilms on passive alloys exposed to natural seawater. Compared to biocides, exopolysaccharides are safe to use with no ecotoxicity. The absence of undesirable toxic compounds is a major benefit associated with the application of natural biopolymers from renewable resources.

POSTER 16

Functional nanoparticles in aquaculture net coatings:
Evaluation of fouling control performance in static field immersion tests

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Fouling on aquaculture net cages is still a big problem for the industry in many ways. Copper-containing coatings remain the most common and effective anti-fouling solution, albeit in combination with frequent cleaning intervals. The aim of this project is to establish a biocide-free alternative with comparable or even better performance. Therefore two sets of PDMS-based coating formulations were developed with different amounts and combinations of functionalized nanoparticles. The rationale of this approach is to achieve a hierarchical structure of particles in the coating matrix so that the functionalized nanoparticles can orientate at the coating surface in order to exert surface effects. Nylon net samples were coated with the experimental systems and immersed at the IFAM static immersion test site at Helgoland, Germany. After one season the performance of all systems was significantly better as compared to the untreated nets. The tested coating systems with the functional nanoparticles thus show a promising effect for reducing biofouling on nylon nets. Funding was provided from the European Union Seventh Framework Program in the SEAFRONT project under grant agreement no. 614034.

POSTER 17

Antifouling property of graphene oxide/copper-silver nanocomposites

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Adhesion of microalgae or biofouling on sensor housing is a severe problem in marine environment. Herein, a novel Graphene oxide (Go)/Copper-silver (Cu-Ag) nanocomposite with marine antifouling property was developed by a facile method. Oxygen groups at Go serve as nucleation sites of Cu-Ag to get Go/Cu-Ag nanocomposite and weaken aggregation of Cu-Ag nanoparticles. Meanwhile, the Cu-Ag nanoparticle with core-shell structure combined strong and wide antifouling property of Ag nanoparticles and cost effective property of Cu nanoparticles. The structure of Go/Cu-Ag nanocomposite was studied by fourier-transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), thermogravimetric analysis (TGA) and Raman spectroscopy, while the morphology of Go/Cu-Ag nanoparticles was studied by scanning electronic microscopy (SEM). A common marine bacterium, *H. Pacifica*, was used to study antifouling property of Go/Cu-Ag nanocomposite.

CORROSION

POSTER 18

Effects of dilution rate on the microstructure, mechanical properties and electrochemical behaviour of laser cladded Ti-Cu-Al coatings on Ti-6Al-4V alloy

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Titanium Alloy (Ti-6Al-4V) unlocks a wide range of useful applications in aerospace industries; these industries make use of different additive manufacturing (AM) techniques to obtain parts of different properties for different uses by this titanium alloy. Titanium alloy mainly stands out due to the properties such as high specific strength to weight ratio, and excellent corrosion resistance. Despite these benefits, the formation of defects such as pores and cracks play a vital role in the quality of the deposited coatings. The presence of these unwanted artefacts on laser deposited coatings depends on the melting, cooling and solidification of the melt pool, dilution rate and process parameters. This research paper focuses on the effect of hybrid coating of Ti-Cu-Al on a grade five titanium alloy (Ti-6Al-4V) using LMD process at different laser process parameters. A 3kW continuous wave ytterbium laser system (YLS) attached to a KUKA robot which controls the movement of the cladding process was utilized for the fabrication of Ti-Cu-Al coatings on Ti-6Al-4V alloy. The titanium cladded surfaces were investigated for its microstructure, mechanical properties and corrosion resistance characteristics at different laser processing conditions. The samples were cut to corrosion coupons and immersed into 5M NaCl solution at 28°C using Potentiodynamic Polarization (LP) and Electrochemical Impedance Spectroscopy (EMS) techniques. Hardness measurements were done using a Vickers micro-hardness tester. Ti-6Al-4V/Ti-Cu-Al composites were analysed using optical microscopy, scanning electron microscopy (SEM) with energy dispersive microscopy (EDS), and x-ray diffraction (XRD). The enhanced tensile strength, yield strength and micro-hardness were attributed to the formation of hard intermetallic compounds (TiCu, Ti₂Cu, CuTi₃, TiCu₃, Al₃Ti) produced through the in situ metallurgical reactions during the LMD process. In addition, the rapidly solidified homogeneous fine microstructure imparts the coatings good combination of strength and toughness, which also contributes to the excellent resistance of the coating to spallation and delamination during dry sliding wear process. The addition of Cu impacts positively on the Young's modulus of the coatings. The enhanced Young's modulus was because of copper interlayer which is attributed to the presence of Ti-Cu intermetallics (like CuTi₃ and Cu₃Ti). The intermetallic also provides an enveloping effect giving rise to a protective barrier against corrosion.

POSTER 19

Low input corrosion protection for electric motors

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Condensation formation on electric motors causes corrosion to housings and winding, impeding performance and promoting failures. A surface temperature 5-10°C above ambient will prevent condensation formation. Current methods require the use of internally or externally mounted heating elements or trickle heating by running a reduced voltage through motor windings. Mounted elements can require motor disassembly for proper installation and trickle heating requires up to 25% of the motor's rated input demands. A thermal coating system exists that requires less operational power and provides corrosion protection as a barrier and condensation preventer. Motor operational lifespans are also increased by reduction of thermal cycling extremes. This presentation gives initial results from testing in marine environments.

POSTER 20

(Microbial) Corrosion and cathodic protection of steel sheet pilings in a harbour in The Netherlands

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MIC is the deterioration of metals as a result of metabolic activity of microorganisms. Different genera of microorganisms convert nutrients which are available in soil and water into acids and other corrosive by-products that change the environmental conditions and may accelerate corrosion processes. MIC can be recognized very well by its typical tubercles or corrosion products, being relatively soft layered structures consisting of orange iron hydroxide products and black products containing iron sulfide. These layers are only weakly attached to the steel surface; underneath this the steel is shiny with pits, craters and holes. To protect structures such as sheet piles in marine and harbour environments, a thorough failure analysis and diagnosis is essential to conclude if MIC is really the root cause of the damage observed. On basis of the results of a comprehensive failure analysis package proper recommendations for appropriate mitigation methods can be given. During inspection works in a harbour in the Netherlands pits and full perforations were detected in steel sheet pilings in an older part of the harbour, whereas structures that were recently installed in this same harbour showed no damages. Next to holes, reddish brown spots on the surface of the steel sheet pilings were found. A complete failure analysis, including material cross sections, SEM analyses, microbial investigations and wall thickness measurements was carried out to clarify the reason for the present failure. Additionally, potential measurements were done to investigate the performance and protective capacity of sacrificial anodes which are placed on various parts of the structure. Results of this failure case investigation will be presented.

POSTER 21

Preparation and characterization of nitrate and molybdate intercalated Zn-Al-layered double hydroxide nanocontainers towards anticorrosion applications

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Zn-Al layered double hydroxides (LDHs) intercalated with molybdate anion was developed as a nanocontainer for controlled delivery of corrosion inhibitors against corrosion of mild steel in neutral chloride conditions. The LDH compounds were prepared by a method involving co-precipitation and anion-exchange and characterized by scanning electron microscopy (SEM), X-ray diffraction (XRD) and Fourier transform infrared spectroscopy (FTIR). The anticorrosion capabilities of inhibitor loaded LDHs were analyzed by open circuit potential (OCP), electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization curve. A significant reduction of the corrosion rate is observed when a 2 g/L concentration of inhibitor loaded LDHs are dispersed in the corrosive media. The mechanism is that loaded inhibitor can slowly diffuse out of inner structure of LDHs and result in a relatively long-term effect of corrosion inhibition. The result presented here, underlines the great potential of controlled delivery mechanism of nanocontainer/inhibitor materials for anticorrosion applications. (Funding provided by National Nature Science Foundation of China, 51525903, 51679227 and AoShan Talents Outstanding Scientist Program Supported by Qingdao National Laboratory for Marine Science and Technology, No. 2017ASTCP-OS09).

POSTER 22

Super slippery coating by ZnO based on aluminum and its anti-corrosion performance

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Similar to the “lotus leaf effect”, superhydrophobic surfaces have excellent self-cleaning characteristics and corrosion resistance. However, in the process of droplet condensation on a rough surface, the droplets on the surface can transform from the Wenzel-Cassie state to the Wenzel state, leading to failure of the superhydrophobic effect and greatly reduced corrosion resistance of the alloy surface. Aizenberg et al. first proposed the concept of a slippery liquid-infused porous surface (SLIPS), where lubricating oil is poured into the porous surface for preparation of super-slippery surfaces; a dynamic oil film forms on the surface, solving the problem of super-hydrophobic failure. Since then, research has been focused on mimicking nature and trying to fabricate such surfaces artificially. In this paper, double-layer zinc oxide was synthesized on an aluminum substrate by a sol-gel and hydrothermal method. The aluminum sheet coated with zinc oxide was infiltrated into the Dupon Krytox GPL104 lubricating oil for 2h to obtain an aluminum-based double-layer super-slippery surface. The surface has all the properties of a SLIPS, repelling all simple and complex liquids (including water, milk, coffee, juice, ink, and others); it also exhibits good anti-corrosion and antifouling properties. The corrosion resistance of the surface was tested by electrochemical impedance spectroscopy (EIS) in 3.5 wt% NaCl aqueous solution (simulated seawater test); the result was four orders of magnitude higher than that of an untreated aluminum sheet. It shows good corrosion resistance, and the corrosion resistance did not change significantly after three months. This provides potential application prospects for aluminum alloy corrosion protection.

POSTER 23

The influence of surface roughness and cathodic protection potential on calcareous deposit formation on ship propellers

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The influence of substrate, surface roughness and polarized potential on calcareous deposits formed under impressed current cathodic protection was studied in natural seawater. Marine grade stainless steel specimens of surface finish corresponding to A, B, C, D propeller blades roughness of Rubert Scale, were polarized potentiostatically in seawater at -850mV , -950mV and -1050mV (Ag/AgCl). The nature of the calcareous deposits that formed was characterized by monitoring the cathodic current density and analyzing the calcareous deposits with respect to structure, composition, morphology and thickness using a scanning electron microscope. The observed trends are discussed in terms of the cathodic current density, roughness and impressed current density.

POSTER 24

Microbial influenced corrosion evaluation in natural seawater: Laboratory vs offshore testing

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Microbial Influenced Corrosion (MIC) is an aggressive type of corrosion that occurs in aqueous environments as a consequence of the development of a complex biological matrix over the metal surface. This phenomenon generates microenvironments that locally change water chemistry at the metal-liquid interface. MIC in marine environments is exacerbated because surfaces are exposed to environmental variations, which makes local studies crucial to understand biofilm composition, characteristics and corrosivity. To evaluate material performance and anti-corrosion strategies, experimental testing is essential. Usually, solutions are tested under controlled laboratory condition where natural fluctuations and gradients are not effectively replicated. In this study, two different testing set-ups were used to evaluate MIC on stainless steel AISI 316L coupons exposed to east south pacific seawater for 103 days. Compared set-ups consist on: (i) acrylic tanks where coupons were exposed in a running-seawater laboratory and (ii) an offshore testing system with two immersed plastic frames where coupons were aged at two depths (5 and 15 m). Results of electrochemical evaluation, along with microbial community analysis and micrographs of formed biofilms reveal significant differences between tested conditions. Indeed, since coupons aged at 5 m deep show abundant biofouling, including algae and barnacles; coupon exposed at 15 m deep and in tanks exhibit presence of few algae and an early biofilm formation. The results of this research highlight the importance of testing conditions for a reliable simulation and evaluation of material performance and biofouling in marine environments.

POSTER 24B

Biofouling and MIC of coated steel in marine environment

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Microbiologically Influenced Corrosion (MIC) is an important degradation mechanism for materials in civil infrastructure. Recent findings in Florida showed severe corrosion of submerged steel bridge piles associated with microbial activity. Furthermore heavy marine growth such as Tunicates, Hydroids, Barnacles, etc. were observed on the steel piles, which was also thought to affect the corrosion process by creating oxygen concentration cells and causing the initiation of localized corrosion. Antifouling coatings are considered as one of the corrosion prevention methods for steel microbial degradation. Also, polyurea coating has been used to provide corrosion protection of steel in certain industries and has favorable characteristics such as low curing time, good adhesion strength and high corrosion resistance. The objective of this research is to evaluate the performance of antifouling and polyurea-based coating to prevent MIC of submerged steel. Research including field examination were created evaluated the applicability of polyurea and water based antifouling coating to enhance environmental resistance to biodeterioration. Coated steel coupons were installed in a field bridge site to be periodically tested for microbial presence and corrosion activity.

FOULING AS A VECTOR FOR INVASIVE SPECIES

POSTER 25

Project “GEBIO”: Achievements, lessons learned and best practices in management of biofouling and bioinvasion control in Brazilian coast

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Marine bioinvasions mediated by biofouling on ship hulls and other vessels were reported worldwide. Since 2011 the International Maritime Organization (IMO) requested urgent actions to minimize the transfer of invasive aquatic species by ships' biofouling (MEPC.207(62)). Aligned with this resolution, the project GEBIO just ended after five years of cooperation between IEAPM (Brazilian Navy) and CENPES (PETROBRAS). The primary goal of the project was create a basis for control and management of biofouling and bioinvasion in Brazilian coast. For such purpose, it was built the database "Marine Fouling Species from the Brazilian Coast". It is a web-based system implemented to provide open access information about Brazilian fouling species distribution. Nowadays the database contains 1081 fouling species distributed over more than 9000 geographical occurrences. As part of the project, a scientific collection housed at IEAPM was organized to catalogue fouling species (indigenous and non- indigenous) from Brazilian coast and has 2200 specimens until now. The database in conjunction with the scientific collection provided a robust tool regarding the detection and identification of invasive species hereafter. Furthermore, Arraial do Cabo harbor area (22°58'20"S, 42°00'50"E, Brazil) was studied as a model area to risk assessment analysis. It has been surveyed to early detect non-indigenous species establishment and monitor invasive populations already established (e.g. *Tubastraea spp.*). All the project achievements are important and they contributed to best practices in biofouling management and bioinvasion control. Funding by Cooperation Agreement N° 0050.0087475.13.9.

POSTER 26

Early warning system for non-indigenous species:
From ballast water management to fouling mediated introductionE. MAGALETTI (1), F. GARAVENTA (2), M. DAVID (3), L. CATRIOTA (1), R. KRAUS (4),
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Shipping is one the main pathways for NIS introductions, mainly through ballast water or ships' biofouling. Harbors and marinas have a decisive role in this process: the former as sink and source for NIS, the latter for secondary spread. In fact, artificial structures provide suitable habitats for fouling NIS enhancing their introduction; they can be considered as priority target areas for early detection of NIS. The methodological approach to develop an Early Warning System (EWS) for NIS is described. It satisfies both ballast water management needs (to warn vessels to prevent loading of BW when critical conditions occur in ports and surrounding areas) and to warn environmental and health authorities to enable an early response. Its application can also satisfy the need to monitor and manage NIS occurrence due to other vectors (ships' biofouling). The EWS satisfy the implementation of parallel obligations, by taking into consideration different legal scopes and decision-making needs. The EWS was developed with an Adriatic Sea focus but can be used as a model for other locations. The role of the actors is discussed and recommendations on further developments of the EWS are presented. The EWS resulted to be a suitable tool to reduce the spread of potentially harmful and shipping mediated species.

Commercial vessel biofouling surveys in Australia

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The biofouling pathway of marine biological invasions is complex and frequently unpredictable. The risk posed by this pathway is integrative, dictated by the voyage history of the vectors in question, which typically includes multiple ports and bioregions over variable timescales. Complicating this risk, regulation of the pathway varies greatly between jurisdictions globally, creating difficulties in the application of consistent, coherent management. The Australian government has placed an emphasis upon management of this pathway using a preventative approach and through the development of biofouling management measures. On this basis, the Department developed and funded a program to survey international vessel arrivals into Australia during 2017 and 2018 to collect the necessary data to inform biofouling policy/regulatory development. International trading vessels were the focus of the surveys, the immediate aim of which was to characterise the broad nature and extent of fouling communities on the commercial vessel population. Vessels of opportunity were selected from across each Australian state and the Northern Territory for participation in the survey, which included both a physical inspection of the hull and an evaluation of vessel voyage history and hull husbandry practices. The data collected from 40 ships is in the process of being used to develop a suite of indicators for evaluating the biofouling risk profiles of incoming vessels. The findings of this just-completed work will be discussed in the context of the methods used to collect the data, implementation challenges and the overall findings across the surveyed population of vessels trading to Australian waters.

HYDRODYNAMICS & DYNAMIC TESTING

POSTER 28

An alternative dynamic testing device for marine coatings and materials

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Currently, dynamic testing devices utilize a flow channel or rotating drum design for testing the erosion and performance of immersed marine coatings and materials. Flow channels are high-maintenance units whose use for research and testing are limited by the small number of available devices. Drums produce vortices which may not realistically simulate hull flow patterns, and samples must be curved to match the drum's diameter. This work presents an alternative dynamic test fixture that uses rotating vertical disks, half-submerged in seawater, to replicate ship's movement through water. Disk diameters range in size from 2-4 meters and can rotate samples at speeds >20 knots. The system is simpler and more energy-efficient than current dynamic testing methods.

POSTER 29

An experimental investigation of the hydrodynamic performance of marine antifouling coatings during their working life

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This study presents an experimental investigation of the hydrodynamic performance of marine antifouling coatings during their working life. Commercially available antifouling coatings have been applied to test plates of 200mm by 600mm. The plates have undergone a series of testing using Newcastle University's facilities, including the new Multi-Purpose Flume. The flume is designed for long-term exposure of a coated plate in seawater, open to a fully developed and turbulent flow regime, which can be directly related to the flow around a ship's underwater hull. The flume caters for measuring, aging, polishing and foul release testing of biocidal and non-biocidal fouling coatings. The flume is divided into two sections, the first section is used for skin friction measurements as well as aging and the second section is used for aging only. The flume can also be used with a Laser Doppler Velocimetry system, to collect the boundary layer data of each coating. With the differing range of roughnesses observed on coated hull surfaces, many replicates of the coatings were developed with different roughnesses. Biofilms were also developed on the coatings, artificially grown in the new dynamic slime farm and naturally grown on the RV Princess Royal. This will assist to gain knowledge in measuring and characterizing biofilm, and its effects on the drag penalty. The measured boundary layer data is analyzed, using different analysis methods to compare the skin friction characteristics and predict the hydrodynamic performance of antifouling coatings upon application. (Research funded by International Paints)

POSTER 30

Effect of cuprous oxide particles on the roughness and drag characteristics of marine antifouling coatings under the internal and external flow conditions

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In this paper, pressure drop measurements and boundary layer tests were conducted to evaluate the drag characteristics of the surfaces coated with different size cuprous oxide particles under internal and external flow conditions respectively. Eight different sizes of cuprous oxide (D50 ranging from 2 μ m to 250 μ m) were applied on Newcastle University flat test panels (600mm x 210mm in size L x B) by spray application using a suitable binder. The test panels were fitted to a special wall type insert (3m long) where they were subjected to different dynamic flow speeds, in the testing section (800mm x 800mm in size B x H) of the Emerson Cavitation Tunnel (ECT) of Newcastle University. Under these conditions the boundary layer characteristics of the coated surfaces and the smooth reference surface were measured by using the two-dimensional Laser Doppler Velocimetry (LDV) system of the ECT. The pressure drop measurements were carried out using turbulent flow channel (Newcastle University) under dynamic flow conditions at different speeds. The test section of the turbulent flow channel was 10 x 180 x 2700 mm in height, width and length respectively. The surface roughness characteristics were analyzed by Scanning Electronic Microscopy (SEM) and an optical roughness profilometer to assess the detailed roughness statistics of the surfaces. Based on the analysis results of the roughness and frictional drag measurements, a correlation between the relevant roughness parameters and drag of the tested surfaces was established, and provided insight into how frictional drag (for external flows) or pressure drop (for internal flows) relates to the particular roughness topography.

POSTER 31

In situ dynamic platform for the evaluation of fouling release coatings

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The development of fouling on submerged surfaces depends on many parameters: nature of the surface, composition and temperature of the surrounding environment, shear stress (speed of ships, currents). It appears, however, that the succession of colonizing organisms follows an order: microfouling then macrofouling. The design of antifouling protection systems requires the implementation of evaluation tools to study these different parameters. The "Rotofoul" experimental platform makes it possible to evaluate antifouling coatings or surfaces in situ, under static and dynamic conditions (variable flows along the radius of the experimental discs). The immersed samples can then be analyzed in the laboratory to characterize the colonization (micro and macrofouling). The work presented concerns the study of fouling-release and biocides-release coatings and references (PVC surfaces). In addition, the platform makes it possible to evaluate coatings under conditions close to their use on ships by alternating static and dynamic periods (variable speed), and alternating exposure to light. Microfouling present after a few weeks of immersion is characterized by the 16S/18S RNA evaluation of organisms present (bacteria, micro-algae, spores) and of the microalgal and bacterial biovolumes (confocal scanning laser and scanning electron microscopies). In parallel, the physicochemical characteristics of the surrounding water were monitored: temperature, pH, dissolved oxygen content, chlorophyll content; these different data enable to understand the different colonization phases observed. These results provide a better understanding of i) the mode of action of different types of coatings, ii) the impact of different parameters such as shear stress and brightness and iii) the role of microfouling in the development of fouling. Acknowledgments for financial support: French National Research Agency, University South Brittany.

POSTER 32

A microfluidic assay to test the adhesion of the marine bacterium *Cobetia marina*
under dynamic shear conditions

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The accumulation of the marine algae *Navicula perminuta* under dynamic shear conditions can be measured by a dedicated microfluidic laminar flow system (Nolte et al. 2017). Based on this microfluidic system, a parallelized version was constructed to improve the throughput of microfluidic experiments while a simultaneous measurement of four different surfaces is possible. As bacterial model organism for such microfluidic attachment assays we investigated the marine bacterium *Cobetia marina* (*C. marina*), formerly *Halomonas marina*, as it is frequently found in biofilms (Arpa-Sancet et al. 2012). To identify a suitable shear stress range to perform microfluidic attachment assays, the attachment behavior of *C. marina* was investigated at different shear forces on hydrophobic and hydrophilic surfaces, whereby *C. marina* tends to adhere best on hydrophobic coatings. During the optimization of the assay parameters it was found that the growth state of *C. marina* on the marine Agar prior to colony picking influences the outcome of the microfluidic experiments. The optimized assay parameters will be presented as well as selected examples how coating chemistries alter the attachment of the marine bacterium *C. marina* under dynamic shear conditions. (Research funded by Mercator Research Center Ruhr GmbH, 45128 Essen and ONR N00014-16-12979) Reference Arpa-Sancet, M. P.; Christophis, C.; Rosenhahn, A. (2012): Microfluidic assay to quantify the adhesion of marine bacteria. In: Biointerphases 7 (1-4), 26. DOI: 10.1007/s13758-012-0026-x. Nolte, Kim A.; Schwarze, Jana; Rosenhahn, Axel (2017): Microfluidic accumulation assay probes attachment of biofilm forming diatom cells. In: Biofouling, 531 - 543. DOI: 10.1080/08927014.2017.1328058.

POSTER 33

New slime farm design for dynamic biofilm growth using computational fluid dynamics

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Biofilm grows on the underwater surface of a ship and increases drag. New coatings are designed to counteract this phenomenon and require extensive testing in controlled condition. Dedicated devices, often called slime farms, can be used to monitor and control marine biofilm grown on a surface in laboratory conditions. This study presents the investigation of flow field of the slime farm using computational fluid dynamics (CFD). The slime farm was designed and is operated by Newcastle University. Biofilm grown under shear flow shows different hydrodynamic drag performance compared to statically grown biofilm. A slime farm should, therefore, satisfy certain flow conditions on a test plate to grow biofilm which mimics the full-scale conditions of a sailing ship. These conditions are homogeneously a fully developed turbulent flow and wall shear stress on the surface. Ideally, in a controlled setting, these conditions occur in a long flow section. However, the length and width of the slime farm was limited by the laboratory size. To achieve ideal flowing conditions in a limited space, the usage of guide vanes, honeycombs and vortex generators was investigated in this study. The design was improved by using Computational Fluid Dynamics (CFD) to accurately simulate the flow field. Different configurations were tested to produce a final optimized design. The RANS solver was employed to define the flow field characteristics. Finally, actual flow speed measurements were compared to CFD results. The results show a very good agreement found between the CFD and measurements. This study demonstrates the capability of the slime farm to grow biofilm on any coated surface dynamically and homogeneously. (Research funded by International Paints).

Cavitation erosion resistance of polydimethylsiloxane – modified polyurethane surfaces

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Cavitation erosion is a phenomenon that typically creates shock waves and water jets in turbulent flows. These impact pressures can impact surfaces, generate fatigue in materials, lead to crack propagation and severe material degradation. In this study, we have developed polydimethylsiloxane-modified polyurethanes (Si-PU) with hydroxypropyl polydimethylsiloxane (H-PDMS) and polytetramethylene glycol (PTMG) as mixed soft segments and 2,4-tolylene diisocyanate, 1,4-butanediol, triethanolamine as hard segments via a polycondensation reaction. The investigation on anti-erosion performance were measured by coating the polyurethane and Si-PU on the alloy steel surfaces. The cavitation wear experiment showed that the cavitation erosion resistance of Si-PU continuously improved with the increasing of H-PDMS content, while the adhesion force of Si-PU reduced with the increasing of H-PDMS content. The cavitation surfaces were observed using scanning electron microscopy (SEM) and 3D optical microscopy. The cumulative mass loss of Si-PU with 12.5% wt H-PDMS was only 2.96 mg and the surface showed no obvious holes and cracks after 80 hours cavitation. The results showed that cavitation resistance has a correlation with degree of crosslinking, hardness, loss modulus and so on. It seemed that the Si-PU coating could withstand a longer period cavitation erosion resistance compared to the high strength epoxy, which can be used as protective coating of flow components under water.

MACRO & INTEGRATIVE BIOLOGY

POSTER 35

Fouling ascidians in the coastal waters of China: A review

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Ascidians are one of the major fouling groups in the marine environment and can cause a series of problems for the aquaculture industry. To date, a total of 40 ascidian species within 20 genera and 8 families are identified from fouling communities in the coastal waters of China: 7 species were found in the Bohai Sea, 17 in the Yellow Sea, 23 in the East China Sea and 27 in the South China Sea. The dominant species in the northern sea area of China are *Styela clava*, *Molgula manhattensis* and *Diplosoma listerianum*. However, *Styela canopus*, *S. plicata* and *Symplegma oecania* become dominant in southern waters. The characteristics of fouling ascidians are closely related to factors such as geographic location, immersion duration and local environmental conditions. To thoroughly elucidate species composition, distribution, population characteristics and trends in China seas, further work should be continuously conducted in representative and commercially important waters. Furthermore, combined with the needs of marine economic development and scientific research, the study of fouling communities colonizing offshore facilities, particularly in deep water, should also be strengthened.

POSTER 36

A comparative study of shell morphology and the mass moment of inertia of
Perna viridis (Linnaeus, 1758) and *Mytella strigata* (Hanley, 1843)

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In bivalves, shell morphologies are highly reflective of the environmental demands and they determine the animals' ability to interact and colonize different substrates. In this study, we examined the shell morphologies of two invasive bivalves, *Perna viridis* and *Mytella strigata*, and explored how this may affect their locomotion and attachment. Key morphometric variables such as shell length (SL), shell width (SW), shell height (SH), and wet mass were measured, and the mass moment of inertia were obtained based on 3D models of the shells. Bivariate analyses showed SH of *P. viridis* increased at a greater rate with SW than SH that were measured from *M. strigata*. Principle Component Analyses showed *P. viridis* and *M. strigata* are two morphologically distinct species. Mean total organism density of *M. strigata* was less than *P. viridis* by a significant difference of 0.184 g/cm³ (95% CL, 0.124 to 0.244 g/cm³). Results also showed that the species had the least moment of inertia about the axis along the anterior-posterior dimension and at every increase of mussel's mass, the rate of increase in mass moment of inertia of *M. strigata* was higher than *P. viridis* by approximately 0.6% in the principle axes. We postulate that *P. viridis* and *M. strigata* exhibit phenotypic differences that contribute to their ability to exploit different habitats. Although both species are well adept to invade man-made environments, *P. viridis* is better adept to hard substrates. (Funding supported by the Office of Naval Research).

POSTER 37

Characterization of longitudinal canal tissue in cirripede *Amphibalanus amphitrite*

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As major hard foulants, barnacles present a serious challenge to seaborne vessels in low flow conditions over an extended time period. In order to know how these marine invertebrates are able to settle so effectively on a variety of surfaces, it is important to understand the physiology of the animal itself. Here we seek to elucidate the role of tissue confined within longitudinal canals of the parietal plates of *Amphibalanus amphitrite*. The tissue is surrounded by an epidermal layer and appears to terminate at the leading edge of the barnacle basis in clusters of finger-like projections. Hematoxylin and eosin (H&E) stained histological sections revealed the presence of nuclei as well as micron-sized granules that were found to stain positive with the lipophilic dyes Nile Red and Bodipy FL. In addition the lower sections of the longitudinal canal tissue was directly connected to the sub-mantle tissue, which mainly consists of female reproductive tissue (ovarioles). Subsequent proteomic analysis of the canal tissue compared to sub-mantle tissue revealed a near 50% overlap in the protein profile, with the greatest number of hits against vitellogenin, a yolk protein precursor. Combined, these results strongly suggest the longitudinal canal tissue is part of the female reproductive system. While a typical arthropod ovariole consists of a germarium and a vitellarium, barnacles, as hermaphrodite arthropods, appear to possess a unique female reproductive system that has long been referred to as egg lamella, in which oocyte clusters develop in units designated as oviducal sacs. Instead, *Amphibalanus amphitrite* ovarioles appear to have a pooled vitellarium that connects with numerous germaria. Our results indicate the barnacle ovariole differs from those intensively studied model arthropods (e.g. insects) in two major aspects: 1. the germaria do not comprise bundles but disperse within the calcified shell; 2. all germaria terminate at a common and massive vitellarium.

POSTER 38

Relationship between marine bacterial biofilm and the establishment of periphyton and zooplankton on early biofouling process

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This work presents how time, texture, orientation, bacterial biofilm, antifouling paint (copper), and zooplankton potential influence on the establishment of the periphyton and zooplankton on hard substrates based on laboratory experiments developed for 12 days. For this purpose, acrylic substrates (25 cm²) were placed into 18 experimental units (20 L) with natural seawater and plankton community. The substrates were exposed to different situations (natural, antifouling paint, and antimicrobials), orientations (vertical and horizontal), and textures (smooth and textured), totaling 12 treatments. The community was evaluated at 12, 72, 144, 216, 288 hours of exposure. The whole community (biofilm bacteria, periphyton, protozooplankton colonization, and settled meroplankton), established on acrylic substrates showed significant differences ($p < 0.001$) in density and composition in relation to exposure time and substrate situation. Experiments simulating natural situation showed the highest organisms diversity, followed by those that used antifouling paint. The situation with antimicrobials (inhibition of bacterial biofilm) presented the lowest density of colonizers. Horizontal surfaces were more attractive for the establishment of the periphyton and the meroplankton ($p < 0.001$) while the texture (2-20 μ m) was not an important factor for the colonization of these organisms. A positive (0.914) and significant ($p < 0.001$) correlation between the biofilm bacteria density, biofilm chlorophyll-a concentration and settled meroplankton density was observed, attesting the positive influence of bacterial biofilm in the ecological succession in biofouling processes. Funding: PDSE-CAPES-88881.132844-2016-01/FAPERGS-PRONEM-16-2551-000244-4.

Effect of biofilm age, substrate material, and microbial biofilm composition on metazooplankton colonization

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The settlement of invertebrates can be modulated by different factors as substrate material and microbial biofilm. In this context, the aim of the current work was to test if there is a relationship between the metazooplankton colonization and the microbial biofilm age, density, and composition on different materials, exposed to laboratory and field conditions. One experiment was realized under laboratory condition to test the influence of biofilm age (0, 5, 10, 20 days) on two different substrates (wood and steel). Other experiment was carried out in a natural environment (Mediterranean Sea) where the effect of different microbial communities' composition on wood, concrete fiber, and acrylic substrates were evaluated. In both experiments the zooplankton colonization potential was estimated. The biofilm age affected metazooplankton colonization, being older biofilms more attractive and usually characterized by a higher bacterial density when compared to young biofilms. Wood and concrete fiber surfaces were more attractive than steel and acrylic substrate materials. The bacterial biofilm is more important than periphyton for meroplankton settlement, although cyanobacteria also shows a positive and significant correlation with settlement, depending on the substrate material. Meanwhile, the zooplankton potential, in terms of number of species, may reflect the colonization, even though the proportionality was not observed, confirming that external factors can influence the biofouling process, as substrate characteristics and microbial community composition. Funding: PDSE-CAPES-88881.132844/2016-01 and FAPERGS-PRONEM-16/2551-000244-4.

MANAGEMENT OF VESSEL FOULING

POSTER 40

History of research of biofouling and antifouling systems conducted by Brazilian Navy

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Biofouling research carried out by the Institute of Marine Studies Admiral Paulo Moreira (IEAPM), a R&D Brazilian Navy Institute, in the last three decades was essential for fouling control and management on Navy vessels. Initially, it was proposed the inclusion of a manual for fouling species identification in the docking reports and a database was created to store these information, providing a tool for an objective evaluation of the performance of commercial antifouling systems (AFS). Over the years, several aspects were integrated for best practices, such as consider in the evaluations the operational profile of the vessels and the environmental parameters of the anchoring areas of navy vessels. This new approaches support decision makers about which AFS was more suitable. IEAPM had an effective contribution to the 2001 Antifouling Paint Convention with 30% of the proposed articles approved in the Convention. Methods developed by IEAPM to test AF systems has national and international recognition as well as the use of the Biofouling Index to evaluate and compare the different types of AFS. The participation of IEAPM in the project Low Emission Antifouling (LEAF), project funded by the European Community, the coordination of GEBIO project for management and control of biofouling and bioinvasion in Brazilian coast and the recent nomination of the IEAPM as coordinator of the GloFouling Project in Brazil, demonstrate the international level that biofouling research has achieved in the Brazilian Navy.

POSTER 41

Effects of grooming on an ablative copper coating subjected to static or dynamic immersion

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Biofouling development differs between constant service ships and those that sit pier side for extended periods of time. It was hypothesized that differences in operational schedules will impact the frequency of grooming required to effectively improve the performance of fouling control coatings. This study measured the differences between statically and dynamically immersed BRA640 panels that were either ungroomed or groomed once a week, with respect to biofouling development, biofouling composition, coating roughness and coating thickness. (Research funded by ONR Grant N00014-16-1-3123 and N00014-16-1-3050).

POSTER 42

Design requirements and evaluation of vertically rotating brushes utilized on hull grooming underwater vehicles

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Grooming brush design plays an important role in both grooming tool development and coating performance. The requirements for a brush are to impart sufficient force to remove biofilm and incipient fouling, not cause damage to the surface, and have minimum energy consumption. There are several factors that determine brush effectiveness. These include: bristle type, hub diameter, tuft angle, filament diameter, tuft quantity, and tuft arrangement. A test method was designed to measure the brush characteristics for different designs. The tests were conducted in a 150-gallon water tank. Brush rotation was controlled with a variable frequency drive (VFD) motor, torque was measured with a FUTEK rotary sensor and the applied forces by load cells that could measure both normal and tangential forces. Selected data will be presented to illustrate how brush design affects performance. (Research funded by Office of Naval Research Grant N00014-16-1-3050).

POSTER 43

Acute toxicity of antifouling biocides and water-jet derivatives to copepod *Acartia omorii* and *Paracalanus parvus* s.l

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The copepods, the dominant members of the zooplankton and major grazers of phytoplankton in the pelagic ecosystem, are at risk from the exposure to antifouling biocides and water-jet derivatives. This study investigated the toxicity of antifouling biocides (Diuron, Irgarol 1051, Sea-nine 211) and water-jet derivatives [water-jet effluent (WJE) and its MeOH extract (WJEME)] to the copepods *Acartia omorii* and *Paracalanus parvus* s.l., by the use of an egg hatching rate and nauplius mortality. The results from the study showed that Sea-nine 211 had the strongest effects on the hatching rates and nauplius mortality of both species, followed by Diuron and Irgarol 1051. In water-jet derivatives, the egg hatching rate of *P. parvus* s.l. in WJE was slightly lower than that of WJEME. However, no significant difference between the treatments was observed in *A. omorii*. The mortality rate of both species was higher in WJE than in WJEME. Although our study needs to be verified thoroughly through additional experiments, our results can be used for baseline studies concerning the toxicity of antifouling biocides against the marine environment. [Research funded by Korea Institute of Marine Science and Technology Promotion (PE99624)].

POSTER 44

Development of management process to reduce transfer of ship's biofouling during in-water hull cleaning activity

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In relation to the 2011 IMO Guideline for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species, we have embarked a research project to develop robust methods for assessment of the risk arising from the discharge of wastes during in-water hull cleaning activities, to draft regulatory guidelines on the surface of ship hull for the upcoming 5 years. In order to establish these methods the following factors need to be considered: (1) analysis of active substances such as biocides discharged from antifouling coating systems, (2) identification and assessment of risk posed by biofouling debris from ships' surfaces, (3) risk assessment through toxicity testing of the coastal and international test organisms to target toxic materials, (4) development of integrated management processes for in-water hull cleaning activities. The anticipated results of this project will contribute to the IMO-led "GEF-UNDP-IMO GloFouling Partnerships Project" starting this year, and establish a scientific basis for managing changes in the global market related to in-water cleaning techniques.

POSTER 45

Preliminary characterization of active substances and paint particles in wastes released during ship's hull cleaning using high pressure water jet spray

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During periodic maintenance of ship on a dry dock, pressurized jet water is sprayed for clearing off fouling attached on the ship's hull. The sprayed water can be contaminated with particles and active substances released from ship's antifouling paints, and then introduced directly into the marine environment. The active substances can be a source of hazard to marine organisms through continuous release from the paint particles into the environment. This study is to characterize the wastes being released into the marine environment during ship's hull cleaning by spraying of pressurized jet water. Wastes from various ships' hull cleaning and adjacent environmental samples (jet water effluent, fouling organisms, paint chips, and adjacent seawater and sediment) were collected for metal and particle analysis. Metal concentrations were determined using ICP/MS. Total suspended solid and particle size distribution in the jet water effluents were also characterized. Change of seawater quality before and after the discharge of the effluent from jet water cleaning into the environment was also monitored. Physical and chemical characterization of wastes from ship's hull cleaning will give insights to the fate and leaching analyses of active substances for risk assessment of various hull cleaning activities including in-water cleaning.

POSTER 46

Tackling the ancient problem of biofouling using modern sensing technology

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Biofouling detection and management is a significant global industrial problem whereby the economic and occupational cost of hull inspections are a necessity carried out by dry-docking or divers. The aim of this study was to develop a novel electromagnetic wave sensor to detect *Mytilus edulis* fouling on different artificial surfaces. Four treatment materials (PVC, PTFE, nylon 6 and silicone; n=60) were selected due to their varying relative permittivity, surface properties and industrial uses. Mussels were allowed to attach to the treatment materials and were compared with a control (no mussel plaque; n=60). A planar electromagnetic wave sensor connected to a vector network analyzer (VNA) generated a frequency to measure the reflected power (dBm) of the samples. Operating at microwave frequencies, mussel fouling in the form of plaque attachment to the materials was successfully detected at key frequencies. This novel sensory surface when installed has the potential for real-time, in-situ monitoring of biofouling which will facilitate a reduction in cleaning and inspection costs within the maritime industry. (Funding provided by Liverpool John Moores University).

POSTER 47

Reactive management of biosecurity risk vessels entering Australia

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The identification of vessels that pose an unacceptable biofouling risk coming to Australia is integral to effective pathway management. Early identification gives both the vessel and department the opportunity to manage the potential risk in the most efficient and effective manner. However, once identified, how are high risk vessels managed? The Australian and New Zealand Antifouling and In-water Cleaning Guidelines were developed in 2013 to support decision maker consideration of the appropriateness of in-water cleaning activities. The uptake and utility of these guidelines is currently under review. Having proactive and reactive options for management of biofouling is critical to effectively managing biofouling risk. The introduction of biofouling regulation focusing on proactive hull and niche area management, along with updating the above guidelines, will create an environment for innovation. For example, the Australian government is currently funding the review and testing of available systems to treat internal niche areas of commercial vessels. Acknowledgements: The work presented in this study has been undertaken by the following service providers: Efficacy of in-water treatment systems (Internal niches) - Biofouling Solutions Pty Ltd; Cawthron Institute.

MARINE BIOFILMS ON NATURAL & ARTIFICIAL SURFACES

POSTER 48

Microbiomes on recycle categories of preproduction plastic pellets

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Seawater leachates from 7 recycle-categories of preproduction plastic pellets are acutely toxic to barnacle larvae from < 1 mg of plastic pellet leached per ml of seawater to < 0.01 mg pellet leached per ml of seawater. We characterized microbiomes that developed on plastic pellets using 16s ribosomal DNA. Plastic pellets were exposed to the same flowing seawater for 70 days and microbiomes sampled at 8, 16, 24, 32 and 70 days. Each plastic category was colonized by different species and microbiome composition changed over time. Except for polyvinyl chloride, complexity of the microbiomes tended to increase over time. After 70 days polystyrene had a microbiome comprised of over 1000 operational taxonomic units while PVC had a microbiome comprised of less than 600. The 2 dominant groups of bacteria in the microbiomes depended on the type of plastic. Polyvinyl chloride microbiomes were dominated by *Methylophaga lonarensi* and *Crenothrix polyspora*. Polypropylene was dominated by *Methylophaga kenyense* and *Thermodesulfovibrio thiophilus*. Polystyrene by *Erthrobacter longus* and *Alcanivorax indicus*. By day 70, *Bifidobacterium bombi* was a dominant in the micobiomes of the other 4 recycle categories. Preproduction plastic particles have dynamic biofilms that reflect their chemistry. (Funding Provided by the Oak Foundation).

POSTER 49

Biofilm attachment is affected by flow and surface hydrophobicity

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Biofilms are intricate communities of microorganisms encapsulated within a self-produced matrix of extra-polymeric substances, creating complex three-dimensional structures allowing for liquid and nutrient flow through. These aggregations offer constituent microorganisms enhanced protection not only from environmental pressures like flow but are associated with higher resistance to antimicrobial compounds, providing a persistent cause of concern in relation to marine biofouling and medicinal infections. Bacterial attachment is affected by surface properties, such as hydrophobicity, as previously shown. Using an innovative microfluidic flow cell, we investigated the relationships between both shear stress and surface properties upon early biofilm formation of two biofilm forming species, *Cobetia marina* and *Pseudomonas aeruginosa*. In this study we investigated biofilm development under flow conditions and on surfaces with varying degree of hydrophobicity, namely low-density polyethylene membranes, permanox and glass slides. Biofilm development was measured using nucleic acid staining and end-point confocal laser scanning microscopy. Flow conditions affected biomass, maximum thickness and surface area of biofilms, with higher shear stresses (5.6 Pa) resulting in thinner, more compact biofilms than lower shear stresses (0.2 Pa). Control experiments performed under static conditions have shown that an absence of flow creates much thinner, smaller biofilms suggesting a growth response to the surrounding flow. With respect to surface properties, initial biofilm formation was also impacted as hydrophilic surfaces resulted in thinner biofilms when compared to hydrophobic ones. Alongside this, we observed the formation of biofilm streamer-like structures under laminar flow conditions within straight, micro-channels for the first time.

POSTER 50

Succession of marine biofilm communities in a port in Northern Portugal

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The formation of marine biofilms communities involves a succession of communities, however the specifics about the succession of these communities is not fully known. In this work, we used NGS (Next-generation sequencing) to characterize marine biofilms during a short-term period of 30 days in Northern Portugal. To cover the succession of biofilm communities at a short period, biofilm samples were retrieved at days 1,2,4,7,10,14,21,25 and 30 after immersion. rRNA sequencing was performed using a 300 bp paired-end read (Illumina MiSeq V3) and new prokaryotic universal primers 341F and 785 R were selected. The results showed a dominance of Alphaproteobacteria, particularly of Rhodobacterales during the all days of sampling. Noteworthy was the evolution of Bacillariophyta abundance on biofilms between day 25 (8% of total abundance) and day 30 of biofilm growth (61% of total abundance). This significant shift in the biofilm communities during these days, suggest that photoautotrophic organisms become dominant in this specific period of biofilm formation. Previous works generally did not sample between these days of biofilm development, which seems to be a period of significant modification of marine biofilm community structure and which consequently has significance for future antifouling applications. Funding provided by FCT (SFRH / BD / 99003 / 2013) and ERDF (UID/Multi/04423/2013) by the project INNOVMAR (reference NORTE-01-0145-FEDER-000035, within Research Line NOVELMAR), supported by North Portugal Regional Operational Programme (NORTE 2020), under the PORTUGAL 2020 Partnership Agreement, through the ERDF).

POSTER 51

Seasonal covariation of epibacterial community and surface metabolome in the Mediterranean seaweed holobiont of *Taonia atomaria*

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In marine ecosystems, macroalgae are prone to be colonized at their surface by complex communities of microorganisms including bacteria, archaea, microalgae, protozoa and fungi. This colonization process, named biofouling, can occur on any immersed surface: it is generally initiated by the attachment of bacteria and leads to the formation of tridimensional structures called biofilms. The surface of macroalgae is a privileged zone of chemical interactions between the alga and such natural biofilms, the whole forming a biological system composed of the host and its associated microbiome ("holobiont"). In this study, we investigated by a multi-omics approach the seasonal co-variations between the surface metabolome (UPLC-MS) and the epibacterial communities (metabarcoding 16S rDNA) of the brown macroalga *Taonia atomaria* in the North-Western French Mediterranean coast near Toulon. Bacterial communities remained relatively comparable at a high taxonomic level with a clear biofilm profile related to the co-dominance of Bacteroidetes (mainly Sphingobacteria), α and γ proteobacteria. However, a clear seasonal shift associated to seawater temperature increase was observed at the family level. Simultaneously, LC-MS based metabolomics revealed a marked seasonal variation of the chemical composition of the algal surface. A multiblock PLS-DA plot analysis showed a strong co-variation between the epibacterial communities and surface metabolites according to the season.

POSTER 52

Diatom communities on marine green turtles (*Chelonia mydas*) from distant biogeographic areas:
Recent findings and their implications

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Diatoms are some of the earliest colonizers on any marine substrate and it has been suggested that sea turtles should harbour epibiotic diatom communities. Nevertheless, direct evidence of epibiotic diatoms on sea turtles has only recently been provided from *Caretta caretta* and *Lepidochelys olivacea*. We present a comparison of diatom communities inhabiting carapaces of green turtles *Chelonia mydas* sampled within the Indian (Musandam Peninsula, Sultanate of Oman) and Atlantic (Costa Rica) Ocean basins. Diatom observations and counts were carried out using scanning electron microscopy. Species-poor, well-developed diatom communities were found on all examined sea turtles. Significant differences between the two host sea turtle populations were observed in terms of diatom abundance and their community structure. A total of 16 and 22 diatom taxa were found from sea turtles in Oman and Costa Rica, respectively, and 8 of these species belonging to *Achnanthes*, *Amphora*, *Chelonicola*, *Cocconeis*, *Navicula*, *Nitzschia* and *Poulinea* genera were observed in samples from both locations. *Chelonicola costaricensis* and *Poulinea lepidochelicola* dominate the diatom communities in both localities representing together approximately 68 and 45 % of the entire diatom communities in Oman and Costa Rica samples respectively. These two diatom genera, which have only recently been described from olive ridley carapaces and, so far, have not been observed elsewhere, can be likely considered truly epizoic taxa. (Funding provided by SQU Grant IG/DVC/CEMB/17/01).

POSTER 53

Counting the uncountable: Reliability of quantitative analysis of bacteria using epifluorescent microscopy

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Usually, researchers estimate the total number of bacteria on the substrate by counting stained bacteria in randomly selected fields of view of an epifluorescent microscope and calculating the arithmetic mean. In this study, we evaluated the accuracy and reliability of this method. The aim of this study was to evaluate the accuracy of the estimating total bacterial abundance and to calculate the arithmetic mean variance in relation to the number of fields of view counted. Biofilms were developed on several microscope slides in the Sea of Oman. Bacterial cells were counted from a total of 13,924 fields of view on each slide covering the whole area of the slide. We used the total bacterial count, the abundances of bacteria in each field of view and the distribution of bacteria on a slide to calculate the arithmetic mean and associated variance and bias for each sample. The study revealed a non-uniform distribution of bacterial cells on the glass slide. The resulting count data was not normally distributed irrespective of the total number of cells in the sample counted. Among the three measures of central tendency, the arithmetic mean was found to be the most reliable estimate to obtain total bacterial density. A minimum of 20 random fields of view or a minimum of 350 bacterial cells need to be counted to obtain a reliable value of the arithmetic mean to estimate the total bacterial abundance for a marine biofilm sample on a glass slide. Acknowledgements: This work was funded by HM Sultan Qaboos Research Trust Fund (SR/AGR/FISH/10/01) and The Research Council of Oman (RC/AGR/FISH/16/01).

POSTER 54

Detection of biofilm in seawater pipelines: Experimental validation and case studies of an innovative sensor

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Seawater is used as process element by many industrial plants, in the Oil & Gas, Power production, etc. In such applications, bacterial growth on surfaces (commonly known as biofilm) can cause problems ranging from deterioration of materials to decrease in thermal exchange, thus leading to an increase in power consumption. Large amounts of chemical substances (biocides) are usually employed to prevent biofilm development, but often such treatments do not give the expected results. In most cases, biocide injection is carried out on a regular basis (daily, weekly, ...) or when visible problems arise, and neither the real need of the treatment nor its effectiveness are really verified. Since those chemicals are finally discharged into the sea, an optimization of such treatments can lead to a reduction of their environmental impact, allowing to cut, at the same time, the costs. An innovative biofilm sensor, able to detect bacterial growth since its very first phase, on line and in real time, was developed by the Italian National Research Council, in collaboration with local Companies. This technology, tested in different research projects and currently used in many industrial applications, was submitted to an accurate scientific validation (including state-of-the-art molecular analyses), to verify the representativeness and reliability of the information provided by the sensor. The results from different case studies are also presented.

MOLECULAR BIOLOGY & BIOINFORMATICS

POSTER 55

Comparing analysis of bacterial community of biofilm formed on the corroded steel and other metals immersed in seawaters

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The mechanism of the corrosion process, as influenced by bacteria, has been studied extensively. However, the bacterial communities that create the biofilms that form on metals are complicated, and have not been well studied. The microfouling community samples of steels, aluminum and copper were collected from their surfaces immersed in seawater for different time in Sanya in China. Phylogenetic data were acquired by high throughput Illumina Miseq sequencing techniques. This research revealed Proteobacteria, Firmicutes and Bacteroidetes were the dominant phyla, accounting for 88.84% of the total on corroded steel surface. *Desulfovibrio spp.*, *Desulfobacter spp.* and *Desulfotomaculum spp.* were the dominant genera and accounted for 45.87% of the total. However, on the other metal surfaces such as aluminum and copper, the bacterial communities are different. In this presentation, we will introduce the sampling methods and analysis results of bacterial communities on corroded steel and other metals. This work was supported by the National Basic Research Program (No. 2014CB643304) and National Natural Science Foundation of China (No. 41576080).

POSTER 56

Metabolomic and proteomic responses of the marine biofilm-forming bacterium
Pseudoalteromonas lipolytica to copper stress.L. FAVRE (1), A. ORTALO-MAGNÈ (1), L. KERLOCH (1), C. PICHEREAUX (2,3),
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Copper is an essential element for cells but this metal is present in some marine environment at so high concentrations that it has become toxic for numerous organisms. To prevent cell toxicity, marine organisms in polluted area may develop specific adaptive responses. To investigate the influence of this exogenous oligo-element on the metabolism of a biofilm-forming bacterial strain, a dual approach combining metabolomics and proteomics was undertaken. The response to copper stress of the strain *Pseudoalteromonas lipolytica* TC8, isolated from artificial substrates immersed in the Toulon Bay, was studied both in planktonic and biofilm modes. Growth inhibitory concentrations highlighted differential adaptation according to the phenotype. Copper exposure led to the induction of defense and detoxification mechanisms. Specific metabolic and protein profiles were thus observed in each condition (planktonic vs biofilm and control vs copper-treated cultures). More precisely, copper exposure seemed to induce drastic changes of the lipid composition of the bacterial cell membrane and to improve the production of proteins involved in copper cell homeostasis in both planktonic and biofilm culture modes. Much more proteins differentially expressed after copper treatment were observed in biofilm than in planktonic cells which could indicate a better defense in the case of biofilm cells.

POSTER 57

Comparative toxicity of three alternative booster antifouling biocide on embryonic flounder (*Paralichthys olivaceus*): An approach to transcriptome and morphogenesis

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The use of alternative biocides for antifouling application has increased since the restriction on the use of organotin compounds. However, there is the limited information of those biocides on the toxicity to non-target marine organism. The present study determined the toxic effects of the alternative antifouling compounds including Diuron, Irgarol 1051 and Sea-nine 211 on embryonic flounder. At 48h after exposure, frequency percentage of mortality was <10% in all the exposure group of Irgarol 1051 and Diuron. But embryos were shown 100% of mortality in the exposure group of 100µg/L for sea-nine 211. Overall, three biocides produced a largely overlapping suite of defects including caudal fin fold defects, dorsal curvature, and pericardial edema. Those biocides may be ranked in the following order from highest malformation and mortalities; Sea-nine 211>Irgarol 1051>Diuron. We used high-throughput sequencing (RNA-seq) to characterize the developmental toxic effects from biocide exposure. Genes associated with proteolysis involved in cellular protein catabolic pathway process, and intracellular signal transduction was down-regulated in flounder embryos treated with three biocides. Genes associated with microtubule cytoskeleton and regulation of cell morphogenesis were up-regulated at embryos exposed to Irgarol 1051 and Sea-nine 211, while they were down-regulated in embryos exposed to Diuron. Different gene expression profiles were also observed in embryos exposed to biocides with different chemical compositions. Overall, our study provides a better understanding of the underlying molecular toxic mechanisms via RNA-seq and DEGs in embryonic flounder.

POSTER 58

Developmental toxicity of antifouling system from water jet cleaning effluent on embryonic flounder (*Paralichthys olivaceus*): An approach to transcriptome and morphogenesisJ.H. JUNG, Y.S. MOON, Z.Y. SOON, M. KIM, J.H. KANG, M.C. JANG,
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Antifouling constituents enter the marine environment through hull maintenance. Antifouling paint removed by scraping and blasting and painting constitute are readily transported into the marine environment where they become interspersed with sediments, creating “hotspots” of contamination. Leached biocides of the paint matrix are considerably more persistent and therefore, they likely to pose a longer-term threat to the local marine environment. The present study determined the toxic effects of the water jet effluent from dry-dock cleaning of R/V Ear-Do and methanol extract of water jet effluent on embryonic flounder. At 48h after exposure, two exposure materials produced a largely overlapping suite of malformation defects, including caudal fin fold defects, dorsal curvature, and pericardial edema. But, the embryonic flounder exposed to WJE produced the higher malformation effects than those of WJEM exposure group. We characterized the developmental defects from antifouling paint constitute using high-throughput sequencing. The unigenes were functionally annotated based on protein sequence similarity using GO analysis and KEGG. The distribution of GO terms showed that dendrite and negative regulation of macromolecule metabolic process were enriched in both of exposure group. In embryonic flounder exposed to WJE, the distribution of GO terms showed that cell morphogenesis, regulation of signal transduction, and sarcomere were enriched (cutoff $P < 0.01$) and neurotransmitter transport, diacylglycerol kinase activity and cytoskeleton were enriched in embryonic flounder exposed to WJEM.

NEW ANALYTICAL METHODS

POSTER 59

Quantifying biofouling using image analysis:
Supervised classification of photographs collected with an inexpensive underwater camera

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The objective of this work was to build an image classification library of fouling organisms based on visible attributes (color, shape, etc.) of identifiable taxa (e.g., microalgal biofilm, bryozoans, etc.) to allow organisms to be identified and quantified (as percent cover of the substrate). Here, photographic images ‘collected in situ’ were used to develop and train an algorithm to classify photographic images containing natural assemblages of fouling organisms. Initially, an unsupervised classification was used, and three types of fouling were delineated. Using a supervised approach, seven types of fouling could be identified. This approach was successfully used to quantify fouling over time in experimental panels immersed in seawater. This work was completed using an inexpensive, waterproof camera and a classification scheme developed using standard image processing algorithms. Both of these elements represent a step forward in efforts to quickly and easily classify biofouling. (Funding provided by U.S. Environmental Protection Agency Water Permits Division).

POSTER 60

Exploring the factors affecting biofouling by marine diatoms, via meta-analysis of published data

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Meta-analysis offers a powerful means of exploring the effects of multiple variables on settlement, adhesion, and ease-of-removal of marine biofouling organisms on antifouling surfaces. Biofouling by marine diatoms has been the subject of many published studies, investigating the relationships between surface properties (such as roughness, surface energy, and elastic modulus) and the adhesion of diatom cells and biofilms. For example, data concerning the “model” biofouling organism *Navicula spp.* has featured in over 50 peer-reviewed publications. Rather than relying on the use of a simple narrative summary approach to synthesize these data, this poster presents the outputs from a meta-analysis on data obtained from studies published between 2000 and 2018. This analysis explores the factors affecting density and adhesion strength of *Navicula spp.* cells on a diverse range of surface types, and illustrates the potential usefulness of meta-analysis for similar analyses of other biofouling taxa.

POSTER 61

Artificial ageing of biocides-based antifouling coatings: A universal accelerated test method?

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Biocides-based antifouling coatings are the most employed antifouling solutions around the world. Among them, Self-Polishing Coatings (SPCs) are the most efficient ones, with antifouling efficiency up to 90 months. However, for antifouling coatings end-users, such as the French Navy, knowing the efficiency of such antifouling coatings within a short period of time, without waiting for field feedbacks on ships would be of a great help to choose the most appropriate coating. Several artificial ageing protocols were evaluated within the ACWS (Antifouling Coatings for War Ships) project in 2008-2011. The most promising one consists in a static phase in laboratory where the coating is immersed in an artificial solution, followed by a dynamic period on a rotor apparatus in seawater. The aim of this new study is now to determine the universality of such ageing method, meaning, could it be used to accelerate the ageing of different SPCs? Three commercially available SPCs were evaluated. The influence of the number of artificial ageing cycles was also studied. Artificial and natural ageing were compared in order to quantify accelerating factors, based particularly on erosion and leached layer measurements by SEM. (Research funded by the French Ministry of Armed Forces).

POSTER 62

Artificial ageing of fouling release coatings

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Among commercially available antifouling solutions, Fouling Release Coatings (FRCs), based on silicone elastomers, are promising environmentally-friendly antifouling coatings, as their efficiency rely on their specific properties (low surface energy, low modulus, low roughness) and their self-cleaning ability, without any release of biocides in the marine environment. Such coatings are designed to be efficient up to 10 years. For antifouling coatings end-users, such as the French Navy, knowing the efficiency of antifouling coatings within a short period of time, without waiting for field feedbacks on ships would be of a great help to choose the most appropriate coating. Therefore, the aim of this study was to develop laboratory ageing protocols to accelerate the ageing of several FRCs. Five artificial ageing types have been tested (thermal ageing, photochemical ageing, immersion in solvents or acid solutions, abrasion) as well as their combination. The impacts of each type of ageing, on the specific properties of FRCs were evaluated, before and after immersion in artificial seawater. The artificially aged FRCs were then immersed in the Mediterranean Sea to assess the influence of the artificial ageing on their antifouling performances. (Research funded by the French Ministry of Armed Forces).

NEW ANTIFOULING TECHNOLOGY

POSTER 63

3D modeling 3D printing of arborescent bryozoan for hydrodynamic testing

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It is estimated that nearly 10% of fuel dedicated to propulsion is wasted as a result of biofouling on US Navy ship hulls. To verify the fuel penalty, the Naval Surface Warfare Center Carderock and Philadelphia Divisions (NSWCCD and NSWCPD respectively) are performing hydrodynamic testing of additively manufactured biofouling panels from laser scan data. To capture additional granularity in the realm of biofouling subjects being tested, NSWCPD has considered the 3D modeling and 3D printing challenges of soft biofouling organisms, specifically arborescent bryozoan. Arborescent Bryozoan was isolated from various laser scan data sets and the best two data sets were selected for processing and 3D printing. Two different approaches were taken for the modeling of arborescent bryozoan, both resulting in an accurate representation of the arborescent bryozoan geometry. The models were successfully additively manufactured out of a flexible, rubber-like photopolymer on NSWCPD's additive manufacturing equipment. The model's stiffness was then varied by mixing rigid photopolymer resins with flexible resins to increase the stiffness in an effort to mimic the specimen. Finally, a representative test panel with various hard and soft biofouling scan data sets was combined onto a single panel to demonstrate the ability to place various organisms on a single "engineered" biofouling panel. Additional research is being conducted to validate the deflection characteristics of the 3D printed arborescent bryozoan versus a live specimen in its natural habitat. Additionally, hydrodynamic testing of the 3D printed panels with soft fouling will be evaluated with consideration to varying stiffness of the printed arborescent bryozoan and the resultant hydrodynamic penalty.

POSTER 64

Investigation of the antimicrobial activities of peptide-modified 304 stainless steel

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Antibiofilm formation on the surface is an important research topic in ship tribology. If the biofilms are inhibited or eliminated, this will render subsequent attachment more difficult. Therefore, modification of existing metal surface to resist biofilm formation is an effective strategy in antifouling. In this study, a surface modification procedure was applied in which dopamine was used as a coupling agent allowing a strong binding ability with the two synthetic peptides (P1 and P2). XPS, contact angle measurement, elemental analysis and surface roughness test were used to evaluate the efficiency of the peptide modification. Antibiofilm assay using *Staphylococcus aureus* incubation was conducted to validate the antibiofilm capacity of the peptide-modified stainless steel samples. XPS spectral analysis confirmed the optimal dopamine concentration was 40 µg/mL in the coupling reaction. Element analysis showed that dopamine and the peptides had bound to the steel surfaces. The robustness of the modified surface convinced that most peptide molecular could bound on the surface of stainless steel firmly. Contact angle of the modified stainless steel was significantly increased. Modified steel samples exhibited improved antibiofilm properties in comparison to untreated counterpart and only dopamine treated samples, with the peptide 1 displaying best antibiofilm effect. Modified steel samples also showed antibacterial capacity. It was also revealed from this study that the antibiofilm capacity of the modified surface was surface topography sensitive. The steel sample surfaces polished with 600 # sand paper exhibited stronger antibiofilm capacity than others after peptide modification. The findings present valuable information on material antifouling researches.

POSTER 65

The effect of surface modifying additives on the fouling-release properties of siloxane-polyurethane coatings

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A problem that has been affecting maritime activities for hundreds of years is that of marine biofouling; the undesirable accumulation of marine organisms on submerged structures in seawater. Increased fuel consumption, increased carbon emissions, the spread of non-native species, and decreased speed of naval vessels result from the settlement of over 4000 species of algae, barnacles, mussels, and marine bacterium. To combat this issue, anti-fouling (AF) paints, such as those containing tri-organotin compounds, have been used. However, these AF paints were found to be highly toxic and poison the surrounding marine environment. Therefore, non-toxic fouling-release (FR) paints were developed that employ low surface energy groups to allow a weak adherence of marine organisms, while facilitating an easy removal under shear forces. Previous research done at NDSU resulted in the development of a self-stratifying, hydrophobic, siloxane-polyurethane (SiPU) system which showed FR properties comparable to commercial FR paints. Currently, work is being done to further improve upon the FR properties of this system by incorporating surface modifying additive amphiphiles into SiPU coatings. A series of structurally different co-polymers of polyhydromethylsiloxanes and allyl polyethylene glycol monomethyl ethers were synthesized via platinum catalyzed hydrosilylation and their structures confirmed with Proton Nuclear Magnetic Resonance Spectroscopy and Fourier Transform Infrared Spectroscopy. Varying amounts of the surface modifying additives were incorporated into SiPU formulations and surface analysis techniques were used to observe the surface changes before and after water immersion. Additionally, laboratory biological assays were performed with *C. lytica* and *N. incerta* (marine bacterium and diatoms) to determine AF/FR properties of the coatings. The Office of Naval Research supported this research under grant N00014-16-1-3064.

POSTER 66

Low-fouling peptide sequences with resistance to marine biofouling organisms

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Fouling-release coatings require a suitable combination of a silicone network and additional compounds that reduce adhesion of marine fouling organisms. We explored the fouling-release potential of oligopeptide sequences and tested them as self-assembled monolayers. The design motif of the peptide sequences was inspired by hydrophilic, helical EG6OH, which is known for its excellent antifouling properties. Besides the naturally occurring ones, artificial amino acids are introduced into the sequences. Different sequences were synthesized and hydrophilic peptide coatings were assembled. All surfaces are characterized with respect to their wettability, layer thickness and secondary structure by contact angle goniometry, spectroscopic ellipsometry, and IR- and CD-spectroscopy. The kinetics of the assembly process depended on the peptide sequence, but even under diluted conditions, close packed monolayers could be obtained. Protein adsorption of fibrinogen and lysozyme was very low on the oligopeptide SAMs. The assembled monolayers show remarkable fouling-release behavior against *Navicula perminuta* which was tested in a microfluidic assay. Also settlement of *Ulva linza* zoospores was remarkably reduced by the oligopeptide coatings. Due to their diversity, easy synthesis and biocompatibility, peptides could be used as active, hydrophilic components in fouling-release technologies. (Research funded by Stiftung Industrieforschung and ONR N00014-16-12979).

POSTER 67

The application of ultraviolet exposure to prevent biofouling on ship hull coatings

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Ultraviolet light (UV) is used by many industries to control the presence and growth of unwanted organisms. Present day ship hull fouling control coatings often become fouled when the ship is at rest for prolonged periods of time. This study investigated the concept that an array of UV lights could be used to traverse a ship's hull at a frequency which will control marine growth. Field tests were designed to investigate the effect of UV exposure on three ship hull coatings: a silicone fouling release coating, a copper ablative coating, and an inert epoxy surface control. A 25W UV light source was used to illuminate the surface. The experiments were designed to measure the influence of frequency (no UV exposure, continuous exposure, one minute per six hours, and one minute per day), distance of the UV source from the surface (25 and 50 mm), and coating type (copper antifouling, silicone fouling release, epoxy). The results demonstrated that continuous UV exposure prevented fouling on all surfaces. Fouling was prevented on the fouling release and copper coatings that were subjected to one minute per six hours but the epoxy fouled. The one minute per day frequency was effective at preventing biofouling settlement when compared to the control frequency over the four month period. The antifouling area for each UV treatment was determined for the epoxy coating. This study demonstrated that intermittent exposure of ship hull fouling control coatings can enhance their ability to prevent fouling. (Research funded by ONR Grant N00014-16-1-3123 and N00014-16-1-3050).

POSTER 68

Interaction and layout of laboratory, field and real condition testing for development of new fouling release materials

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Development of new non-toxic fouling release coatings is a major task for paint developer. Laboratory testing and field tests at several different test sides give important information about performance and behavior of new coating systems, but testing on real conditions (e.g. test areas on ships) is still needed. To test as much as possible and reasonable and simultaneous obtain a good characterization of the tested fouling release coatings, a well-considered testing layout is necessary. The creation of such a testing layout is shown exemplary for the development of a fouling-release coating. Also possible accompanying methods and analytical techniques are considered. Therefore different laboratory, toxicity, electrochemical and calometric tests are discussed. Field tests were performed at different North Sea test sides, at Mediterranean Sea and at South China Sea, near Singapore. For testing under real conditions test areas on two different ships were coated in 2015 and 2016. The different test series represent different stages of material development and enable to track the progress.

POSTER 69

The resistance to freshwater of main-chain degradable self-polishing antifouling coating systems

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The resistance to freshwater of antifouling coating systems is important for their field applications, especially in China where the ship building process is mostly affected by freshwater from rivers. We have studied the adhesion of antifouling coating systems immersed in deionized water (DIW) and artificial seawater (ASW) as a function of time, in which the antifouling coatings are based on novel main chain degradable silyl acrylate polymers and rosin. Orthogonal array design for the optimization of antifouling coating formulations was used and three variables were studied: resin/rosin ratio, pigment volume concentration (PVC) and the amount of additives (R). Our studies demonstrate that the adhesion of coating systems decreases with immersion time of DIW, and the decline in adhesion of coating systems immersed in DIW is larger than that immersed in ASW. Through the effects of three variables on the adhesion of antifouling coating systems, we have gained the optimum values (RR3, P1 or P2 and RC1) of resin/rosin ratio, PVC and the amount of additives (R). (Research funded by the "13th Five-Year" Marine Economy Innovative Development Demonstrative Project of China, 16CZB023SF12 and the Research Funds Project of Fujian Collaborative Innovation Center for Exploitation and Utilization of Marine Biological Resource, FJMBIO1604).

POSTER 70

Hydrolyzable additives-based silicone elastomers: A new approach of antifouling coatings

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The universal ban of organotin compounds in antifouling coatings in 2008 was a pioneering step in the development of more ecofriendly ship hull paints. The European Biocidal Products Regulation also contributes to limit or even prohibit the leaching of some toxic substances responsible for non-targeted marine species death. Hence there is a growing interest in developing biocide-free coatings. Among them, Fouling Release Coatings (FRC), based on poly(dimethylsiloxane) (PDMS) elastomers, exhibit self-cleaning ability while immersed in water in presence of hydrodynamic forces, provided by their specific properties: low-roughness surfaces, environmental inertness, low surface free energy, water and fouling repellency, and low elastic modulus. However, they can be covered by fouling organisms during static periods. In this work, PDMS elastomer coatings were developed in order to improve their efficiency in static conditions, by incorporating various amounts of polymers additives which can degrade through a hydrolysis of their main chain or their pending groups. These hydrolyzable polymer additives generate the renewal of the surface chemistry due to the diffusion of the additive to the surface and the release of degradation products which can prevent the settlement of marine organisms. Loss mass tests in water were performed to assess the kinetic of the degradation products release. The surface chemical modification after water contact was assessed by dynamic contact angle measurements. Field tests in the Mediterranean Sea and *A. amphitrite* barnacles adhesion test allowed to evaluate the macroorganisms attachment on these coatings. Inhospitable behavior towards fouling was observed for some additives, which suggests it can have a potential application in marine FRCs. (Research funded by the Direction Générale de l'Armement).

POSTER 71

Effect of ultrasound on meroplanktonic larvae during settlement

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Acoustic waves have been recently applied as a complementary method to antifouling paints in recreational and commercial boats. However, little is known about the direct influence of ultrasound pressure waves on the swimming behavior of fouling organisms, including barnacle larvae. In this work, we studied the behavioral responses of barnacle larvae when exposed to different ultrasound intensities. A 3D optical system was used to acquire information on larval swimming behavior during the settlement period, at the cyprid stage, with and without ultrasound. In addition, a high-speed digital camera attached to an inverted microscope allowed the analysis of rapid behavioral changes preceding the settlement when exposed to ultrasound waves, such as decrease in step length and step duration during substrate inspection. (Funding provided by FAPESP).

POSTER 72

A self-healing lubricant-infused acrylate boron/fluorine polymer coating for antifouling application

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Acrylate boron polymer is a kind of environmental self-polishing polymer, which is without heavy metal ions. It should be combined with the permitted antifouling agents by its controlled hydrolysis property to achieve excellent antifouling effect. In order to avoid the risk of harmful antifoulants, a biocide-free self-healing lubricant coating was prepared by infusing perfluoropolyether lubricant in the acrylate boron/fluorine polymer. The structures of acrylate boron/fluorine polymer were characterized by Fourier transform infrared and nuclear magnetic resonance spectroscopy. As compared to the acrylate boron/fluorine polymer film, there were many micro-nano lubricant droplets dispersed in lubricant-infused acrylate boron/fluorine polymer films in the optical micrographs. To evaluate the storage stability of lubricant, accelerated volatile test was performed, and the results showed that the weight of lubricant-infused acrylate boron/fluorine polymer films had little change compared to that of blank. What's more, the films with more lubricant had bigger weight loss. The result of frictional experiments showed that the friction coefficient decreased obviously after adding perfluoropolyether lubricant, which demonstrates that the lubricant-infused acrylate boron/fluorine polymer has excellent anti-drag property. The interesting thing is, lubricant-infused acrylate boron/fluorine polymer can be healed by itself after sliced by a blade within few hours, and the speed of healing can be accelerated in higher temperature. The diatom inhibited test showed that few diatoms can be observed on the surface of lubricant films.

POSTER 73

Epoxy modified silicone resin with accordion-like structure and its antifouling performance

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The traditional poly(dimethylsiloxane)(PDMS)-based antifouling coatings always suffer from nonspecific protein adsorption and poor adhesion to the substrate. Here, accordion-liked PDMS networks modified with primary/secondary amine groups and epoxy resin which are thermally stable and exhibit excellent mechanical properties can be used for marine application. The silicone resin contained aliphatic polyamine (PSA) was synthesized by condensation polymerization. Apart from this, the epoxy modified PDMS resin was formulated with bisphenol A epoxy resin (DGEBA) for the development of fouling release coatings. The chemical structure of PSA was investigated by Fourier transform infrared spectroscopy (FT-IR), nuclear magnetic resonance spectrum (NMR) and gel permeation chromatography (GPC). The curing behavior of DGEBA/PSA was systematically studied with differential scanning calorimetry (DSC). Thermo gravimetric analysis (TGA) showed that the cured DGEBA/PSA network was thermally stable up to 390°C. The epoxy modified PDMS coatings showed excellent adhesion (>5 MPa) to the substrate and tensile strength (>22 MPa) compared with pure epoxy resin. Six-months marine field test in the Yellow Sea revealed that the modified PDMS coatings exhibited good antifouling/fouling release performance. This research introduces attractive merits such as simplicity, durability and potential application in marine fouling release field.

POSTER 74

Adaptive applications of SLIPS coatings in the marine environment

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Biofouling, corrosion and environmental elements pose numerous challenges to submerged materials over time in the marine industry, requiring innovative coating solutions to preserve structural integrity and equipment functionality. While heavy focus has been placed on developing bottom coatings for the marine vessel industry, there is demand from adjacent marine markets ranging from aquaculture to unmanned underwater vehicles (UUVs) for better coating systems to reduce operational/maintenance cost and extend functional lifetime. The recent development of non-toxic SLIPS coatings, characterized by a unique liquid-like surface, has demonstrated potential to minimize fouling in marine environments over several years. The versatile design of SLIPS coatings enables a range of material properties and application methods to accommodate adjacent marine markets. Based on anticipated stresses for the coated structures, SLIPS coating durability is shown to be modified accordingly. SLIPS coatings are shown to provide effective application and adhesion on a variety of substrates including metals, ceramics, glass and plastics. A clear SLIPS coating has also been developed for areas where optical transparency is vital, including sensors and windows. We present case studies of utilizing a non-fouling, easy-to-clean, and flexible SLIPS coating on marine netting, glass surfaces and structures supporting the broad utility of SLIPS as a protective layer on marine equipment. This work is in part funded by ARPA-E (Contract no. DE-AR0000759) and completed with generous support of Office of Naval Research.

POSTER 75

Dendritic polyglycerols as fouling-release coatings against marine diatoms

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Polyethylene glycol containing surface coatings show outstanding antifouling properties, which is commonly assigned to their hydrophilicity and their highly hydrated nature. A structurally related but hyperbranched version are polyglycerols that increase the spatial density of non-fouling polymer units and decrease the defect density in coatings [1,2]. So far they were successfully applied in biomedicine. Using ring opening polymerization reaction, we grafted dendritic polyglycerols on surfaces [3]. The resulting samples were characterized by spectroscopic ellipsometry, contact angle goniometry, ATR-FTIR and stability experiments in different media. The prepared surfaces show high protein-resistance. The fouling release properties were tested in a standardized lab assay with *N. incerta* and in a novel rotating disk field assay in Florida. The initial attachment of diatoms under static conditions was similar on the PGs as compared to glass. However, PGs show outstanding fouling release properties. Up to 94% of attached diatoms could be removed from the coatings after the exposure to a shear stress of 19 Pa. This high resistance was also confirmed in field experiments. (Research funded by ONR N00014-16-12979 (RUB), ONR N00014-16-1-3123 (FIT), DFG RO2524/4-1, Mercur Pr-2015-0018) [1] M. Wyszogrodzka, R. Haag, Biomacromolecules 2009, 10, 1043. [2] C. Siegers, M. Biesalski, R. Haag, Chemistry 2004, 10, 2831. [3] T. Weber, Y. Gies, A. Terfort, Langmuir 2012, 28, 15916.

POSTER 76

Fabrication of lubricant-infused fibrous porous surface by water-soluble non-woven fabrics sacrificial template

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Slippery liquid-infused porous surfaces (SLIPS) inspired by Nepenthes, also known as super-repellent surfaces, has attracted extensive attention due to their wide variety of practical applications. Despite extensive progress over an intense research, these current super-repellent surfaces are still hampered by problems: limited storage capacity of lubricant and inability to self-healing after lubricant loss in a certain area. Herein, we describe a strategy to create slippery liquid infused fibrous porous surface (SLIFPS) with exceptional storage capacity and storage stability of slippery liquid. In this work, we use water-soluble non-woven fabrics with different formulas as sacrificial templates to build fibrous porous surfaces with average pore size of 15 μ m. The effect and retention of lubricant on the fibrous porous surfaces are investigated and discussed. The capability to repel various liquids (such as deionized water, coffee, fruit juice, hydrocarbons, algae broth and blood) and to restore liquid-repellency (contact angle hysteresis less than 5 $^{\circ}$) after lubricant loss in a certain area or physical damage of SLIFPS was also demonstrated. We assume that fibrous pores provide spaces and channels for the storage and flow of lubricant. Our results suggest that using fibrous porous surface substrates that lock the infused lubricating fluid in situ can solve for the poor storage capacity of lubricant and inability to self-healing. We foresee a wide range of applications in liquid delivery, medicine, adhesion control, self-cleaning surfaces, anticorrosion and antifouling materials. (This paper is funded by the International Exchange Program of Harbin Engineering University for Innovation-oriented Talents Cultivation.)

POSTER 77

Polyelectrolyte multilayers based on polysaccharides as fouling-release coatings

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Polyelectrolyte multilayers (PEMs) are a straightforward way to assemble biomacromolecular coatings on surfaces. Assembly can be driven by both, electrostatic interactions or hydrogen bonding. Using automated spin coating technology, it is possible to construct smooth multilayers with nanometer roughness and highly reproducible thickness. Using the spincoating approach we explored PEMs based on the polymers hyaluronan, chitosan, alginate, and polyethylenimine. To obtain stability in sea water, the multilayers were covalently cross-linked either thermally or chemically. By tuning the degree of crosslinking, either stable coatings or a controlled degradation rate were achieved. The multilayers were tested against attachment of different proteins by SPR and the settlement of *Ulva* zoospores. The chosen polymer combination, the chemistry of the terminating layer, and the degree of cross-linking affected the antifouling performance of the PEMs.

POSTER 78

Basalt fiber flocks as a novel, environmentally friendly antifoulant

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Flock coatings consisting of synthetic fibers have been identified as sufficient solutions against barnacle fouling in the past [1]. However, on the one hand they have not proven to be sufficiently effective against other fouling organisms and on the other hand the synthetic fibers can be released into the marine environment by abrasion. In this project the application and effectiveness of fiber flock coatings consisting of basalt fibers are investigated. Similar to the production of glass fiber filaments, volcanic basalt rocks are melted and pulled to thin filaments (10 to 15 μm). These filaments are coated and bundled to basalt rovings. These rovings get chopped to small fibers of 0.5 to 1.0 mm length and are chemically prepared, making them electrically conductive. For application these chopped fibers are charged electrostatically and flocked onto an adhesive prepared surface. The manufacturing process and the promising results of a first simulated field test in 2017 will be presented. Acknowledgements: The work presented in this poster has been funded by the German Federal Ministry for Economic Affairs and Energy, R&D Project BasaltFaserFlock (Grant Agreement No. 03SX410). [1] B. Watermann, B. Daehne, M. Wiegemann, M. Lindeskog & S. Sievers (2003): Performance of biocide-free antifouling paints. Final report, LimnoMar, Hamburg.

Influence of wrinkled gold-coated polystyrene surfaces on attachment of
Pseudomonas aeruginosa and *Staphylococcus aureus*

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Surface wrinkling, a self-organized phenomenon, provides surface features ranging across the nano- and microscale that has become a facile fabrication approach for a number of technologies. Here, we investigate the surface parameters that influence the attachment behaviour of *Pseudomonas aeruginosa* and *Staphylococcus aureus* bacterial cells to wrinkled gold-coated polystyrene surfaces having topologies at the nano- and microscale. The surface wrinkle topology was shown to comprise stable air-water interfacial areas unavailable for bacterial attachment through confocal laser scanning microscopic, scanning electron microscopic image analyses and time-lapsed contact angle measurements. Imposition of the nanoscale and microscale wrinkles minimised the attachment of *P. aeruginosa* and *S. aureus* down to approximately 7.5% and 14.5%, respectively, compared to their flat equivalent surfaces. The density of attachments revealed an inherent species-specific selectivity that changed with feature dimension, attributable to the scale of the air - water interfaces in contact with the bacterial cell. Factors influencing static bacterial attachment were the total projected surface areas minus the air-water interface areas and the scale of these respective air-water interfaces with respect to the cell morphology. The range of these controlling parameters may provide new design principles for the evolving suite of physical anti-biofouling materials not reliant on biocidal agents under development. (DHKN is the recipient of Swinburne University Postgraduate Research Award).

POLICY & REGULATIONS

POSTER 80

A holistic ranking of construction materials for marine environments in the long term future

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Rapid urbanization of coastal areas combined with global climatic change and unavoidable sea level rise have drastically increased the necessity of resilient infrastructure in these regions. Thus improving the durability of materials in the aggressive marine environment through various approaches is essential. Current research however focuses mainly on improvements and protection methods for materials which are already being used on a large scale. Considering the accelerated depletion of global resources it is imperative from a sustainability perspective to develop an understanding of the long term availability of these construction materials before engaging in costly research to increase their durability. Here we present a generally applicable framework for the ranking of materials covering all areas of relevance, namely durability, economics of use, sustainability and future availability. Together with experts from industry and academia the framework was successfully applied to the ranking of 64 different materials containing metals, concretes, composites and timbers. The result is a detailed overview of the different materials' strengths and weaknesses measured with more than 25 attributes which determine the long term performance in the marine environment across the four mentioned categories. Aside from aiding research for instance in biofouling and corrosion protection to focus on projects with a high long term potential the framework can be easily adapted by practitioners to a large variety of specific material selection problems with shorter timeframes. Finally the exact definition of the rating scales for each attribute enables the efficient expansion of the framework through addition of new materials to the ranking.

POSTER 81

A preliminary approach of laboratory bioassay for the efficacy of antifouling paints using *Ectocarpus siliculosus*

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Antifouling (AF) paints are widely applied on the ships' hull surfaces to prevent the unwanted aquatic organisms through biofouling of ships. To develop more effective AF paints, it is very important to quantify the efficacy of new AF systems including biocides. In order to establish the test methods, test panels were prepared by the different formulations of AF paints by varying content of Cu₂O, and aged by a dynamic rotating device under controlled condition (water temperature: 20°C, rotation speed: 10 knots, period: 45 days) before a laboratory bioassay. After that, a laboratory bioassay was conducted using the unialgal culture strain of a filamentous brown alga *Ectocarpus siliculosus* (KU-1372), which is one of the most common fouling macroalgae, housed in Kobe University Macroalgal Culture Collection (KU-MACC). This laboratory bioassay was evaluated from the fluorescence strength of chlorophyll a extracted from the adhered *E. siliculosus* on the surface of each panel of experimental and control groups. As a result, the fluorescence strength of *E. siliculosus* generally decreased with an increasing of Cu₂O content. The critical value of settlement was observed at between 5 and 20 wt. % of Cu₂O. Furthermore, the validation of the bioassay was evaluated compared to field experiments, and showed the good agreement with field experiments. The authors will propose conventional and universal test protocols on the basis of these results combined with that of the results from mussel and barnacle.

POSTER 82

Regulatory issues associated with the development and use of biocide (DCOIT)-containing rubber

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The goal of Navy-funded basic and applied research projects is to successfully transition to Fleet use. In addition to scientific and technical barriers, projects that involve new biocides, or new uses for existing biocides, for the prevention of biofouling must negotiate additional legal hurdles due to FIFRA (Federal Insecticide, Fungicide and Rodenticide Act) the legislation that covers the development, testing and use of such materials. This presentation will cover the legal issues encountered by NUWC-NPT personnel after the successful demonstration that 4,5-dichloro-2-n-octyl-4-isothiazolin-3-one (aka: DCOIT, Kathon 287T and Vinyzene Max) could protect a variety of different rubbery substrates from marine biofouling, and the Navy wanted to transition the material into several fleet applications. Issues discussed will include the transition between “experimentation” and “manufacturing/production”; the need to properly register the new use of DCOIT with both the US EPA and State Environmental Protection Offices; and the need to satisfy “good stewardship” concerns of the commercial supplier of the biocide. The legal system, though slow, did finally reward the Navy’s perseverance when the US EPA accepted the changes proposed for the Vinyzene Max label proposed by the Navy and the Dow Chemical Company in late June of 2017. This action by the US-EPA has opened the door for the production of DCOIT-treated rubber articles for use in the Fleet.

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