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MAP OF STEPHEN RIADY CENTRE



PROGRAMME

SUNDAY, 6 th July 2014	
3.00pm – 6.00pm	REGISTRATION & HIGH TEA

MONDAY, 7 th July 2014					
8.30am	REGISTRATION				
9.00am	WELCOME BY MR ANDREW SCARDINO DSTO Australia, Chair of COIPM				
9.05am	OPENING ADDRESS BY MR ANDREW TAN Chief Executive, Maritime and Port Authority of Singapore				
9.15am	50 th ANNIVERSARY LECTURE: DISSECTING THE BIOLOGY / MATERIALS INTERFACE FOR INNOVATIVE ANTIFOULING SOLUTION Professor James Callow, Emeritus Professor of Plant Science, School of Biosciences, University of Birmingham, United Kingdom				
10.00am	NETWORK TEA				
	<table border="1"> <thead> <tr> <th>TRACK A - AUDITORIUM</th> <th>TRACK B – LT 52</th> </tr> </thead> <tbody> <tr> <td>MICROALGAL FOULING AND ADHESION PROCESSES Session Chair: Professor James Callow</td> <td>FOULING AS A VECTOR FOR INVASIVE SPECIES Session Chair: Dr Eugene Georgiades</td> </tr> </tbody> </table>	TRACK A - AUDITORIUM	TRACK B – LT 52	MICROALGAL FOULING AND ADHESION PROCESSES Session Chair: Professor James Callow	FOULING AS A VECTOR FOR INVASIVE SPECIES Session Chair: Dr Eugene Georgiades
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1.30pm	LUNCH (NOT PROVIDED)				

MONDAY, 7 th July 2014		
	TRACK A - AUDITORIUM	TRACK B – LT 52
	BIOCIDAL ANTIFOULING TECHNOLOGIES (Continue)	REGULATORY AND ENVIRONMENTAL ISSUES Session Chair: Professor Stephen de Mora
2.30pm	D1A - INVITED: IMPACT OF THE REGULATORY FRAMEWORK ON INNOVATION IN THE ANTIFOULING MARKET – AN ACTIVE SUBSTANCE SUPPLIER'S PERSPECTIVE Dr Rodolphe Querou, Dow Microbial Control, France	1B - KEYNOTE: MANAGING FOULING - REGULATORY CHALLENGES AND OPPORTUNITIES Dr Naomi Parker, Ministry for Primary Industries, New Zealand
3.00pm	1A - ORAL 4: GEL ENCAPSULATED BIOCIDES PROFOUNDLY REDUCING BIOCIDES AND METAL CONTENT IN ANTI-FOULING PAINT Eva Wallström, EnCoat ApS, Denmark	
3.15pm	1A - ORAL 5: POLYGODIAL : A PROMISING ALTERNATIVE TO CONVENTIONAL ANTIFOULING BIOCIDES Patrick Cahill, Cawthron Institute, New Zealand	1B - ORAL 1: COPPER BASED ANTIFOULING - LATEST REGULATIONS AND SCIENCE Neal Blossom, American Chemet Corporation, United States
3.30pm	1A - ORAL 6: 15 YEARS OF PRODUCT DEVELOPMENT – LESSONS LEARNED FROM SELEKTOPE Lena Lindblad, I-Tech AB, Sweden	1B - ORAL 2: LIFE CYCLE CONTRIBUTIONS OF COPPER FROM VESSEL PAINTING Kevin Long, Regulatory Compliance Ltd., United Kingdom
3.45pm	1A - ORAL 7: INCLUSION OF AN ISOTHIAZOLINONE-BASED BIOCIDES INTO RUBBERY SUBSTRATES: MODELING DISPERSION/ DEPLETION RATES AND MEASURING INDUCED CHANGES IN SUBSTRATE PHYSICAL PROPERTIES Thomas Romatowski, U.S. Navy/NUWC Newport, United States	1B - ORAL 3: REASSESSMENT OF ANTIFOULING BIOCIDES IN NEW ZEALAND Matthew Allen, Environmental Protection Authority, New Zealand
4.00pm	TEA BREAK	
	TRACK A - AUDITORIUM	TRACK B – LT 52
	BIOCIDAL ANTIFOULING TECHNOLOGIES (Continue)	REGULATORY AND ENVIRONMENTAL ISSUES (Continue)
4.30pm	1A - ORAL 8: BEYOND SPC – LUBYON®, A NEW SUPERHYDROPHILIC FOULING CONTROL POLYMER TECHNOLOGY Alistair Finnie, AkzoNobel/International Paint, United Kingdom	1B - INVITED: THE NEW EUROPEAN BIOCIDAL PRODUCTS REGULATION AND ITS IMPLICATIONS FOR ANTIFOULING PRODUCT FORMULATORS – A PRACTICAL REVIEW Mrs Linda Jones, Annex3 Consulting, Netherlands
4.45pm	1A - ORAL 9: FROM IDEA TO A NEW ANTI-FOULING PRODUCT Hans Elwing, University of Gothenburg, Sweden	
5.00pm	1A - ORAL 10: COPPER SELECTIVE LBL FILMS AND COPPER NANOWIRES FOR ANTIFOULING APPLICATIONS Dominik Janczewski, Institute of Materials Research and Engineering (IMRE), Singapore	1B - ORAL 4: NEW METHOD FOR RELEASE RATE DETERMINATIONS FOR ANTIFOULING PRODUCTS Erik Ytreberg, Chalmers University of Technology, Sweden
5.15pm	1A - ORAL 11: ANTIBARNACLE ACTIVITY OF ISOCYANIDES DERIVED FROM AMINO ACIDS Yoshikazu Kitano, Tokyo University of Agriculture and Technology, Japan	1B - ORAL 5: MIXTURE TOXICITY IN ANTIFOULING PAINT RISK ASSESSMENT Kevin Long, Regulatory Compliance Ltd., United Kingdom
5.30pm	1A - ORAL 12: SYNTHESIS AND ANTIFOULING PROPERTIES IN MICROFOULING STAGE OF HYBRID ZINC/SILYL ACRYLATE COPOLYMERS FOR MARINE ANTIFOULING Rongrong Chen, Harbin Engineering University, China	1B - ORAL 6: SHADES OF GREEN: ASSESSING FOR ENVIRONMENTAL BENIGN CHEMICALS IN ANTIFOULING BIOCIDES DEVELOPMENT Christina Chai, National University of Singapore and Institute of Chemical and Engineering Sciences (ICES), Singapore
5.45pm	1A - ORAL 13: FROM DINGHY TO DELUXE – AN OVERVIEW OF THE CHALLENGES IN FOULING CONTROL FACED IN THE PLEASURE CRAFT MARKET Cait Cairns, AkzoNobel/International Paint, United Kingdom	1B - ORAL 7: FORMATION OF REGULATED CHLORINATION BY-PRODUCT IN THE COOLING SEAWATER DISCHARGE OF A NUCLEAR POWER PLANT Kamala Kanta Satpathy, Department of Atomic Energy, India
6.00pm	BUS DEPART FOR INDUSTRY NIGHT (OPEN TO ALL PARTICIPANTS)	

TUESDAY, 8 th July 2014		
8.30am	PLENARY 1: MICROBIAL BIOFILMS – BIOLOGY AND CONTROL Professor Staffan Kjelleberg, Director, Singapore Centre on Environmental Life Sciences Engineering, Nanyang Technological University, Singapore; Co-Director, the Centre for Marine Bio-Innovation, University of New South Wales, Australia	
9.20am	SHORT BREAK	
	TRACK A - AUDITORIUM	TRACK B – LT 52
	BIOFILMS AND MICROBIAL FOULING Session Chair: Professor Peter Steinberg	NEW APPROACHES FOR ANTIFOULING Session Chair: Professor Robert Lamb
9.30am	2A - KEYNOTE: MICROBIAL FOULING OF MEMBRANES AND STRATEGIES FOR CONTROL A/Prof Scott Rice, University of New South Wales, Australia; SCELSE, Singapore	2B - KEYNOTE: SEAWATER ABUNDANT COPPER IONS - SELECTIVE AND EFFICIENT COPPER UPTAKE AND RELEASE AS A NEW ANTIFOULING MECHANISM Dr Mikael Larsson, The Ian Wark Research Institute, University of South Australia, Australia
10.15am	2A - ORAL 1: MICROBIAL COMMUNITIES ON SEAWEEEDS Peter Steinberg, Sydney institute of Marine Science, Australia; Nanyang Technological University, Singapore	2B - ORAL 1: COMPARATIVE ANTIFOULING PERFORMANCE OF SELECTED HYDROPHOBIC, SUPERHYDROPHOBIC, FLUOROCARBON AND NOVEL SURFACES Raymond Shane Addleman, Pacific Northwest National Laboratory, United States
10.30am	2A - ORAL 2: ANTI- AND PROFOULING EFFECTS: CHEMICAL MAINTENANCE OF THE HOLOBIONT FUCUS VESICULOSUS? Mahasweta Saha, GEOMAR, Germany	2B - ORAL 2: ELECTROACTIVE POLYMERS: A NEW ANTIFOULING CONCEPT FOR MARINE APPLICATIONS Christine Bressy, University of Toulon, France
10.45am	2A - ORAL 3: GROWTH ON CHITIN SURFACES PROTECTS VIBRIO CHOLERAEE FROM PREDATION Diane McDougald, Singapore Centre on Environmental Life Sciences Engineering, Singapore	2B - ORAL 3: AERATION METHODS FOR IMPROVED HULL FOULING PREVENTION: USING STANDARD AIR AND LOW DOSE ELEMENTAL IODINE INFUSED BUBBLES FOR ENHANCED BIOLOGICAL INTERACTION Natasha Dickenson, Naval Undersea Warfare Center Division Newport, United States
11.00am	COFFEE BREAK	
	TRACK A - AUDITORIUM	TRACK B – LT 52
	BIOFILMS AND MICROBIAL FOULING (Continue)	NEW APPROACHES FOR ANTIFOULING (Continue)
11.30am	2A - INVITED: MARINE BIOFILMS ASSOCIATED WITH ANTIFOULING COATINGS: OUR FRIENDS OR ENEMIES? Prof Sergey Dobretsov, Sultan Qaboos University, Oman	2B - ORAL 4: PHOTOSYNTHETICALLY-DRIVEN MARINE ANTIFOULING, PITTING NATURE AGAINST NATURE Alex Wu, The University of Melbourne, Australia 2B - ORAL 5: PREVENTION OF BIO-FOULING BY USING UV-LIGHT EMISSION OUTWARDS FROM THE SHIP HULL Bart Salters, Philips Research, Netherlands
12.00pm	2A - ORAL 4: SPATIO-TEMPORAL VARIATION OF THE MARINE BIOFILM COMMUNITIES COLONIZING ANTIFOULING COATINGS IN THE MEDITERRANEAN SEA VS THE ATLANTIC OCEAN Jean-François Briand, MAPIEM, France	2B - ORAL 6: TEXTURED, BIOCIDAL ANTIFOULING SURFACES FABRICATED FROM PHOTOLITHOGRAPHY WAFERS Liam Rhys Goodes, National Centre for Advanced Tribology at Southampton, United Kingdom
12.15pm	2A - ORAL 5: WHEN MARINE MICROBES MEET MICRO-FABRICATED POLYDIMETHYL-SILOXANE SURFACES Gee Chong Ling, Centre for Marine Bio-Innovations, Australia	2B - ORAL 7: ANTIFOULING PROPERTIES OF SELF-ASSEMBLED HONEYCOMB-STRUCTURED POROUS FILMS AGAINST BARNACLES Murosaki Takayuki, Tohoku University, Japan
12.30pm	2A - ORAL 6: LABORATORY AND FIELD TESTING OF ANTIFOULING BIOCIDES TETHERED TO ORGANIC POLYMER COATING COMPONENTS AGAINST MARINE BIOFILMS Maria Salta, University of Southampton, United Kingdom	2B - ORAL 8: THE DEVELOPMENT AND ANTIFOULING EVALUATION OF HIERARCHICAL MACRO AND MICRO TOPOGRAPHIES DEVELOPED WITH BENCHTOP METHODS Felicia Wong, University of Nottingham, Ningbo Campus, China
12.45pm	2A - ORAL 7: MICROBIAL FOULING ON COMMERCIAL BIOCIDAL FOULING CONTROL COATINGS Thirumahal Muthukrishnan, Sultan Qaboos University, Oman	2B - ORAL 9: STUDY ON BIOMIMETIC OF SHELL SURFACE MICROSTRUCTURE FOR SHIP ANTIFOULING AND DRAG REDUCTION Xiuqin Bai, Wuhan University of Technology, China
1.00pm	LUNCH (NOT PROVIDED)	

TUESDAY, 8 th July 2014		
	TRACK A - AUDITORIUM	TRACK B – LT 52
	BIOFILMS AND MICROBIAL FOULING (Continue)	ADVANCES IN COATING TECHNOLOGY Session Chair: Professor Dean Webster
2.00pm	2A - ORAL 8: METABOLOMICS AND METABOLOMIC IMAGING OF BIOFILMS ON CORRODING CARBON STEEL SURFACES Jan Sunner, University of Oklahoma, United States	2B - KEYNOTE: HYDROGEL-BASED FOULING CONTROL COATINGS Dr Stefan Olsen, Hempel A/S, Denmark
2.15pm	2A - ORAL 9: INVESTIGATION OF MARINE BACTERIAL ATTACHMENT AND BIOFILM FORMATION ON TITANIUM SURFACES Masoumeh Moradi, Ningbo Institute of Materials Technology and Engineering, China	
2.30pm	2A - ORAL 10: BIOFILM FORMATION PROCESSES ON STEEL SURFACE REVEALED BY AFM Nobumitsu Hirai, Suzuka National College of Technology, Japan	
2.45pm	2A - ORAL 11: POTENTIAL ANTIFOULING ACTIVITY OF TROPICAL MICROALGAE EXTRACTS FOR MARINE COATING APPLICATION Claudia Zea Obando, Laboratoire de Biotechnologie et Chimie Marine, France	2B - ORAL 1: RAFT-SYNTHESIZED HYDROLYZABLE DIBLOCK COPOLYMERS WITH LOW SURFACE ENERGY: NEW POLYMER BINDERS FOR FRC/SPC HYBRID ANTIFOULING COATINGS Marlene Lejars, MAPIEM Laboratory - University of Toulon, France
3.00pm	2A - ORAL 12: THE DEVELOPMENT OF DIATOM BIOFILMS ON FOULING RELEASE COATINGS UNDER DYNAMIC CULTURE CONDITIONS John Finlay, Newcastle University, United Kingdom	2B - ORAL 2: FABRICATION ON AN ANTIFOULING COATING WITH LOW SURFACE ENERGY AND A BIO-INSPIRED MICROSTRUCTURE Yunqiu Li, National University of Defense Technology, China 2B - ORAL 3: SURFACE CHARGE TUNING OF LAYER-BY-LAYER ASSEMBLY FOR MARINE ANTIFOULING APPLICATIONS Xiaoying Zhu, Institute of Materials Research and Engineering (IMRE), Singapore
3.30pm	TEA BREAK	
	TRACK A - AUDITORIUM	TRACK B – LT 52
	NEW METHODS FOR EVALUATION OF ANTIFOULING Session Chair: Professor Axel Rosenhahn	ADVANCES IN COATING TECHNOLOGY (Continue)
4.00pm	2A - KEYNOTE: QUANTIFYING CYPRIDS' BIORESPONSE AS A PERFORMANCE-RELEVANT MEASUREMENT OF ENGINEERED SURFACES Dr William Birch, Institute of Materials Research and Engineering (IMRE), Singapore	2B - ORAL 4: SELF-POLISHING ULTRA LOW FOULING ZWITTERIONIC-BASED MARINE COATINGS Shaoyi Jiang, University of Washington, United States 2B - ORAL 5: NEW ZWITTERIONIC AND ION PAIR POLYMERS: SYNTHESIS TO EVALUATION AS ANTIFOULING POLYMERS IN THE MARINE ATMOSPHERE Satyasankar Jana, Institute of Chemical and Engineering Sciences (ICES), Singapore 2B - ORAL 6: "LOW FOULING" AND "HIGH FOULING-RELEASE" ZWITTER/PDMS MARINE COATINGS Xuewei Xu, Zwitter Technology LLC, United States
4.45pm	2A - ORAL 1: A LABORATORY BASED BIOFILM ASSAY AND THE DEVELOPMENT OF ADVANCED "SLIME" RELEASE COATING TECHNOLOGIES Kevin Reynolds, AkzoNobel/International Paint, United Kingdom	2B - ORAL 7: SEAWATER HYDROLYZABLE GRAFT AND BLOCK PDMS-BASED COPOLYMERS: HOW DOES THE ARCHITECTURE AFFECT THE ANTIFOULING PERFORMANCES OF COATINGS Christine Bressy, University of Toulon, France
5.00pm	2A - ORAL 2: INTEGRATION OF AN IMAGING SPR FACILITY IN A TIRF MICROSCOPE – IMPROVED SPATIAL RESOLUTION AND COMPLEMENTARY DATA IN REAL-TIME, LABEL-FREE IMAGING OF BIOADHESION PROCESSES Thomas Ederth, Linköping University, Sweden	2B - ORAL 8: COMPARISON OF THE BIOLOGICAL PROPERTIES OF PEGYLATED AND FLUORINATED SILOXANE BLOCK COPOLYMERS DISPERSED IN A PDMS MATRIX Elisa Martinelli, University of Pisa, Italy
5.15pm	2A - ORAL 3: LOW EMISSION ANTIFOULING (LEAF) PROJECT: DEVELOPMENT OF AN ANTI-MACROALGAL ASSAY BASED ON ENZYME INHIBITION Claire Hellio, University of Portsmouth, United Kingdom	
5.30pm	BUS DEPART FOR POSTER NIGHT (OPEN TO ALL PARTICIPANTS)	

WEDNESDAY, 9 th July 2014		
8.30am	PLENARY 2: DESIGNING SMALL STRUCTURES TO CONTROL MARINE CORROSION Dr Harvey Hack, NACE International, United States	
9.20am	SHORT BREAK	
	TRACK A - AUDITORIUM	TRACK B - LT 52
	MICROBIOLOGICALLY INFLUENCED CORROSION Session Chair: A/Professor Daniel Blackwood	MARINE BIOADHESION Session Chair: Professor Jonathan Wilker
9.30am	3A - KEYNOTE: POTENTIAL ENNOBLEMENT OF STAINLESS STEEL IN NATURAL SEAWATER Dr Dominique Thierry, French Corrosion Institute, France	3B - KEYNOTE: MUSSEL ADHESION IN A WARMER, HIGH-CO₂ WORLD: AN ECOMATERIAL APPROACH Prof Emily Carrington, University of Washington, United States
10.15am	3A - ORAL 1: IS THE ENZYME ACTIVITY IN MARINE MICROBIAL BIOFILMS A RELIABLE INDICATOR FOR A TEST SYSTEM TO IDENTIFY MICROBIAL INFLUENCED CORROSION IN AN EARLY STAGE? Tim Heusinger von Waldegge, imare GmbH, Germany	3B - ORAL 1: COMPOSITION MORPHOLOGY AND FORMATION OF CALCAREOUS SHELL OF HYDROIDES DIANTHUS AND H. ELEGANS AND CONTROL OF THEIR SETTLEMENT ON SURFACES Nikhil Gunari, University of Toronto, Canada
10.30am	3A - ORAL 2: THE EFFECT OF HOST MEDIA ON THE DEVELOPMENT OF MICROBIOLOGICALLY INFLUENCED CORROSION (MIC) Muhammad Awais Javed, Swinburne University of Technology, Australia	3B - ORAL 2: SEA STAR TENACITY IS MEDIATED BY A PROTEIN THAT FRAGMENTS, THEN AGGREGATES Elise Hennebert, University of Mons, Belgium
10.45am	3A - ORAL 3: CARBON STEEL CORROSION INDUCED BY A COLD-GROWING ENRICHMENT CULTURE ISOLATED FROM THE DEN HELDER HARBOR Felipe Leon, ENDURES BV, Netherlands	3B - ORAL 3: BACTERIOATTRACTIVE AND BACTERIOCIDAL EFFECTS OF BARNACLE SETTLEMENT AND DISRUPTION ON SILICONE SURFACES Tara Essock-Burns, Duke University Marine Lab, United States
11.00am	COFFEE BREAK	
	TRACK A - AUDITORIUM	TRACK B - LT 52
	MICROBIOLOGICALLY INFLUENCED CORROSION (Continue)	MARINE BIOADHESION (Continue)
11.30am	3A - INVITED: CORROSION UNDER THE INFLUENCE OF BIOFILM OF MARINE ENVIRONMENT Dr Valeriy Alain Karpov, IEE RAS, Russia	3B - INVITED: HOMOLOGOUS BUT NOT SIMILAR: THE ADHESIVE PROTEINS OF STALKED AND ACORN BARNACLES Dr Anne Marie Power, National University of Ireland Galway, Ireland
12.00pm	3A - ORAL 4: A TRIAL FOR MIC STUDY USING A CIRCULATION-TYPE LABORATORY BIOFILM REACTOR Hideyuki Kanematsu, Suzuka National College of Technology, Japan	3B - ORAL 4: NON-SPECIFIC ADSORPTION OF BARNACLE SETTLEMENT-INDUCING PROTEIN C=COMPLEX (SIPC) TO DIFFERENT SURFACE CHEMISTRIES, MEASURED USING SURFACE PLASMON RESONANCE Luigi Petrone, Linköping University, Sweden
12.15pm	3A - ORAL 5: BIOCIDAL MECHANISM OF IODINE BY IODIDE-OXIDIZING BACTERIA (IOB) ISOLATED FROM BRINE IN NATURAL-GAS RELATED FACILITIES Kazuhiko Miyanaga, Tokyo Institute of Technology, Japan	3B - ORAL 5: SYNERGISTIC ROLES FOR LIPIDS AND PROTEINS IN THE PERMANENT ADHESIVE OF BARNACLE CYPRID LARVAE Nick Aldred, Newcastle University, United Kingdom
12.30pm	3A - ORAL 6: MICROBIAL CORROSION INFLUENCED BY ELECTROACTIVE BIOFILMS: RECENT PROGRESS ON ELECTROCHEMICAL AND MICROBIOLOGICAL APPROACHES Jizhou Duan, Institute of Oceanology, Chinese Academy of Sciences, China	3B - ORAL 6: PROTEOMICS OF BIOLOGICALLY ACTIVE ODORS FROM BARNACLES AND OYSTERS Daniel Rittschof, Duke University, United States
12.45pm	3A - ORAL 7: THE USE OF CONTINUOUS-OPTIMIZING CONFOCAL REFLECTION MICROSCOPY (COCRM) FOR STUDYING INTERACTIONS OF BACTERIAL ATTACHMENT WITH STAINLESS STEEL WELDS Miyano Yasuyuki, Akita University, Japan	3B - ORAL 7: UNDERSTANDING OYSTER CEMENT - SIMILARITIES AND DIFFERENCES COMPARED TO OTHER BIO-ADHESIVES Jonathan Wilker, Purdue University, United States
1.00pm	LUNCH (NOT PROVIDED)	

WEDNESDAY, 9 th July 2014		
	TRACK A - AUDITORIUM	TRACK B - LT 52
	ADVANCES IN ANALYSIS OF CORROSION Session Chair: Prof Hideyuki Kanematsu	BIOLOGY OF FOULING ORGANISMS Session Chair: Dr Nick Aldred
2.00pm	3A - KEYNOTE: THE EFFECT OF BIOTIC COMPONENTS ON CORROSION: CURRENT ADVANCES AND FUTURE PERSPECTIVES Prof Iwona Beech, University of Oklahoma, United States	3B - KEYNOTE: THE BIOLOGY OF FOULING ORGANISMS: A FIELD PERSPECTIVE Prof Geoffrey Swain, Florida Institute of Technology, United States
2.45pm	3A - ORAL 1: EVALUATION OF DIAGNOSTIC METHODS FOR MICROBIOLOGICALLY INFLUENCED CORROSION Satoshi Wakai, Kobe University, Japan	3B - ORAL 1: AN OVERVIEW OF FOULING SEDENTARY POLYCHAETES Tao Yan, Key Laboratory of Tropical Marine Bio-resources and Ecology, South China Sea Institute of Oceanology, Chinese Academy of Sciences, China
3.00pm	3A - ORAL 2: QUANTITATIVE ANALYSIS OF INITIAL STAGE OF BIOFOULING USING QUANTITATIVE PCR TARGETING BACTERIAL 16S RRNA GENE Akiko Ogawa, Suzuka National College of Technology, Japan	3B - ORAL 2: THE EFFECT OF CUES AND CONDITIONING ON THE SETTLEMENT OF MARINE MACROFOULING AND COMMUNITY DEVELOPMENT Emily Ralston, Florida Institute of Technology, United States
3.15pm	3A - ORAL 3: APPLICATION OF TRIPLE COMPOSITE FUZZY FUNCTIONS IN PREDICTING SSRT BEHAVIOR OF CARBON STEEL IN ENVIRONMENTS CONTAINING SULPHATE REDUCING AND IRON REDUCING BACTERIAL SPECIES Hideyuki Kanematsu, Suzuka National College of Technology, Japan	3B - ORAL 3: THE EFFECTS OF FEEDING LEVELS AND TEMPERATURE ON GROWTH AND ADHESIVE PRODUCTION IN BALANUS AMPHITRITE Sheelagh Conlan, Liverpool John Moores University, United Kingdom
3.30pm	TEA BREAK	
	TRACK A - AUDITORIUM	TRACK B - LT 52
	RISK MANAGEMENT IN MARINE CORROSION Session Chair: Dr Brenda Little	BIOLOGY OF FOULING ORGANISMS (Continue)
4.00pm	3A - KEYNOTE: SEAWATER NUTRIENT POLLUTION AND THE LONG TERM IMMERSION CORROSION OF STEELS Prof Robert Melchers, University of Newcastle, Australia	3B - INVITED: CHEMICAL AND VISUAL CUES FOR GREGARIOUS SETTLEMENT IN BARNACLES Prof Kiyotaka Matsumura, Tokyo College of Biotechnology, Japan 3B - ORAL 4: A NEW METHOD TO COMPARE THE POTENTIAL TOXICITY OF FOULING RELEASE COATING LEACHATES ON AMPHIBALANUS AMPHITRITE LARVAE Giuliano Greco, CNR - ISMAR, Italy
4.45pm	3A - ORAL 1: AN UNDERSTANDING OF ENVIRONMENTAL FACTORS CAN IMPROVE CORROSION RISK ASSESSMENT IN NATURAL WATERS Malayappan Eashwar, CSIR - CECRI, India	3B - ORAL 5: INSTANTANEOUS FLOW STRUCTURES AND OPPORTUNITIES FOR LARVAL SETTLEMENT: BARNACLE CYPRIDS SWIM TO SETTLE Lena Granhag, Chalmers University of Technology, Sweden
5.00pm	3A - ORAL 2: PREDICTING RISK OF MICROBIOLOGICALLY INFLUENCED CORROSION: A STATE OF THE ART REVIEW Brenda Little, Naval Research, Laboratory, Stennis Space Center, United States	3B - ORAL 6: EFFECT OF LECTINS ON CONSPECIFIC SHELL EXTRACT-INDUCED SETTLEMENT OF LARVAE OF THE PACIFIC OYSTER CRASSOSTREA GIGAS Hebert Ely Vasquez, Nagasaki University, Japan
5.15pm	3A - ORAL 3: COMPOSITE COATING TO CONTROL BIOFILM FORMATION AND MIC Hideyuki Kanematsu, Suzuka National College of Technology, Japan	3B - ORAL 7: THE EFFECT OF SILVER NANOPARTICLES ON BIOFILM COMMUNITY COMPOSITION AND MUSSEL PLANTIGRADE SETTLEMENT Jin-Long Yang, Shanghai Ocean University, China
5.30pm	BUS DEPART FOR CONGRESS DINNER (FOR PARTICIPANTS WHO HAVE PURCHASED TICKET)	

THURSDAY, 10 th July 2014		
8.30am	PLENARY 3: ANTIFOULING RESEARCH & DEVELOPMENT Dr Steve McElvany, US Office for Naval Research Coatings Program, United States	
9.20am	SHORT BREAK	
	TRACK A - AUDITORIUM	TRACK B – LT 52
	SHIP HYDRODYNAMICS AND ENERGY EFFICIENCY Session Chair: Dr Andrew Scardino	MARINE CORROSION - MATERIALS AND COATINGS Session Chair: Dr Dominique Thierry
9.30am	4A - KEYNOTE: THE EFFECT OF ANTIFOULING PAINTS ON LONG TERM HYDRODYNAMIC PERFORMANCE OF SHIPS RELATED TO ENERGY EFFICIENCY Dr Noriyuki Sasaki, Monohakobi Technology Institute, Japan	4B - KEYNOTE: METALS AND THEIR CORROSION BEHAVIOUR IN SEAWATER - AN ENGINEERS OVERVIEW Mrs Carol Powell, Copper Development Association and Nickel Institute, United Kingdom
10.15am	4A - ORAL 1: FOULING AND VESSEL PERFORMANCE ON AN ALUMINIUM HULLED PATROL BOAT OPERATING IN TROPICAL WATERS Andrew Scardino, Defence Science & Technology Organisation, Australia	4B - ORAL 1: STUDY OF PHYSICO-CHEMICAL AND MICROBIOLOGICAL TESTING PARAMETERS IN RELATION TO MARINE CORROSION Scott Wade, Swinburne University, Australia
10.30am	4A - ORAL 2: FOULING-RELEASE PROPELLER COATINGS : EFFICACY AND DURABILITY ON A US NAVY LSD-CLASS VESSEL Elizabeth Haslbeck, Naval Surface Warfare Center, Carderock Division, United States	4B - ORAL 2: CORROSION PERFORMANCE OF 25%CR SUPERDUPLEX STAINLESS STEEL FOR DIFFERENT SEAWATER APPLICATIONS Nicolas Larché, Institut de la Corrosion, France
10.45am	4A - ORAL 3: LONG TERM DRAG PERFORMANCE OF HULL COATINGS FOR OCEAN GOING VESSELS Asger Lindholdt, Technical University of Denmark, Denmark	4B - ORAL 3: LOCALIZED CORROSION OF 316L STAINLESS STEEL IN SINGAPORE SEAWATER Daniel Blackwood, National University of Singapore, Singapore
11.00am	COFFEE BREAK	
	TRACK A - AUDITORIUM	TRACK B – LT 52
	SHIP HYDRODYNAMICS AND ENERGY EFFICIENCY (Continue)	INDUSTRY SESSION Session Chair: Mr John Lewis
11.30am	4A - ORAL 4: HYDRODYNAMIC PERFORMANCE EVALUATION OF FDR-SPC (FRICTIONAL DRAG REDUCTION SELF-POLISHING COPOLYMER) Inwon Lee, Pusan National University, Korea	4B - KEYNOTE: CONVENTIONAL AND INNOVATIVE ANTIFOULING TECHNOLOGIES IN INDUSTRIAL COOLING WATER SYSTEMS Dr Sanjeevi Rajagopal, Radboud University Nijmegen; IMARES, Wageningen University, Netherlands
11.45am	4A - ORAL 5: A NUMERICAL TOOL DEVELOPMENT ON THE EFFECT OF COATING AND BIO-FOULING ON THE MARINE PROPELLERS Kwangcheol Seo, Newcastle University, United Kingdom	
12.00pm	4A - ORAL 6: PREDICTION OF THE EFFECT OF HULL FOULING ON SHIP RESISTANCE USING CFD Yigit Kemal Demirel, University of Strathclyde, United Kingdom	
12.15pm	4A - ORAL 7: AN INVESTIGATION INTO DIFFERENT SKIN FRICTION ANALYSIS METHODS FOR COATINGS WITH DIFFERENT ROUGHNESS RANGE Irma Yeginbayeva, Newcastle University, United Kingdom	
12.30pm	4A - ORAL 8: BOUNDARY LAYER AND ROUGHNESS CHARACTERISTICS OF HULL COATINGS Irma Yeginbayeva, Newcastle University, United Kingdom	4B - ORAL 1: THE BURDEN OF BIOFOULING: WHAT DOES IT WEIGH? John Lewis, ES Link Services, Australia
12.45pm	4A - ORAL 9: HULL AND PROPELLER PERFORMANCE MEASUREMENT FOR VESSEL IN SERVICE Andreas Krapp, Jotun A/S, Norway	4B - ORAL 2: PREVENTING THE ESTABLISHMENT OF INVASIVE PESTS IN A MARINE CONSERVATION AREA THROUGH EFFECTIVE MARINE BIOSECURITY Simon McKirdy, Chevron, Australia
1.00pm	LUNCH (NOT PROVIDED)	

THURSDAY, 10 th July 2014		
	TRACK A - AUDITORIUM	TRACK B – LT 52
	SHIP HULL MANAGEMENT Session Chair: Professor Geoffrey Swain	INDUSTRY SESSION (Continue)
2.00pm	4A - KEYNOTE: HULL EFFICIENCY: A REVIEW OF 100 IN-WATER HULL CLEANINGS AND THEIR IMPACT ON REDUCING FUEL CONSUMPTION AND EMISSION ON OCEAN GOING VESSELS Mr Daniel Kane, Propulsion Dynamics, United States	4B - ORAL 3: EFFECT OF PARTICLE SIZE OF COPPER PYRITHIONE ON LEACH RATES FROM ZINC ACRYLATE ANTIFOULING COATINGS Paul Kappock, Lonza, United States 4B - ORAL 4: MICROBIOLOGICALLY INFLUENCED CORROSION RISKS IN THE INTERIOR OF OFFSHORE WIND MONOPILES Felipe Leon, ENDURES BV, Netherlands 4B - ORAL 5: EVALUATION OF ANTIFOULING PAINTS AND DEVELOPMENT OF BIVALVE MOVEMENT SENSOR FOR BIOFOULING CONTROL IN COOLING WATER SYSTEM Kamala Kanta Satpathy, Department of Atomic Energy, India
		FOULING IN AQUACULTURE Session Chair: Dr Belinda Yaxley
2.45pm	4A - INVITED: MANAGING UNDERWATER HULL PERFORMANCE Dr Raouf Kattan, Safinah Limited; Newcastle University, United Kingdom	4B - KEYNOTE: CHALLENGES AND OPPORTUNITIES FOR UNDERSTANDING AND MANAGING BIOFOULING IN MARINE AQUACULTURE Dr Oliver Floerl, SINTEF Fisheries and Aquaculture, Norway
3.15pm	4A - ORAL 1: DATA MASHING, BIG DATA AND MULTIVARIATE MODELLING TO PREDICT COATING PERFORMANCE Jeremy Thomason, Ecotecnica SCP, Mexico	
3.30pm	4A - ORAL 2: THE EFFECTS OF GROOMING ON COPPER ABLATIVE COATINGS: A SIX YEAR STUDY Melissa Tribou, Florida Institute of Technology, United States	4B - ORAL 1: BLUE MUSSEL (MYTILUS GALLOPROVINCIALIS) OVER SETTLEMENT ON NEW ZEALAND'S GREEN-LIPPED MUSSEL (PERNA CANALICULUS) FARMS Javier Atalah, Cawthron Institute, New Zealand
3.45pm	4A - ORAL 3: MANAGING IN-WATER HULL INSPECTIONS, CLEANING AND OTHER TREATMENTS TO REDUCE BIOSECURITY RISK AND BIOLOGICAL ROUGHNESS: THE EXPERIENCE AT SINGAPORE Robert Hilliard, Intermarine Consulting Pte Ltd, Australia	4B - ORAL 2: THE ROLES AND DYNAMICS OF CALCIUM ION AND GLW-AMIDE PEPTIDES IN SETTLEMENT AND METAMORPHOSIS OF ACTINULA LARVAE OF MARINE HYDROID TUBULARIA MESEMBRYANTHEMUM Keiji Yamashita, Sessile Research Corporation, Japan
4.00pm	4A - ORAL 4: DRYDOCK COATING INSPECTION METHODOLOGY AND SHIP HULL MANAGEMENT Abhishek Koka, Florida Institute of Technology, United States	4B - ORAL 3: ARE SALMON FARMS PROPAGULE RESERVOIRS FOR MARINE BIOFOULING ORGANISMS? Nina Blecher, SINTEF Fisheries and Aquaculture, Norway
4.15pm	CLOSING REMARKS	
4:30-6:00pm	NETWORKING TEA	

50TH ANNIVERSARY LECTURE

LECTURE

DISSECTING THE BIOLOGY/MATERIALS INTERFACE FOR INNOVATIVE ANTIFOULING SOLUTIONS

*Professor James Callow
Emeritus Professor of Plant Science, School of Biosciences,
University of Birmingham, United Kingdom*

Biofouling in the marine environment involves a complex interaction between living organisms exhibiting specific selective attachment behaviours and adhesion properties, and the physico-chemical properties presented by the coating, which are in turn modified by biotic and abiotic factors (biofilms, grazing, conditioning layers etc). If we are to understand this complexity, and use the resulting information in predictive models to facilitate rational design of non-biocidal coatings, quantitative, reproducible and carefully controlled, hypothesis-driven experimentation is required. This is most readily achieved through laboratory-scale experimentation that enables clear structure/property/performance correlations to be established through the use of well-defined settlement/adhesion bioassays and, for example, sophisticated approaches to imaging.

It is often argued that laboratory-scale experimentation/bioassays do not take account of variables associated with the 'real world'. Whilst this is obviously true, informed investigators see laboratory assays as a necessary part of a continuum of investigations at different levels of scale and complexity, rather than providing a solution per se.

The purpose of this presentation, is to consider some examples of interdisciplinary investigations that have attempted to study, in a systematic way, the influence of specific surface properties on the settlement behaviour and adhesion properties of certain fouling organisms. The examples will be drawn mostly from collaborative, interdisciplinary programmes supported by The US Office of Naval Research (ONR) and the European Commission, and will focus on the green macroalga *Ulva linza* and slime-forming diatoms.

Examples of the successful translation of laboratory investigations into practical coating development and 'real-world' evaluation will be considered.

MICROALGAL FOULING AND ADHESION PROCESSES
SESSION CHAIR: PROFESSOR JAMES CALLOW
EMERITUS PROFESSOR OF PLANT SCIENCE, SCHOOL OF BIOSCIENCES,
UNIVERSITY OF BIRMINGHAM, UNITED KINGDOM

1A - KEYNOTE

MICROBIAL ADHESION AND COLONIZATION – ASSAYING METHODS TO ASSIST IN THE FUTURE DESIGN OF FOULING RESISTANT COATINGS

Paul Molino¹, BinBin Zhang¹, Michael J Higgins¹, Timothy Hanks², Richard Wetherbee³

¹Intelligent Polymer Research Institute, University of Wollongong, NSW 2500, Australia ²Furman University, South Carolina 29613, USA ³Botany Department, University of Melbourne, Victoria 3010, Australia

Critical to the design of efficient fouling resistant materials is a basic understanding of the nature of microbial adhesion and colonisation, as well as the ability to rapidly assay surfaces of different chemistry and morphology. In recent years a number of innovative techniques have been developed, or adapted from other fields, in order to investigate the mechanisms through which microbial cells, including algal spores and diatoms, interact and colonize coatings and structures. Herein I present a suite of techniques that have provided significant insight into microbial cell attachment and growth, including turbulent flow channels, atomic force microscopy and optical and fluorescence microscopy. I will also discuss emerging techniques such as quartz crystal microgravimetry (QCM) and scanning ion conductance microscopy (SICM) that promise to advance our understanding of microbial fouling processes.

1A - ORAL 1

CHEMICAL AND MORPHOLOGICAL CUES GUIDE SETTLEMENT OF ALGAL ZOOSPORES

L. Xiao^{1,2}, X. Cao², S. Schilp², M. Röhrig³, J. Fu⁴, J. Ji⁴, J. Li⁵, P. Levkin⁵, S. Thompson⁶, J.A. Finlay⁶, M.E. Pettit⁶, M.E. Callow⁶, J.A. Callow⁶, M. Grunze^{1,2}, A. Rosenhahn^{1,7}

¹Institute of Functional Interfaces, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany ²Applied Physical Chemistry, University of Heidelberg, 69120 Heidelberg ³Institute of Microstructure Technology, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany ⁴Department of Polymer Science and Engineering, Zhejiang University, 310027 Hangzhou, China ⁵Institute of Toxicology and Genetics, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany ⁶School of Biosciences, University of Birmingham, Birmingham, B15 2TT, UK ⁷Analytical Chemistry - Biointerfaces, Ruhr-University Bochum, 44801 Bochum

Recruitment of algal zoospores occurs selectively and various surface cues have been identified that guide their settlement¹. Surface chemistry determines wettability, surface hydration, charge, and lubricity. All of these factors have been found to influence spore attachment. Also, surface morphology alters settlement, revealing that an optimized combination of surfaces properties is necessary to create resistant surfaces². Using a range of periodic and nonperiodic surface patterns, the response of Ulva zoospores to morphological cues is analyzed in detail and compared to diatom adhesion. Especially diatom adhesion is largely guided by the local attachment area. In turn, specific attachment geometries seem to facilitate settlement of zoospores and especially sheltered edges are preferred³. Interestingly, an increase in surface lubricity by morphologically stabilized overlayers significantly reduces attachment of marine algae⁴. The results will be discussed in view of the mechanism of surface selection as recently determined by 3D holographic tracking¹.

1. A. Rosenhahn and G. H. Sendra, *Biointerphases*, 2012, **7**, 63
2. X. Cao, M. E. Pettitt, F. Wode, M. P. Arpa-Sancet, J. Fu, J. Ji, M. E. Callow, J. A. Callow, A. Rosenhahn and M. Grunze, *Advanced Functional Materials*, 2010, **20**, 1984
3. L. Xiao, S. Thompson, M. Röhrig, M. E. Callow, J. A. Callow, M. Grunze and A. Rosenhahn, *Langmuir*, 2013, **29**, 1093.
4. L. Xiao, J. Li, S. Mieszkin, A. Di Fino, A. S. Clare, M. E. Callow, J. A. Callow, M. Grunze, A. Rosenhahn and P. A. Levkin, *ACS Applied Materials & Interfaces*, 2013, **5**, 10074-10080

Acknowledgments:

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1A - ORAL 2

DIATOM COMMUNITY STRUCTURE ON IN-SERVICE SHIP HULLS

Kelli Zargiel, Abhishek Koka, and Geoffrey Swain

Center for Corrosion and Biofouling Control, Florida Institute of Technology,
150 West University Blvd, Melbourne FL, 32901

There are few published studies on the settlement of diatoms to ship hulls. More data is needed to better understand the interactions of diatoms with the coating systems and also the environmental conditions that they experience while a ship is underway. This study investigated the diatom community structure on two cruise ships with the same cruise cycles, one coated with an antifouling system (Jotun Copper SPC) and the other coated with a fouling release system (PPG Sigma Glide). Samples were collected during dry docking in horizontal and vertical zonation along the ship hull, including niche and damaged areas of the hull. The fouling diatoms *Achnanthes*, *Amphora*, and *Navicula* were the most common genera regardless of horizontal ship zonation and coating type. Other genera were abundant, but the presence was more dependent on the ship zonation and coating type. *Navicula* was present at all depths along the ship hull, and dominated the biofilms collected along the flats. Samples collected from damaged areas of the ship hull showed the community composition to be similar to undamaged areas but to have a larger diatom abundance. Diatom fouling on the niche areas differed from that of the surrounding ship hull. Additionally, diatom richness was greater on the ship coating with the fouling release system, including the identification of several new genera to the biofouling literature: *Lampriscus* and *Thalassiophysa*. These results are the first to describe diatom community composition on in-service ship hulls coated with fouling release systems. These newer classes of coatings appear to have a larger diatom community compared to the copper based antifouling systems, with new diatom genera, which have the ability to stick to ship hulls and withstand hydrodynamic forces, creating the potential for new problematic species in biofilm fouling. The results of this study are complimentary to the different communities that have been reported from static and dynamic testing (Zargiel and Swain 2013).

Acknowledgments:

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1A - ORAL3

ISOLATION AND BIOCHEMICAL CHARACTERIZATION OF UNDERWATER ADHESIVES FROM DIATOMS

Nicole Poulsen¹, Nils Kröger^{1,2}, Matthew J. Harrington³, Eike Brunner², Silvia Paasch² and Matthias T. Buhmann¹

¹ZIK B CUBE, Technische Universität Dresden, Dresden, Germany; ²Department of Chemistry and Food Chemistry, Technische Universität Dresden, Dresden, Germany; ³Department of Biomaterials, Max Planck Institute of Colloids and Interfaces, Potsdam, Germany

Many aquatic organisms are able to colonize surfaces through the secretion of underwater adhesives. Diatoms are unicellular algae that have the impressive capability to colonize any natural and man-made submerged surfaces. There is great technological interest in both mimicking and preventing diatom adhesion, yet the responsible biomolecules have so far remained unidentified. Surface adhesion of diatoms belonging to the raphid pennate type requires the secretion of so-called adhesive mucilage strands through a dedicated slit in the silica cell wall, which is termed the raphe. Adhering cells can then move across the surface, which is accomplished through an actin and myosin dependent cytoskeletal motor that translocates the adhesive mucilage strands in a rearward direction through the raphe thereby moving the cell forward. When the adhesive mucilage strands reach the end of the raphe they are released and left as a trail behind the moving cell. Here the first method for isolation of diatom adhesive trails is described, and its amino acid and carbohydrate composition determined. The adhesive material isolated from two model fouling diatoms (*Amphora coffeaeformis* and *Craspedostauros australis*) show differences in their amino acid and carbohydrate compositions, but also share characteristic features including a high content of uronic acids, the predominance of hydrophilic amino acid residues, and the presence of 3,4-dihydroxyproline, an extremely rare amino acid. Proteins containing dihydroxyphenylalanine (Dopa), which mediate underwater adhesion of mussels are absent from the adhesive material.

Acknowledgments:

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FOULING AS A VECTOR FOR INVASIVE SPECIES

SESSION CHAIR: DR EUGENE GEORGIADES

MINISTRY OF PRIMARY INDUSTRIES, NEW ZEALAND

1B - KEYNOTE

RISK ASSESSMENT FOR VESSEL BIOFOULING - HOW GOOD ARE WE AT PREDICTING RISK AND COMPLIANCE?

Dr Graeme J. Inglis

National Institute of Water & Atmospheric Research Ltd (NIWA), PO Box 8602, Christchurch, New Zealand

The transport of biofouling and discharge of ballast water by vessels are recognised as the most important contemporary pathways for the global spread of invasive marine organisms. While international measures to manage risk from ballast water have been under development for almost two decades, policy makers have only recently begun to draft preventative measures for vessel biofouling. If they are to be implemented efficiently, any new regulatory requirements will need to be supported by risk assessment frameworks that are capable of distinguishing vessels that have unacceptable levels of biofouling or which may be carrying species of concern from those that do not. Risk assessment frameworks developed for ballast water have taken both species-specific and more generic approaches to evaluate risk, based on environmental-matching and the recent voyage history of the vessel, but have generally suffered from a lack of data on the organisms present in the discharge to test the accuracy of their predictions. The task for biofouling risk assessment is, perhaps, even harder. While risk for ballast water is greatest for recent port-to-port cargo movements, the development of biofouling assemblages is integrated over the service life of a vessel's antifouling coatings, which may span up to 5 years of operations. During that time, the vessel may have visited several hundred different ports in many different global regions and been exposed to several thousand species of biofouling organisms. In this paper, I discuss the results of recent scientific surveys of in-service vessels that have attempted to identify useful predictors of biofouling risk based on the vessel type, its operations (including its antifouling measures) and voyage history. I describe the predictors that offer the most promise for use by border-authorities in screening protocols and discuss the prospects for misclassification of high- and low-risk vessels (Type I and Type II errors).

Acknowledgements:

This talk draws upon data and research funded by NIWA under Coasts & Oceans Research Programme 4 (2013/14) and the NZ Ministry for Primary Industries (contract ZBS2004-04). Oliver Floerl (SINTEF), Kimberley Seaward, Martin Unwin (NIWA), Daniel Kluza, Andrew Bell (Ministry for Primary Industries) and Chad Hewitt (University of Waikato) made significant contributions to the research and its outcomes.

1B - ORAL 1

GLOBAL PATTERNS OF NONINDIGENOUS SPECIES SPREAD VIA BIOFOULING

Erin Grey^{1,2}, Jian Xu^{3,4}, Thanuka Wickramaratne^{1,3,4}, Nitesh Chawla^{1,3,4}, David Lodge^{1,2}

¹Environmental Change Initiative, ²Department of Biological Sciences, ³Department of Computer Sciences and Engineering, and the ⁴Interdisciplinary Center for Network Science and Applications, University of Notre Dame, IN USA 46617

Aquatic non-indigenous species (NIS) are a growing global problem that cause significant economic and environmental harm. The majority of aquatic NIS are introduced via shipping, with about half attributed to ballast water and half to biofouling. Despite this equal contribution, most current research and policy has focused solely on ballast water. Using a global dataset of commercial ship movements from 1997-2013, we use a novel network approach to identify global patterns of NIS spread via biofouling. In this approach we first create a network where ports ("nodes") are linked by "edges" that represent the probability of species spread via biofouling. We then use a clustering method to identify groups of ports within which biofouling species spread is very high. This method provides a qualitative, large-scale view of NIS biofouling spread that is more robust to uncertainties than previous methods. We will discuss how the large-scale patterns of biofouling NIS spread change over time, and will also compare patterns biofouling NIS spread to patterns of ballast NIS spread estimated in a previous study. Finally, we will demonstrate how this network analysis can inform policy by identifying key ports, ship types and routes for targeted biofouling management.

1B - ORAL 2

SHUFFLING SLIME: LINKING BIOFILM ORIGIN TO FOULING COMMUNITY COMPOSITION AND DEVELOPMENT

L. Holly Sweat and Kevin B. Johnson

*Department of Marine and Environmental Systems, Florida Institute of Technology
150 West University Blvd, Melbourne FL, USA, 32901*

Biological invasions threaten marine ecosystems by altering native communities and causing severe ecological and economic losses. Hull fouling is a major pathway for invasive species transport via the global shipping industry. Management techniques to reduce hull fouling have historically focused on inhibiting macrofoulers while largely disregarding biofilms. However, biofilms have been shown to affect the recruitment of a variety of benthic organisms, and are not entirely removed in transit or by hull grooming programs. It is therefore reasonable to consider these films as possible vectors for, or facilitators of, the spread and establishment of exotic species, and to expect that larvae might exhibit variable recruitment responses to biofilms originating from different locations. This study examines biofilms and macrofouling communities at two biologically distinct Florida inlets before and after reciprocal transplant. Preliminary results show that biofilm assemblages between inlets are distinct, and suggest that community composition of biofilms relocated to new ports can alter subsequent macrofouling community structure.

1B - ORAL 3**NEXT-GENERATION DETECTION OF NON-INDIGENOUS SPECIES FROM BIOFILM COMMUNITIES OF MARINE VESSELS***Pochon X, Bott N, Hopkins G, Atalah J, Banks J, Cahill P, Wood S*

Biofouling is a major transport pathway that can facilitate the establishment of marine Non-Indigenous Species (NIS). Identification of early life history stages of marine organisms by morphology is difficult particularly in initial 'slime layers'. Traditional DNA-based taxon identification methods have proven efficient in detecting and identifying targeted NIS at low densities, but are often constrained to single species detection. The recent development of Next-Generation Sequencing (NGS) technologies and its applicability for characterizing entire communities from environmental samples show tremendous potential for marine environmental surveillance. We recently applied NGS to the detection of NIS in a range of environmental samples and demonstrated that it is extremely sensitive and able to detect a wide range of organisms. In this study we investigated four different sampling devices (modified syringe, sterilised sponge, underwater tape and clinical swab) for NGS characterization of ship's biofilm communities. Biofilm communities were isolated from 1-month-old perspex settling plates using each sampling device in triplicate. Sampling was applied both underwater and after retrieving plates (i.e., on land) to assess possible accumulation of background diversity from the surrounding water column. Complete results from this experiment will be presented and future plans outlined, including up-scaling of sampling devices and on-vessel trials both within New Zealand and across Trans-Tasman voyages.

1B - INVITED**MUSSELS, CRABS AND SLIME: FILTHY BOTTOMS TRAVELLING THE GLOBE***Dr Justin McDonald**Department of Fisheries, Western Australia*

About 90% of world trade or 80% of the world's commodities are carried by sea. The international character of shipping is reflected in the fact that it is common to see a fouling community in one port almost identical to one in another part of the world. This trend has been greatly accelerated by globalisation of trade and travel, with vessels now moving more regularly and covering greater distances in shorter timeframes. Yet despite this global homogenisation of fouling there is always the threat of a new pest species being introduced. The Asian green mussel *Perna viridis* is a listed pest species in many parts of the world and in Australia has a history of incursions into Western Australia. This species has wide tolerances that should enable it to establish in ports in Western Australia. It has been detected as fouling on a range of vessels, yet to date has not been recorded as established anywhere. Compare this to the recent detection of the colonial ascidian *Didemnum perlucidum*, a tropical species with limited reported compatibility and that has limited history of incursions. Yet since 2010 this species has exploded in its spatial coverage across our state. This talk explores the fouling risk posed by vessels to Western Australia and how increased vessel movements and changes in climate will influence our invasive species risk.

1B - ORAL 4**ANTICIPATING BIOINVASION RISKS IN A COASTAL CONTEXT***Daniel A. Kluz**Science and Risk Assessment Directorate, Ministry for Primary Industries, Wellington 6011, New Zealand*

The ability to manage marine bioinvasion risks can be bolstered by proactive assessment of potential likelihoods and consequences of a species' introduction, establishment, and spread. To this end, the New Zealand Ministry for Primary Industries (MPI) is developing risk profiles for New Zealand's major commercial, recreational, and passenger vessel ports. The risk profiling effort is a systematic assessment of port-specific pathway characteristics from which potential biofouling risk organisms (or organism types) can be identified, and the likelihood of establishment and impact can be estimated. For a given port and its surrounding region, an organism's establishment likelihood and life-history characteristics are assessed within a spatially-explicit context to determine the potential risks (likelihood × consequence) to coastal marine environmental, economic, and social values. Here, I demonstrate the assessment process and show how these outputs are being used to inform MPI's Marine High Risk Site Surveillance programme.

1B - ORAL 5**MARINE BIOSECURITY IN HAWAII: PROGRESS IN MANAGING VESSEL BIOFOULING***Sonia Gorgula¹, Ian Davidson², Greg Ruiz²**¹State of Hawaii, Department of Land and Natural Resources, Honolulu, HI, U.S.A. 96813**²Smithsonian Environmental Research Center, MD, U.S.A. 21037*

In Hawaii, the majority of the 343 introduced & cryptogenic marine and estuarine species arrived as biofouling; that is, attached to hulls or to other protected areas on the wetted portions of vessels. A number of these have become invasive and cause negative impacts to Hawaii's unique economy, natural environment and the health and lifestyle of Hawaii's people and visitors. The Department of Land and Natural Resources is the lead agency for minimizing the arrival of non-indigenous aquatic organisms and is charged with implementing management measures for biofouling of vessels and floating structures. The department works in consultation with its Alien Aquatic Organism Task Force (AAOTF) to formulate and implement strategies for aquatic invasive species management. Currently, however, there are no measures in place to manage the invasive species risks associated with biofouling in the Main Hawaiian Islands.

Since 2013, the department has been working with the Smithsonian Environmental Research Center to assess the factors that contribute to biofouling transfers and invasion risk from ships and boats in Hawaii. The factors affecting biofouling accumulation (and transfer) on ships and boats are numerous and can interact in complex ways. In an effort to capture this complexity, questionnaires were developed in consultation with AAOTF to collect data relating to the: (a) physical and operational characteristics of vessels, (b) voyages and port visits, (c) hull husbandry practices, and (d) inactive periods. Where possible, this was supported by biota sampled from vessel's submerged areas. The primary purpose of these data is to inform science-based policy development that can help to reduce introductions and act as a conservation tool for near shore environments of Hawaii for years to come. This presentation will examine the outcomes of this data collection and analysis with insights into future biofouling policy development in Hawaii.

Acknowledgments:

The work presented in this study has been funded by grants from the Hawaii Invasive Species Council, the United States Fish and Wildlife Service and the Hau'oli Mau Loa Foundation.

1B - ORAL 6**MARINE BIOFOULING ON RECREATIONAL BOATS ON SWING MOORINGS AND BERTHS**

Oriana Brine¹, Lou Hunt¹, Mark John Costello³

¹The Ministry for Primary Industries, PO Box 2526, Wellington, New Zealand ²Leigh Marine Laboratory, Institute of Marine Science, The University of Auckland, Warkworth, New Zealand

Biofouling on the hulls of recreational boats kept on swing moorings and marina berths poses a risk of transporting invasive species. A survey of 360 boats was undertaken of both mooring types at six sites near Auckland, New Zealand by visual observation from the waterline and underwater video. Both methods showed that the boats on swing moorings had more biofouling than those in berths ($p < 0.001$), and the video found more biofouling than visual observation ($p < 0.001$). A survey of boat owners found that boats on swing moorings moved at lower speeds (a function of different vessel types), making their speed insufficient to dislodge biofouling and potentially increasing their biosecurity risk. Five invasive marine species were known in the study area and the video images suggested that some of these and other invasive marine species were growing on boat hulls. About 8,700 recreational boats may be moored in the region, indicating that they have the potential to disperse invasive marine species beyond their present range.

Acknowledgements:

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1B - ORAL 7**THE BIOFOULING PROBLEM: NEW (AND IMPROVED) ZEALAND DEVELOPMENTS, REGULATORY AND TECHNICAL SOLUTIONS**

Eugene Georgiades¹, Daniel Kluza¹, Andrew Bell¹
Ministry for Primary Industries, New Zealand

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 (<http://www.biosecurity.govt.nz/files/regs/imports/risk/vessel-biofouling-risk-analysis-0211.pdf>). Acknowledging these risks, regulatory measures have been drafted to minimise the risk of entry of harmful organisms into New Zealand via vessel biofouling.

Furthering New Zealand's ongoing commitment to address the biofouling problem, the Ministry for Primary Industries has funded the following research initiatives:

Biofouling management

The objective of this project is to inform both shipping and regulatory authorities of activities that could constitute best practice in biofouling management. An international collaborative network will provide detailed information on the condition and attributes of ship hull management systems on arrival in dry dock. These observations will be assessed against the preventative management practices and vessel operational profiles.

Efficacy of in-water cleaning systems

This project will develop standard testing requirements for in-water cleaning systems. These are needed to provide independent assessments of the efficacy of in-water cleaning systems with respect to biosecurity risk.

Settlement arrays

MPI currently operates a Marine High Risk Site Surveillance programme which is conducted at key locations around New Zealand. This programme uses a range of active surveillance tools and methods with the goal of early detection of as many non-indigenous species as possible.

Settlement arrays are a passive surveillance tool that will enhance New Zealand's marine biosecurity surveillance system. The purpose of the arrays is to provide an attractive surface for the settlement of non-indigenous species that are associated with vessel biofouling. To implement them MPI requires recommendations for a system and underpinning methodology that will provide a timely, efficient and cost effective way of detecting species that should not be present in New Zealand.

Aquaculture snapshot

Key biological risks to the aquaculture industry include the introduction or exacerbation of pests (biofouling) and diseases. These can result in production losses and potential impacts to trade. These risks can be managed through border measures (e.g., Government import health standards) and through on-farm best management practices (e.g., biosecurity and animal health plans).

The depth and scope of biosecurity and farm health management plans varies widely across and within sectors of the New Zealand aquaculture industry. Gaining an understanding of the range of biosecurity planning, on-farm implementation and stakeholder understanding, perceptions, concerns and needs will inform risk profiling of the industry, and planning for greater resilience to biological threats.

Acknowledgements:

The work presented in this study has been undertaken by the following service providers:

Biofouling management – ES Link Services Pty Ltd

Efficacy of in-water cleaning systems – National Institute of Water and Atmospheric Research Ltd

Settlement arrays – National Institute of Water and Atmospheric Research Ltd

Aquaculture snapshot – Coast and Catchment Ltd

BIOCIDAL ANTIFOULING TECHNOLOGIES
SESSION CHAIR: MR DAVID STARK
AKZO NOBEL/INTERNATIONAL PAINT SINGAPORE PTE LTD, SINGAPORE

1A - KEYNOTE

THE TANKER INDUSTRY PERSPECTIVE – MODERN ANTIFOULING SYSTEMS; EXPERIENCE AND IMPACTS

Mr Tim Wilkins
 INTERTANKO, Singapore

Growing focus on efficiency coupled with invasive species legislation is renewing the industry's interest in antifouling systems. An overview of the experience of INTERTANKO's members in using modern antifouling systems will be provided. With this backdrop of experience, consideration as to the operational and regulatory impacts to the owner of using certain systems will be provided against the mounting pressure from local, national and international environmental regulators.

1A - ORAL 1

**OVERVIEW AND REPORT ON THE STATUS OF THE FP7-EU PROJECT LEAF
 - LOW EMISSION ANTIFOULING -**

E. Pinori¹; M. Berglin¹; J. Lausmaa¹; H. Elwing²; C. Pansch^{2,3}; P. Jonsson³; C. Hellio⁴; G. Id Daoud⁴; L. Benedetti⁵; A. Cartaxo⁶; R. Coutinho⁷; D. Bueno Sudatti⁷; M. Legrottaglie⁸; S. Garofoli⁸; C. Kritikou⁹
¹SP, Technical Research Institute of Sweden; ²UGOT, University of Gothenburg, "Dep. of Chemical and Molecular Biology", Sweden; ³UGOT, University of Gothenburg, "Dep. of Biological and Environmental Sciences", Sweden; ⁴UOP, University of Portsmouth, "Dep. of School of Biology", UK; ⁵CESA, Community of European Shipyards Association, Brussels, Belgium; ⁶Lisnave Estaleiros Navais SA, Setubal - Portugal; ⁷IEAPM, "Istituto de Estudos do Mar Almirante Paulo Moreira", Brazil; ⁸Boero Bartolomeo S.p.A "R&D Department – Yachting Division", Genova, Italy; ⁹Entarco SA, Chemical Enterprise, Athens, Greece.



Present biocide-based antifouling strategies are based on a continuous exposure of biocides at the film/water interface, and consequently release into the environment, if the antifouling efficacy is to be maintained. Such biocide-based solutions are not sustainable.

The aim of the LEAF project is to develop antifouling coatings based on a new strategy. Instead of releasing the bioactive molecule into the water the biocide will be "entrapped" in the paint matrix and it is first after stimuli by organism penetrations paint surface that intoxication takes place. This concept was recently validated in the case of barnacles (Pinori et al. 2011, Pinori et al. 2013) but has been expanded to other organisms. The technical challenge of the project is to find the optimal combination of biocide/coating matrix in order to lower or completely eliminate the release of biocides. In order to carry out this project an international consortium consisting of partners with competences ranging from biology, material science and LCA assessment to coating formulations was formed. Field studies are conducted in several different marine waters, ranging from Mediterranean, subtropical and tropical, in order to take into account different climates and ecosystems.

The entrapped antifouling strategy opens up the possibility to achieve long term antifouling (>10 years) as there is no need for sustained release and use of erosive binders. The results achieved to date show a very good efficacy in all the waters tested. From an industrial perspective, the results are promising in terms of cost per litre produced paint, and light weight compared to classical copper antifouling paint.

An overview of the status of this project will be presented, together with selected results. This contribution will also discuss how LEAF is dealing with the challenge of innovation from science to market, keeping a good balance between scientifically relevant questions, environmental aspects and end user perspectives.

Acknowledgments:

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1A - ORAL 2

THE EFFICACY OF COPPER-BASED ANTIFOULING COATINGS

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Copper-based antifoulings continue to dominate the Marine and Yacht fouling control technologies in use today. This presentation outlines the various copper-based technologies available, and discusses how effective they are, not only in keeping hulls smooth, and thus reducing drag and greenhouse gases, but also in helping prevent the spread of unwanted non-native invasive species (NIS).

The overall conclusion is that high performance copper-based antifoulings play an essential role in the efforts by regulators and vessel owners and operators to prevent NIS. For commercial shipping, companion strategies such as hull performance monitoring systems that can detect micro-fouling growth on the outer hull at an early stage, along with appropriately scheduled in-water cleaning, are essential for improving energy efficiency of vessels. For recreational vessels, it is recommended that any cleaning carried out is done on-shore, where the arisings can all be collected and then safely disposed of.

1A - ORAL 3

NON-COVALENT AFFINITY BETWEEN BIOCIDES AND MATRIX COMPONENTS – FRIEND OR FOE

M. Berglin¹⁻²; M. Hulander¹, E. Pinori¹; M. Dahlstrom¹⁻², C. Hellio³, R. Trepos³, and H. Elwing²
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Controlling biocide release from antifouling coatings is important from an environment, antifouling efficacy as well as on a service length perspective. The best example of controlling release is the well-known covalent attachment of the bioactive molecule to the backbone of the polymer binder and then releasing the molecule by water hydrolysis. This strategy was successful with the TBT-acrylics but attempts to mimic it with environmentally benign substances have shown relatively little success. Recent activities in controlling release include biocide encapsulation [1]. We have evaluated another strategy in controlling the release by taking advantage of high non-covalent affinity between paint components and biocide, as exemplified with high affinity between medetomidine and rosin binder [2] and medetomidine and metal-oxides particles [3]. By immobilizing the low molecular mass biocide on a larger paint component the diffusion in the paint layer is restricted and thereby the unintended release can be minimized.

This strategy has now been expanded to a number of selected biocides and common paint components such as pigments and fillers in order to find interesting “biocide-paint component pairs” showing differences in the strength of non-covalent affinity. In order to evaluate the non-covalent affinity we have developed several new methods including surface sensitive optical methods and thin-layer chromatography (TLC) based approaches. Biocide-paint component “pairs” were added to model antifouling binders and the release was monitored. Simultaneously the effect on biofouling was studied in bioassay experiments. Results from selected studies will be presented and discussed. Although the benefits of reduced release are highlighted the concerns with high affinity between common paint components and the biocide will also be discussed in terms of “biocide depletion”. In this situation the biocide can be considered as permanently immobilized and not further bioavailable.

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Acknowledgments:

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 Project name: LEAF - Low Emission Anti-Fouling



1A - INVITED**IMPACT OF REGULATORY FRAMEWORK ON THE INNOVATION IN THE ANTIFOULING MARKET – AN ACTIVE SUBSTANCE SUPPLIER PERSPECTIVE**

Dr Rodolphe QUEROU
Regulatory Affairs Manager Europe, Dow Microbial Control

Legislation is a key driver for innovation, as it can be either an incentive or an obstacle to the placing of new products on the market. For antifouling products, when evaluating the impact of specific regulatory provisions on innovation, it is necessary to take into account some basic characteristics of the market, when compared to other biologically active products like pharmaceuticals or plant protection products.

Through the example of the EU Biocidal Products Directive (BPD) recently replaced by the Biocidal Products Regulation (BPR), we will highlight how, by setting up a very high level of requirements for protecting human health and the environment and a very high cost of compliance, BPR has both created lots of space for new products but also unfortunately created barriers for innovation.

We will present our experience with the support of SEA-NINE™ anti-fouling technology through the BPR, the multiple challenges to achieve final approval, and how this experience can be helpful when considering the development of new active substances.

Then within this difficult context, we will present how the development of new formulations or delivery systems for active substances, like our new SEA-NINE™ ACR, advanced controlled release technology, will probably be the basis for innovation in the coming years in regulated areas.

1A - ORAL 4**GEL ENCAPSULATED BIOCIDES PROFOUNDLY REDUCING BIOCIDES AND METAL CONTENT IN ANTI-FOULING PAINT**

Eva WALLSTRÖM
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During the last couple of years it has been shown that it is possible to develop yacht paint with encapsulated biocides and to obtain application and usage properties that match present commercial anti-fouling products for yachts. The resulting anti-fouling product is with no cuprous oxide and zinc oxide that may cause long-term adverse effects in the aquatic environment and with a profoundly reduced amount of biocide compared to present commercial products. These prototype paints have shown good anti-fouling properties in three different harbours in Denmark.

It has been demonstrated that biocides for other marine purposes can be encapsulated in silica gel and implemented in prototype anti-fouling paint for large ships/vessels.

The silica gel encapsulation technology makes it possible to reduce the amount of biocide, to control the leaching of the biocide and thus the amount of biocide present in the paint film surface layer exposed to sea water. The gel also contributes to the polishing properties of the paint film. When a gel particle is opened by wear the biocide is already effective on the coating surface due to gel swelling when it is exposed to water. When formulating a prototype anti-fouling paint it is possible to match commercial products with regard to polishing rate.

Raft tests have shown that the biocide zinc pyrithione is more efficient in an anti-fouling formulation, when the biocide is encapsulated in a gel compared to a situation where the biocide is outside the gel. The choice of biocide in the gel structure will be dependent on the use of the anti-fouling product, e.g. zinc pyrithione for yachts and copper pyrithione for larger ships. It is also possible to include other biocides and/or compounds in the gel structure. One crucial property for large ships is the water uptake. Different designed gels have been tested in anti-fouling formulations, including encapsulated copper pyrithione, and the conclusion is that the water uptake as well as the polishing rate can be regulated by gel design and the paint formulation. It is also possible to reduce the amount of cuprous oxide gradually. Initial raft tests have been performed at different locations in and outside Denmark.

The main factor is to formulate the anti-fouling paint with good application properties, where the paint film targets water uptake and polishing rate according to the use. In this connection we have tested many different pigments/fillers. The paint properties are documented by laboratory as well as raft tests.

It is thus possible to build from the technical experiences gained within the area of yachts together with laboratory tests and initial raft tests with prototype products for large ships to achieve anti-fouling properties that are satisfactory for larger ships while reducing the amount of cuprous oxide.

1A - ORAL 5**POLYGODIAL: A PROMISING ALTERNATIVE TO CONVENTIONAL ANTIFOULING BIOCIDES**

P. L. Cahill^a, J. M. Kuhajek
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Conventional antifouling biocides tend to be toxic compounds with non-specific activity, low degradability, and high environmental impact. Systemic toxins such as these are being placed under increasing regulatory scrutiny, thus the development of environmentally sound substitutes is warranted. One promising alternative is polygodial, a sesquiterpene derived from terrestrial plants. Polygodial was tested for antifouling activity in a laboratory-based assay against the model ascidian species *Ciona savignyi*. The concentration of polygodial required to kill 99% of *C. savignyi* larvae was 3 ng ml⁻¹, which exceeds the potency of tributyltin, arguably the most effective known biocidal antifouling agent with a lethal concentration for most fouling organisms of around 1 µg ml⁻¹. The unusually high potency of polygodial appears to derive from the specificity of this compound towards larval metamorphosis, whereby the transition from settled larva to established juvenile is targeted and arrested. Polygodial had no appreciable effects on non-target adult shellfish at concentrations between 0.03 and 30 ng ml⁻¹, further highlighting the specificity of this compound. What's more, polygodial appears to be contact-active, whereby direct contact between settled larvae and a paint matrix containing bound polygodial is sufficient to halt metamorphosis. The effectiveness of polygodial as a bound compound means release into surrounding waters is unnecessary, greatly reducing environmental risk of this alternative biocidal agent. Fully elucidating the antifouling activity of polygodial against a range of common fouling taxa, developing practicable application methods, and establishing a structure-function relationship could yield commercially viable antifouling formulations that are effective yet environmentally 'friendly'.

Acknowledgments

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1A - ORAL 6**15 YEARS OF PRODUCT DEVELOPMENT – LESSONS LEARNED FROM SELEKTOPE**

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The route from the lab bench to an authorised product is a long and costly process. The main issues are to secure efficacy and safety data that can be compared and understood by all parties involved; academic researchers, industrial partners and before market introduction, the regulators representing society to ensure safety.

One of the key issues has been to establish a track record of performance in different paint formulations. Three years and preferable five years of proven efficacy is expected from an antifouling substance. The track record for Selektope started with static panels on the Swedish west coast but has grown through collaborations between different paint companies and ship owners allowing test patches on vessels.

From our experience, the transfer between the academia and industry towards viable products can be made more efficient with some common agreed protocols, involving a standardised paint formulation proposed by the industry, some preliminary tests as requested by the regulators and adherence to the MIABE (Minimum Information About a Biological Entity) list to increase the general knowledge and information availability regarding new antifouling substances. If such information could be available, the transfer between the lab and the industrial setting could be facilitated and enable selection for possible product development programs within the industry.

1A - ORAL 7**INCLUSION OF AN ISOTHIAZOLINONE-BASED BIOCIDES INTO RUBBERY SUBSTRATES:
MODELING DISPERSION/DEPLETION RATES AND MEASURING INDUCED CHANGES IN
SUBSTRATE PHYSICAL PROPERTIES**

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The U.S. Navy has traditionally used biocide-impregnated elastomers for a number of specialty applications including surface ship SONAR domes and small acoustic windows/domes. Conventional antifouling paints and coatings perform poorly in these applications because of extensive flexing by the rubbery substrates and/or the need for smooth water-elastomer boundaries for good acoustics. We have been assessing the efficacy of an isothiazolinone-based biocide known as "DCOIT" or 4,5-dichloro-2-n-octyl-4-isothiazolin-3-one (Dow Chemical Company) as an alternative for bis-tri-n-butyltin oxide (TBTO) in these applications. DCOIT has been successfully incorporated into ethylene propylene diene monomer (EPDM) and neoprene rubber, and also into several different polyurethanes. The incorporation of the biocide into these rubbery substrates tends to have a plasticizing effect. Data documenting the induced changes in modulus, elongation, tear strength and adhesion will be presented for DCOIT loadings up to 6% by weight in these materials. We have also been studying the diffusion kinetics of DCOIT within EPDM rubber and polyurethane to enable us to model how quickly the biocide diffuses out of its host material. The construction and operation of our models will be discussed, and examples of model-calculated "concentration profiles" for DCOIT across a given thickness of rubber after specified periods of time have elapsed, or percent depletion levels have been reached, will be presented. The ability of the model to calculate how long a rubbery substrate with a specified thickness and initial loading of DCOIT can be expected to prevent biofouling, or, given a required service lifetime and thickness, how much DCOIT must be added initially to the rubber to ensure biofouling does not occur, will be demonstrated. With further improvements and calibration against experimental data, we envision this kind of modeling possibly replacing the "rotating cylinder" leaching rate experiments currently required by many environmental agencies for the registration biocide-containing rubbery materials.

Acknowledgements:

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1A - ORAL 8**BEYOND SPC – LUBYON®, A NEW SUPERHYDROPHILIC FOULING CONTROL POLYMER
TECHNOLOGY**

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Antifouling paints based on metal acrylate and silyl acrylate polymer technologies were first introduced in advance of the IMO's action to ban TBT antifouling products. Between them, these technologies have since come to dominate the SPC antifouling sector. Both share many behavioural attributes of TBT-SPCs but the underlying physical and chemical characteristics of metal acrylate and silyl acrylate polymers depart from that of the TBT-SPC mechanistic model. While both technologies have an impressively large track-record of providing a high level of sustained in-service antifouling performance, these underlying mechanistic differences may contribute to the perception of some ship owners that the performance of these tin-free technologies does not quite reach the level of performance shown by the TBT-SPC products they replaced.

To address this, a new class of metal- and metalloid-free polymers has recently been developed. Lubyon® technology is based on acrylamido ammonium sulfonate copolymers. By design, the physical and chemical characteristics of these polymers lead to antifouling paints having persistent linear polishing rates and controlled and sustained zero order biocide release through a mechanism that more closely resembles that of TBT-SPC. Moreover, Lubyon® polymers impart superhydrophilic properties on the paint film surface leading to lower hydrodynamic drag in comparison to previous generations of SPC products.

1A - ORAL 9

FROM IDEA TO A NEW ANTIFOULING PRODUCT

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Background. My interest of marine biofouling and anti-fouling started in the middle of the 90th. Before that I was active as a surface chemist both as a researcher and inventor. With this background it may be expected that I should have continue to study aspects of foul-release coatings. But, the poor performance of the foul release coatings in the marine environment made me take another direction. Instead I concentrated my efforts to find new ways of preventing the barnacles from marine coatings with the use of the latest generation of biocides.

The medetomidine (selectope) method. The inspiration comes from a Japanese group (Fusetani) who published a paper showing that adrenergic pharmacological compound, inhibited settlement of barnacles in in vitro experiments (1). Lena Lindblad and I had earlier made research on related pharmacological compounds. For this reasons Lena, Mia Dahlstrom (Ph.D. student at the time) and I made up a screening program of different adrenergic compounds in the simple barnacle settlement assay performed in petri dishes. The medetomidine compound (fig 1) was outstanding in preventing the cyprid larvae from colonization at very low concentrations, probably due to a vigorous swimming reflex of the cyprid larvae (2). Mia also continued to make experiments by adding the medetomidine in rosin based paint formulations and Mia also made her Ph.D. thesis on the medetomidine-antifouling concept (3). A patent application was made for the marine use of medetomidine that was filed 1999 (4) and the patent rights was sold to I-Tech AB (www.i-tech.se) company founded by myself and others. Since then, I-Tech has got the medetomidine (selectope) approved for marine anti-fouling use in several countries and registration is pending in Europe.

The avermectin (ivermectin) method. In the medetomidine project we noted that beside high biological activity against cyprid larvae, high non-covalent affinity of medetomidine at the coating layers was important for the biocide retention in the coating. Therefore we continued our work to find more substances that were active against barnacle colonization and also had a high non-covalent affinity to the coating. There are many commercial pesticides that are toxic against small crustacean. By doing an extensive literature search I found that a pesticide group called avermectins may be interesting candidates. The avermectins are also large hydrophobic molecules giving them a little tendency to leach from rosin-based paint layers (fig1). Most experiments with avermectin (Ivermectin) included in an ordinary rosin based paint formulation, was very effective in preventing barnacle colonization as shown by Pinori (5) who also made his PhD thesis (6) on the avermectin concept. Continuous research also showed that intoxication occurs when the juvenile barnacle start to penetrate the coating layer, whereas leached toxin molecules seems to have little effect on the cyprids. Thus, we accidentally discovered a previously un-known intoxication principle of the barnacle. This could lead to the development in anti-barnacle coating that leach very little toxin and has a service length of decades rather than years. Further research is performed the FP-7 Low emission antifouling project (LEAF).

Conclusions The leaching rate (ng/cm²/day) of the medetomidine and avermectins (ivermectin) is at least 100 times lower than copper in active rosin based anti-barnacle paint formulations (3,6). Addition of medetomidine or an avermectin replace the need of copper compound additives in the waters around Scandinavia, as demonstrated in numerous yacht experiments.

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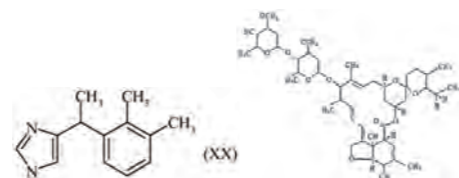


Figure. Medetomidine or selectope (left) and avermectins (right). Two of the winners for replacement of copper in marine antifouling ?

1A - ORAL 10

COPPER SELECTIVE LBL FILMS AND COPPER NANOWIRES FOR ANTIFOULING APPLICATIONS

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Marine biofouling incurs substantial costs to maritime industry. It is also a major problem for harbour installations, oil rigs, underwater sensors, pipelines, and other submerged artificial structures. Since ban of tributyltin (TBT) paints, various strategies were proposed to control undesired deposition of marine organisms. Copper is currently broadly used as an antifouling replacement of tin in various paints and coating formulations.

In presented research we investigate two novel approaches to fabricate copper rich polymeric structures for antifouling applications. Thin polymeric films constructed using electrostatic layer by layer (LbL) fabrication method were used as a scaffold to incorporate Cu ion receptors. High affinity to metal was achieved by the molecular copper imprinting in the process of film crosslinking. The metal imprinted film shows substantially higher Cu affinity compared to the non imprinted one. In the second approach Cu nanowires fabricated by disproportionation method were integrated into structure of polymeric matrix. Special fabrication method was established to use nanowires as a top coat layer of polymeric coating. Both LbL films and nanowire structures were evaluated for antifouling and antibacterial activities.

Acknowledgments:

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1A - ORAL 11

ANTIBARNACLE ACTIVITY OF ISOCYANIDES DERIVED FROM AMINO ACIDS

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Creation of new potent antifouling-active compounds is important for the development of environmentally friendly antifouling agents. Recently, we performed detailed structure-activity relationship studies and produced various antifouling active isocyanide compounds.^{ref} Here, we focused on isocyanides derived from amino acids because amino acid-isocyanides would eventually be biodegraded to the original non-toxic amino acids. In particular, we characterized the antibarnacle activity of newly synthesized isocyanides derived from amino acids. The amino group and carboxy group in the amino acids were converted to isocyanide groups and esters for the synthesis of amino acid-isocyanides. Isocyanides derived from several amino acids were synthesized and evaluated for their antifouling activity and toxicity against cypris larvae of the barnacle *Balanus amphitrite*. All the amino acid-isocyanides synthesized showed potent anti-barnacle activity. In addition, none of the compounds synthesized showed significant toxicity at high concentrations. The LC_{50}/EC_{50} ratios of nearly all the synthesized compounds were greater than 10^3 . Therefore, these amino acid-isocyanides are promising low-toxicity antifouling agents.

Kitano et al. *Biofouling*, **2011**, 27, 205; *Biofouling*, **2004**, 20, 93; *Biofouling*, **2004**, 20, 87; *Biofouling*, **2003**, 19, 187; *Perkin Trans 1*, 2002, 2251.

1A - ORAL 12

SYNTHESIS AND ANTIFOULING PROPERTIES IN MICROFOULING STAGE OF HYBRID ZINC/SILYL ACRYLATE COPOLYMERS FOR MARINE ANTIFOULING COATINGS

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In this paper, a series of novel hybrid Zn/Si-acrylate copolymers composed of tri(isopropyl)silyl acrylate (TIPSA) and Zinc-2-Ethylhexanoate methacrylate (Zn-monomer) were synthesised, and their hydrolysis properties and antifouling performance were investigated in the microfouling stage. The diatom *Phaeodactylum tricorutum Bohlin* were used as model fouling to study its settlement and cell growth inhibition on the Zn/Si-acrylate copolymer. All the Zn/Si-acrylate copolymer exhibit excellent resistant performance of diatom growth and the Zn/Si-acrylate copolymer with high content Zn-monomer demonstrate the best performance. When the polymer surfaces immersed into sea water, the hydrolysis of TIPSA and Zn-monomer eventually makes a thin surface layer hydrophilic, which is gradually dissolved and washed away and the inner layer is further exposed to sea water. Here, both the self-peeling and the release of Zinc compound lead to antifouling properties. Moreover, adding the Zn-monomer in silyl-acrylate polymer reduces the amount of expensive TIPSA so that the coatings become more cost-effective, which is vitally important for industrial applications.

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1A - ORAL 13

FROM DINGHY TO DELUXE – AN OVERVIEW OF THE CHALLENGES IN FOULING CONTROL FACED IN THE PLEASURE CRAFT MARKET

Cait Cairns
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The Yacht Market is a complex sector with significant regional as well as vessel size variability. As a result, the challenge for fouling control is quite different from that of the Marine sector particularly in the owners' desire for impeccable aesthetics and in the area of DIY application. International Paint Ltd. aim to provide fouling control solutions for all of our customers: from those with the smallest dinghies to the owners of vast Superyachts, exceeding 100m in length. Increasing regulatory pressure combined with the broad diversity of regional fouling challenges makes ensuring the future of effective fouling control in the Yacht Market an increasingly complex challenge. This paper aims to discuss these current and likely future challenges and present solutions applicable to the whole of this diverse market sector.

REGULATORY AND ENVIRONMENTAL ISSUES

SESSION CHAIR: PROFESSOR STEPHEN DE MORA

PLYMOUTH MARINA LABORATORY, UNITED KINGDOM

1B - KEYNOTE

MANAGING FOULING - REGULATORY CHALLENGES AND OPPORTUNITIES

Dr Naomi Parker
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Managing biofouling on ships is both an environmental and an economic concern, and good biofouling management will minimize the risk of transfer of invasive species and improve ship efficiency. Voluntary guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species were adopted by the International Maritime Organization (IMO) in 2011, but the extent of uptake of these measures and the effectiveness of different management approaches and systems remain unclear. Experience in New Zealand and at the IMO has highlighted the need for a practical and pragmatic regulatory approach that supports innovation in biofouling management and results in real change in the management of invasive species.

1B - ORAL 1

COPPER BASED ANTIFOULING - LATEST REGULATIONS AND SCIENCE

Neal Blossom
American Chemet Corporation

Recent and pending regulatory reviews and decisions regarding copper's use in antifouling coatings from New Zealand, the EU, Japan, the US EPA and the state of California will be compared. The various methods and regional issues that are used in each area will be discussed. How science is both used and misused, and risk and benefit analysis is either a key consideration or not a consideration at all will be vetted. Finally some of the latest studies regarding copper based antifouling coatings will be summarized.

1B - ORAL 2

LIFE CYCLE CONTRIBUTIONS OF COPPER FROM VESSEL PAINTING

Kevin Long
Regulatory Compliance Ltd, Edinburgh, United Kingdom

Copper-based epoxy and ablative antifouling painted panels were exposed in natural seawater to evaluate environmental loading parameters. In situ loading factors including initial exposure, passive leaching, and surface refreshment were measured utilizing two protocols developed by the US Navy: the dome method and the in-water hull cleaning sampling method. Cleaning techniques investigated included a soft-pile carpet and a medium duty 3M™ pad for fouling removal.

Results show that the passive leach rates of copper peaked three days after both initial deployment and cleaning events (CEs), followed by a rapid decrease over about 15 days and a slow approach to asymptotic levels on approximately day 30. Additionally, copper was more bioavailable during a CE in comparison to the passive leaching that immediately followed. A paint life cycle model quantifying annual copper loading estimates for each paint and cleaning method based on a three-year cycle of painting, episodic cleaning, and passive leaching is presented.

1A - ORAL 3

REASSESSMENT OF ANTIFOULING BIOCIDES IN NEW ZEALAND

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The New Zealand Environmental Protection Authority has completed its reassessment of antifouling paints. These substances contained one or more of the following 15 biocidal active ingredients that were approved for use in New Zealand: DCOIT, chlorothalonil, copper, copper pyriithione, copper thiocyanate, dichlofluanid, diuron, irgarol, mancozeb, octhilineone, thiram, tolyfluanid, zinc pyriithione, zineb and ziram.

The reassessment looked at the risks and benefits associated with these substances, with particular focus paid to the effects on human health, the environment, socioeconomic and cultural values. By undertaking the review of the entire group of antifouling paints, the EPA was able to ensure consistent decisions by determining the effects of individual formulations in the broader context of the group of antifouling paints.

The outcome of the reassessment is that antifouling paints containing irgarol or chlorothalonil will no longer be able to be manufactured in or imported into New Zealand. The remaining antifouling paints have been approved, noting that those paints containing diuron, octhilineone or ziram are subject to time-limited approvals and will not be available indefinitely.

This presentation will summarise the assessment, the regulatory outcomes and the risk-mitigation measures imposed on the retained approvals, and how the EPA has approached communication of its decisions in order to assist importers, manufacturers and users to comply with the new rules for safe use of antifouling paints.

Acknowledgments:

The work was completed with the assistance of NIWA, MPI and Covec.

1B - INVITED**THE NEW EUROPEAN BIOCIDAL PRODUCTS REGULATION AND ITS IMPLICATIONS FOR ANTIFOULING PRODUCT FORMULATORS – A PRACTICAL REVIEW**

Mrs Linda Jones
Annex3 Consulting, The Netherlands

In the midst of other global regulatory schemes for biocides, the European Union system is one of the most comprehensive: its developments are followed and felt worldwide. Other government competent authorities have studied Europe's advancements as an example, but also the global antifouling industry has closely watched these changes, with its product portfolio in mind.

Until now the attention was focused mainly on the active substances, their assessment under the vastly delayed Review Programme - as started under The EU BPD (Biocidal Products Directive 98/8/EC) - and on the active substances' subsequent regulatory status. With relatively little practical experience under the Directive with respect to actual biocidal product formulations, the EU legislation underwent a major transformation through the introduction of the BPR (Biocidal Products Regulation (EU) No. 528/2012). Now, past the Regulation's application date of September 1st, 2013, with the first active substance already approved under antifouling Product Type 21 and others to follow soon, regulatory procedures for product formulations are imminent; it is time to concentrate on the antifouling.

This presentation looks at practical regulatory issues encountered by the antifouling industry as a result of EU biocides legislation. It will review the main differences between EU BPD and BPR, transitional measures, f.i. in relation to keeping existing product portfolio on the market, practical points to take into account when developing a new antifouling formulation and strategic and practical aspects to be considered before and during product authorisation. The various topics will be addressed mainly from a formulator's perspective.

1B - ORAL 4**NEW METHOD FOR RELEASE RATE DETERMINATIONS FOR ANTIFOULING PRODUCTS**

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In EU and elsewhere, antifouling paints have to pass an environmental risk assessment (ERA) prior being put out on the market. In the ERA, release rate determination of the active substances used in the antifouling product is a critical input parameter. Today the CEPE mass-balance method is accepted to be used for deriving release rates of biocides in EU [1]. However, the CEPE method has shown to overestimate the release rate and therefore a correction factor of 2.9 can be applied on the CEPE method calculated release rate [1]. The correction factor on copper release rates is based on data from only six different antifouling paints as determined by the US Navy Dome Method [1]. Thus, the EU member states have agreed that the size of the correction factor needs to be further investigated and validated, but until then, the correction factor of 2.9 may be used for Tier 2 assessments.

The aim of the current study was to develop a new copper release rate method where the loss of copper in the paint per time is determined with a handheld X-ray fluorescence spectrometer (XRF). The calibration of this new XRF application was performed by the development and analyzes of our own made antifouling paint standards. The copper concentrations in the standards were determined by ICP-MS following aqua regia digestion and incorporated in the application.

In the release rate study, panels were coated with antifouling paints designed for use on leisure boats (Paint A-C) and vessels (Paint D), and subsequently analyzed for copper with our XRF antifouling paint application. The coated panels were immersed in two marinas located in the Baltic Sea and on the west coast of Sweden, respectively. After 119 days (Baltic Sea) and 138 days (west coast of Sweden) the panels were taken up from the water and re-analyzed with the XRF-method. For all paints tested, the release rate of copper showed to be significantly higher as compared to the CEPE Tier 2 assessment. The results also indicate that the release rate of copper is higher when the panels were immersed on the Swedish west coast as compared to the less saline Baltic Sea.

Table. Release rates of copper from four different antifouling paints

Area	Metod	Release rates of copper (ug/cm ² /d)			
		Paint A	Paint B	Paint C	Paint D
Baltic Sea	XRF	3.2	8.2	7.8	9.5
	XRF 95% CI	2.8-3.6	7.6-8.9	6.7-8.9	8.3-10.7
Swedish west coast	XRF	3.6	12.1	14.8	13.3
	XRF 95% CI	3.3-3.9	11.0-13.2	14.0-15.6	12.3-14.4
	CEPE	2.5	14.7	18.4	14.6
	CEPE TIER 2	0.9	5.1	6.3	5

Conclusion:

This new XRF-method to determine release rates of copper from antifouling coatings appears to be a promising, fast and reliable method useful in many applications. Further measurements will be provided in the coming year.

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1B - ORAL 5

MIXTURE TOXICITY IN ANTIFOULING PAINT RISK ASSESSMENT

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Antifouling substances are under scrutiny in many different areas of the globe, in part due to the wide-spread, dispersive nature of their emissions. While the antifouling substances themselves are currently being assessed rather than the entire product (the antifouling paint), rules for the assessment of other types of biocidal products in the EU are being developed which may have a serious impact on the future market. In particular, the problem of addressing mixture toxicity is attracting much effort, and rules have been proposed on the performance of risk assessments on products containing 2 or more hazardous substances. The impact of the EU review and the implications of the product assessment proposals will be analysed in detail with reference to current product ranges.

1B - ORAL 6

SHADES OF GREEN: ASSESSING FOR ENVIRONMENTALLY BENIGN CHEMICALS IN ANTIFOULING BIOCIDES DEVELOPMENT

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Current environmental legislations have made the registration of chemicals for use in the environment a monumental challenge. Product dossiers require information on the environmental fate and behavior of chemicals but this information is not easily attained or measured. Consequently the costs of registration of chemicals are high, and in some cases prohibitive for small commercial players. In early stages of product discovery and development, it would be ideal if one could predict *a priori* which chemicals are potentially 'environmentally benign' candidates for further R&D investment. In this presentation, we examine approaches to assess compounds that have been reported to possess anti-fouling properties using property estimation methods such as BIOWIN and ECOSAR developed by Syracuse and the Environmental Protection Agency of the USA. Our studies show that these methods of estimation have limitations but may still be useful for compound selection for further development as anti-foulants when applied with discretion.

1B - ORAL 7

FORMATION OF REGULATED CHLORINATION BY-PRODUCT IN THE COOLING SEAWATER DISCHARGE OF A NUCLEAR POWER PLANT

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The inevitable problem of biofouling in seawater cooled condenser system of power plant is most commonly and quite appreciably managed by chlorinating the intake seawater. Minimum desired chlorine residual is maintained throughout the cooling conduits, complying with environmental guideline for its discharge into receiving water body. Although, chlorination has been fairly successful in combating biofouling, the benefit of using chlorine as biocide for water treatment has been on serious review after the discovery of trihalomethanes (THMs) in chlorinated water owing to its adverse environmental impacts. THMs, group of four toxic compounds (CHCl_3 , CHCl_2Br , CHClBr_2 & CHBr_3), are the major fraction of all toxic chlorination by-products (CBPs) formed due to the reaction of chlorine with the organic matters present in the water. Dependence of load and character of THMs formation on Cl_2 dose, contact time & reaction temperature was investigated to evaluate its formation kinetics in seawater chlorination. Trihalomethanes level and species distribution in the discharged chlorinated cooling seawater of a nuclear power plant was assessed periodically. Its concentration was the highest during Nov - Jan & lowest during in Feb-Mar, during two years of field study. Maximum THM concentration observed was 52 $\mu\text{g/L}$ which is below the WHO guideline of 100 $\mu\text{g/L}$. Laboratory chlorination experiments showed significant level of THMs formation within half an hour of reaction followed by prolong formation at a very slow rate. Though the concentration of THMs formed increased with increasing Cl_2 dose, the % of chlorine equivalent halogen incorporation into natural organic matter (NOM) decreased possibly due to the limiting amount of fast reactive NOM fractions. Higher temperatures not only fasten the rate of THMs formation but also enhanced the overall yield. The effect of temperature on the total yield of THMs was found to be more significant for temperature change at higher range. The formation order of THM species at all studied conditions was observed to be $\text{CHCl}_2\text{Br} < \text{CHClBr}_2 < \text{CHBr}_3$. CHCl_3 was not observed and bromoform was the dominant (96-98 %) THM species. The concentration of THM formed within 5-15 min under laboratory chlorination of intake seawater with 1ppm Cl_2 dose is in agreement with the actual THM concentration in the discharge water.

PLENARY**PLENARY 1****MICROBIAL BIOFILMS – BIOLOGY AND CONTROL**

*Professor Staffan Kjelleberg
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Centre for Marine Bio-Innovation, UNSW, Australia*

Recent years have witnessed a rapid development in our understanding of biofilm biology. These are derived from both mechanistic studies of genetic development programs and biofilm structure and function, as well as whole biofilm community meta-omics and systems biology approaches. Unravelling the fundamentals of biofilm biology is essential for targeting and controlling biofilm processes across a range of natural and engineered systems.

This talk will address the identification of specific stages of the biofilm lifecycle as targets for control. These include, for example, intra and extracellular signaling and molecular components and interactions that define the structure and function of the matrix in which the biofilm cells are embedded. Specifically, interactions between extracellular signals and polymeric components, matrix structural and developmental features, and the intracellular nitric oxide mediated signaling cascade for biofilm cell dispersal will be discussed.

Unexpectedly, the extracellular matrix domain greatly contributes to the activity of the biofilm. The matrix displays extensive electroconductivity, employing several soluble electron shuttles. Further, bioelectrochemical matrix systems provide conduits for likely attachment and transfer of small signalling and/or electrogenic compounds. These functions mediate biofilm-based bioconversion, including those with detrimental outcomes such as microbially induced corrosion.

The recent advances in next generation sequencing and systems biology have enabled a detailed assessment of the structure and function of complex communities. Metagenomics and metatranscriptomics approaches have elucidated unexpected diversity and function of natural biofilms. This has opened up opportunities for biofilm management and control. For example, combined metagenomics and analytical chemistry informs on the elaborate communal extracellular signaling engaged by a large number of different species for specific outcomes by the community. Furthermore, combining metatranscriptomics and metagenomics has mapped the intricacies of communal co-metabolism, suggesting a mechanism by which the community attains stability.

BIOFILMS AND MICROBIAL FOULING

SESSION CHAIR: PROFESSOR PETER STEINBERG
DIRECTOR, SYDNEY INSTITUTE FOR MARINE SCIENCES; CO-DIRECTOR,
CENTRE FOR MARINE BIO-INNOVATION, UNSW, AUSTRALIA;
CO-DIRECTOR, ADVANCED ENVIRONMENTAL BIOTECHNOLOGY CENTRE,
NANYANG TECHNOLOGICAL UNIVERSITY, SINGAPORE

2A - KEYNOTE**MICROBIAL FOULING OF MEMBRANES AND STRATEGIES FOR CONTROL**

*Associate Professor Scott Rice,
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Bacteria form biofilms on almost all surfaces, ranging from ship hulls to cooling towers, to indwelling biomedical devices. Biofilms also play positive roles, for example, floc and granule formation for the biological remediation of contaminated water. Therefore, there is strong drive to understand the processes of biofilm formation, to either eliminate biofilm formation in some industrial processes and human health, or to encourage their formation, for processes such as remediation. To develop innovative, environmentally friendly, biofilm control technologies, it is essential to understand the process of biofilm formation and to evaluate natural systems that prevent or reduce biofilm formation. For example, we have discovered that the endogenous production of small molecules within the biofilm, both reactive oxygen species (ROS) and cell-cell signalling molecules, can induce biofilm dispersal. Thus, by understanding biofilm formation from both the bacterial and environmental perspective, it is possible to manipulate the biofilm, to encourage or discourage formation, to benefit specific needs.

2A - ORAL 1

MICROBIAL COMMUNITIES ON SEAWEEDS

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Much of our research on the microbial fouling of manmade surfaces has derived from using microbial biofilm communities on seaweeds as natural models. We have now characterized these communities across a wide variety of taxa (red, brown and green macroalgae) and spatial and temporal scales (from different fronds of a single alga to cross continental differences, days to seasons) using techniques ranging from molecular fingerprinting to meta'omics. Significant variation in microbial communities occurs across all taxa and scales, but some clear patterns were evident. At both very large and very small scales, the condition of the surface (here the health of the alga) was the main factor affecting microbial community characterization, overshadowing the effects of differences in location even at continental scales. There was also strong partitioning of communities across taxa, even among closely related species, suggesting that the most important effect dictating community composition was again the nature of the surface, rather than the source community. This conclusion was further supported by studies of microbial communities on seaweeds following transplanting into different habitats. Functional analyses indicated substantial functional ecological redundancy within these communities, which does not map onto phylogenetic relatedness. These results suggest that microbial fouling on manmade surfaces (ships, aquaculture structures, etc.) will be primarily determined by the nature of the surface or the coating rather than the location. Moreover, because of functional redundancy, the absence of particular taxa in any given location will have minimal functional effect on the interaction between the surface and its associated biofilm.

2A - ORAL 2

ANTI- AND PROFOULING EFFECTS: CHEMICAL MAINTENANCE OF THE HOLOBIONT FUCUS VESICULOSUS?

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The brown macroalga *Fucus vesiculosus* is a dominant habitat forming alga along the Western Baltic coast occurring between depths of 0-3m. While the alga is exposed to high bacterial densities in the Kiel fjord (0.7 to 2.24×10^6 bacterial cells ml^{-1} of seawater) and does offer a potential substratum to micro and macro epibionts - quite often *Fucus* remains free from heavy fouling and is covered by a thin film of epibiotic microorganisms. It has been also found that in a given habitat, this alga harbors a distinct bacterial community when compared to neighbouring algae, surrounding seawater or inanimate substrata. Bioassay guided fractionation of chemical extract originating from the *Fucus* surface has led to the identification of fucoxanthin, DMSP and proline responsible for reduced bacterial settlement. These compounds have also been found to be strain specific in their action, thus probably assisting *Fucus* in maintaining a distinct bacterial community on its surface. This idea was further supported by a study that correlated the surface concentration of the defence compounds under different light and temperature conditions with the presence or absence of different bacterial clades, which were detected by in-depth sequencing of the 16S rDNA gene: Several groups of bacteria were found to be positively or negatively affected by the defence chemicals present on surfaces of *Fucus* individuals.

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2A - ORAL 3

GROWTH ON CHITIN SURFACES PROTECTS VIBRIO CHOLERAE FROM PREDATION

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Vibrio cholerae forms biofilms on the chitinous surfaces of zooplankton in the marine environment. These chitin-associated biofilms have been suggested to be protective against a variety of stresses as well as providing a nutrient source, as *V. cholerae* uses chitin as a nutrient source. Predation by heterotrophic protists has a major impact on the survival of *V. cholerae* and biofilm formation is the main defensive strategy. Previous work in our laboratory has shown that biofilms are resistant to grazing while planktonic cells are eliminated, and that biofilms produce quorum sensing (QS) regulated anti-protozoal factors. Here, we investigated the role of chitin in *V. cholerae* grazing resistance and demonstrate that QS regulates chitin metabolism and anti-protozoal activity.

V. cholerae wild type and QS mutant biofilms grown on chitin flakes were exposed to the bacteriotrophic surface-feeding flagellate *Rhynchomonas nasuta*, and grazing resistance was reflected by biofilm biomass and enumeration of *R. nasuta*. Chitin metabolism by *V. cholerae* results in the production of ammonium, therefore, the concentration of ammonium produced during chitin degradation was also determined. Toxicity of ammonium to *R. nasuta* was assessed by enumeration of surviving flagellates in biofilm supernatants and in control medium supplemented with ammonium. Finally, RNA-Seq was used to elucidate the QS regulation of genes involved in chitin metabolism and anti-protozoal activity.

Data show that both WT and QS mutant strains formed more biofilm biomass in the presence of chitin. The growth of *R. nasuta* was inhibited by WT biofilms grown on chitin flakes compared with non-chitin controls, while the inhibition was attenuated in QS mutant biofilms. Ammonium accumulated in supernatants of *V. cholerae* biofilms grown on chitin, and the supernatants of WT biofilms and medium with ammonium supplementation were inhibitory against *R. nasuta*. The supernatants of the QS mutant biofilms were lower in ammonium concentration and less toxic to *R. nasuta*. RNA-Seq revealed that the majority of genes involved in chitin metabolism and chemotaxis were down-regulated in QS mutant biofilms.

Therefore, chitin association not only provides *V. cholerae* nutrient for growth, but is also a protective niche for long-term persistence of *V. cholerae*, where QS regulation is critical for chitin metabolism and anti-protozoal activity.

2A - INVITED

MARINE BIOFILMS ASSOCIATED WITH ANTIFOULING COATINGS: OUR FRIENDS OR ENEMIES?

Professor Sergey Dobretsov

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Marine biofilms are multispecies communities composed of bacteria, microscopic algae and protozoa incorporated in an expolymeric matrix. Microorganisms in biofilms cause severe problems for marine industries. The growth of biofilms on ships promote settlement of propagules of some macrofouling organisms, increases microbial corrosion, shear stress and drag, eventually leading to higher fuel consumption and increased production of CO₂. Biocidal and non-biocidal paints effective at managing macrofouling organisms are less effective against microorganisms. Our knowledge of biofilms associated with antifouling coatings is limited. Recent studies employing molecular techniques indicate diverse microbial communities on antifouling coatings. In this talk I will focus on novel findings about diversity, density and the role of marine bacteria and diatoms in management of biofouling on antifouling coatings.

2A - ORAL 4

SPATIO-TEMPORAL VARIATION OF THE MARINE BIOFILM COMMUNITIES COLONIZING ANTIFOULING COATINGS IN THE MEDITERRANEAN SEA VS THE ATLANTIC OCEAN

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When immersed in sea water, any substrate would be rapidly colonized by micro and then macroorganisms¹. This complex and sequential natural process called biofouling induces economic and ecological prejudices, especially as far as ship hulls or aquaculture nets are concerned^{2,3}.

Biocidal based antifouling (AF) coatings include several active molecules that aim to prevent the diversity of potential colonizers that could come across in marine environment. Generally several biocides are associated without clear idea of their effect^{4,5}. In this study, we intend to characterize the individual effect of three commercial biocides (Copper pyrithione, Zinc pyrithione and Zineb[®], respectively called C, Z and I when formulated) on biofilm communities that represent the first step of colonisation of immersed artificial surfaces. Each biocide was dispersed in a (meth)acrylic-based matrix (Neocryl B725[®]). Coatings composed of the polymer matrix alone (named M) together with a Poly(vinyl chloride) reference surface (named R) were also immersed in triplicates as controls. Coated panels and controls were immersed in sea water for one month in order to get mature biofilms beyond pioneer stages⁴, at each season (Winter, Spring, Summer and Autumn), in two temperate but contrasted French coastal sites, (i) Toulon Bay (North-Western Mediterranean Sea) and (ii) Lorient harbour (Atlantic Ocean). Water quality including dissolved trace metals (Cd, Co, Cu, Ni, Pb, Zn), nutrients and organic carbon concentrations was monitored during the immersion periods. Microbial communities were analysed using complementary tools: PCR-DGGE, 454 pyrosequencing, flow cytometry (FCM) and microscopy.

FCM shows that C and Z were the most efficient coatings in both locations. Bacterial density was decreased down to 8 times when compared to R. On the contrary, I displayed no significant difference compared to R (and M). Higher densities were observed at Toulon without a clear seasonal effect, whereas a highest density was observed in spring at Lorient. MDS analysis of pyrosequencing data shows that bacterial community clustering was mainly based on coating (C and Z vs R, M and I) and site, whereas seasons appeared of less importance. γ - and α - Proteobacteria dominated the communities, followed by Bacteroidetes (mainly Sphingobacteria), independently of the site and the season. γ / α ratios were in the range between 1 and 2 for R and M. Interestingly, for C and Z, if the ratio decreases at Toulon it increases at Lorient. In addition, C and Z exhibited significant lower richness and diversity for both sites and whatever the season. Considering diatoms, MDS analysis evidences that clustering was mainly influenced by the site and then the coating. Similarly as for bacteria, Z and C exhibited both a decrease of abundance and diversity. Finally, canonical correspondence analyses clearly identified the main abiotic parameters in terms of community structuration for each site.

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2A - ORAL 5

WHEN MARINE MICROBES MEET MICRO-FABRICATED POLYDIMETHYL-SILOXANE SURFACES

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Marine biofouling can have numerous negative impacts to maritime industries, such as increasing the operating costs, and posing an environmental threat by the potential introduction of invasive organisms. Recent antifouling research has been focusing on the development of non-toxic environmentally benign solutions since the ban of the organotin based antifouling approach. This study attempts to challenge the inherent colonisation of micro- and macrofouling organisms in the marine environment through the deployment of micro-fabricated polydimethyl siloxane (PDMS) surfaces with 1 – 10 µm periodicity corrugated topographies in marine waters. The effect of such surfaces on the development of microbial biofilms was examined using confocal laser scanning microscopy as well as terminal restriction fragment (T-RF) analysis for phylogenetic fingerprinting, over a period of 28 days and during different seasons. The established marine biofilms were significantly impacted by the micro-scale topography, with altered attachment pattern and reduced microcolony formation, on the 1, 2, and 4 µm PDMS surfaces. In addition, field deployments over 28 days showed significant reduction in biovolume on the 4 and 10 µm PDMS surfaces despite altered environmental conditions during different seasons. The impact of the micro-fabricated topography further inflicted in the altered community composition of the biofilms, as revealed by the T-RF profiles, at different developmental stages. Attempt to explore the consequences of the affected marine biofilms revealed altered biofilm resistance, demonstrated by exposing pre-established biofilms on 10 µm micro-fabricated surfaces to enhanced flagellate predation by a heterotrophic protist. The significant changes of the overall marine microbial biofilm development as well as community composition supports the viability of substratum modification for marine antifouling applications.

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2A - ORAL 6

LABORATORY AND FIELD TESTING OF ANTIFOULING BIOCIDES TETHERED TO ORGANIC POLYMER COATING COMPONENTS AGAINST MARINE BIOFILMS

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Marine biofilms which are often referred to as microfouling, remain unaffected by the current antifouling technologies utilised in shipping. The mechanistic understanding of biofilm adhesion is largely unexplored especially on antifouling surfaces that utilise a range of different strategies from chemical repulsion (e.g. biocide-based coatings) to physical removal (e.g. foul release coatings). Environmental concerns on the fate of biocides entering the environment when released from coatings have generated an imperative need for active but non-leaching surfaces. For this reason, the European FP7 project Foul-X-Spel has investigated covalently fixing bioactive molecules (commercial biocides) to avoid leaching and to promote a long-term effect of surface protection.

Here we report the initial results from both laboratory and field experiments where two approved commercial biocides have been covalently linked to components of polyurethane (PU) surface coatings. Initially, the new compounds were tested in solution (0.5 ppm – 256 ppm) against the marine biofilm forming bacterial species *Cobetia marina* and *Marinobacter hydrocarbonoclasticus* in the laboratory via attachment and growth assays. Following the initial bioassays, the biocide linked paints were applied on to glass coupons, placed in 24-well plates and tested against biofilm growth over 24 hours against the aforementioned species. The bioassay protocol has been developed in order to allow *in situ* observations of biofilm formation and growth, by corroborating different techniques such as a multidetection microplate reader and confocal laser scanning microscopy (through nucleic acid staining). The coatings containing the linked commercial biocides (up to 5 %) have been immersed as part of field trials in the UK (Southampton Water) and Singapore for eight weeks.

Acknowledgments:

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2A - ORAL 7

MICROBIAL FOULING ON COMMERCIAL BIOCIDAL FOULING CONTROL COATINGS

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Due to the perceived general ability of many commercial fouling control coatings to prevent macrofouling, there is increasing interest in microfouling (biofilms) as its impact on ship performance, although significantly less than for macrofouling, can still be significant. This study aims to characterize biofilm growth on a number of commercial biocidal fouling control coatings upon static immersion in two locations in Oman (Marina Bandar Rowdha and Marina Shangri La) over a 1 year period. Coatings tested included examples of the main biocidal fouling control technologies in widespread current use, namely Self Polishing Copolymer, Self Polishing / Hybrid, and Controlled Depletion Polymer coatings. An inert, non-toxic, non-foul release reference coating was used as a control. After 1 year, all of the biocidal fouling control coatings were free of macrofouling at both locations and only biofilms were present. In contrast, the control coating surface was heavily fouled with both macro and microfouling. The abundance of adhered photosynthetic microorganisms in biofilms was estimated using chlorophyll a concentrations and the total wet weight of the biofilm was recorded. The bacterial densities and microbial community structure of biofilms developed on antifouling coatings were assessed using epifluorescent microscopy and 454 pyrosequencing, respectively. Our experiments demonstrated that the nature and quantity of biofilm present differed from coating to coating and from location to location. These differences may reflect the response of the coating chemistries to the water quality and the population of microfouling organisms at each location.

Acknowledgements

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2A - ORAL 8

METABOLOMICS AND METABOLOMIC IMAGING OF BIOFILMS ON CORRODING CARBON STEEL SURFACES

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Biofilms are frequently highly heterogeneous and the effect of such heterogeneity on the corrosion of an underlying metal is not well characterized. The lack of experimental work is explained by the difficulty in characterizing a biofilm metabolome from very small areas and volumes of biofilm. We have solved this problem by sampling biofilm by laser ablation, followed by collection of the ablated material and HPLC/Q-ToF MS analysis. For imaging, 20 pulses of a focused 3.28 μm mid-IR laser is used to ablate about 0.1 mm^3 of biofilm from a small area. The ablated material is captured on a hanging droplet, which in turn is forced to jump to an inlet capillary and directed to the electrospray ion source. The process is repeated about three times every second. In this direct infusion experiment, about 2×10^3 compounds can be detected from every pixel. The experiment is repeated a few hundred times and individual chemical images are constructed from the data. Imaging of, for example, *Marinobacter* sp. grown in seawater yield about 2,000 separate images. Software is used to group together similar images, i.e. of compounds that are present in the same metabolic environment. The interpretation of the data is aided by results from experiments in which a larger amount of biofilm is ablated, captured and analyzed by HPLC/Q-ToF MS. Typically, about 10^4 features (compounds) are detected. Matching the results against compound databases results in putative identification of a few hundred compounds. The mass peaks observed in the imaging experiments are then matched against the full HPLC/MS results. After metabolome characterization and imaging, the surface is cleaned, The metal surface is then characterized by profilometry and other surface-analytical technique, and the results correlated with the metabolomic images.

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2A - ORAL 9

INVESTIGATION OF MARINE BACTERIAL ATTACHMENT AND BIOFILM FORMATION ON TITANIUM SURFACES

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Bacterial attachment to metal surfaces is an extremely complicated process that is affected by many factors including environment, bacterial properties and material surface characteristics. This process affects various domains of applications, such as biomedical, industrial, marine and environmental and result heavy costs of cleaning and maintenance. So, studying and understanding the mechanism of bacterial cell adhesion to metal surfaces is becoming increasingly important. The present study attempts to define the parameters which affect the initial bacterial adhesion on titanium surfaces. We tried to get more details about bacterial attachment and biofilm formation for understanding and controlling these interactions in various technological areas such as biofouling or biocorrosion. Different electrochemical and thermodynamic techniques were used in this study and the results compared to data obtained by scanning electron microscopy (SEM) and confocal scanning laser microscopy (CSLM) to image the cell distribution and biofilm morphology. EDS analysis was also used to detect the elements that attached on the surface. The results showed that in the presence of bacteria, EOCV changes with exposure time and reached its highest value when the EPS and biofilm produced on the metal surface. EIS results show the different electrochemical behavior of biofilm formation in two strains. In the presence of PS strain, the biofilm formation results an electron transfer barrier between the redox probe and the electrode surface. While bacterial adhesion of PF strain can not hinder the movement of ionic charge in electrolyte, so the diffusion process takes place in the presence of this bacteria. The combination of surface tension and contact angle results verified the high adhesion rate of hydrophilic bacteria on hydrophobic surfaces when the surface tension of bacteria is less than suspending liquid. EDS analysis shows the deposition of K, Na and Ca cations on the metal surface in the presence of both strains. However the concentration of these ions in the presence of PF strain is much higher than PS strain. So, it can be concluded the first adhesion of PF strain has physical characteristic and is related to surface tension and deposition of ions on the metal surface. But the deposition of PS strain can affect the double layer capacitance and shows the electrochemical behavior. Two different models are suggested to explain initial adhesion and biofilm formation of PS and PF strains. The differences behaviors of these two strains are because of EPS production capability of PS strain and its biofilm degradation after 6 days.

Acknowledgments:

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2A - ORAL 10

BIOFILM FORMATION PROCESSES ON STEEL SURFACE REVEALED BY AFM

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Microbial induced corrosion (MIC) has created considerable interest in recent years. It is well known that MIC is caused by the biofilm, which consist of water, microbes, extracellular polymeric substances (EPS), and so on, in some cases, so that the control of biofilm formation is strongly desired. Kanematsu *et al.* have been reported that the biofilm was formed less on stainless steel or tin than on carbon steel. Atomic force microscope (AFM), by which the material surface not only in air but also in water is observed, can assist in understanding the initial stage of biofilm formation processes. In the present study, how to observe the biofilm formation process in water by AFM was examined. Alginate, which is the main component of EPS of *Pseudomonas aeruginosa*, has been used as a simulant of biofilm. Alginate gel was formed on the carbon steel SS400 when it was dipped in sodium alginate aqueous solution. So, alginate gel formation process in 1g L⁻¹ of sodium alginate aqueous solution has been observed in water by AFM, as shown in Fig. 1. It is found that small spots increase with time in height mode images. The scratches observed in height mode is not observed in phase mode, however, small spots are observed in both height and phase mode images. Phase mode images reflect to viscoelasticity of the material surface so that it can be deduced that small spots correspond to alginate gel formed. Carbon steel after biofilm formation from germs in air for 10 days using "circulation-type laboratory biofilm reactor"⁽¹⁾, was also observed, as shown in Fig. 2. There are many protrusions in the height mode image, but only the center protrusion has high viscoelasticity, suggesting that it is the biofilm.

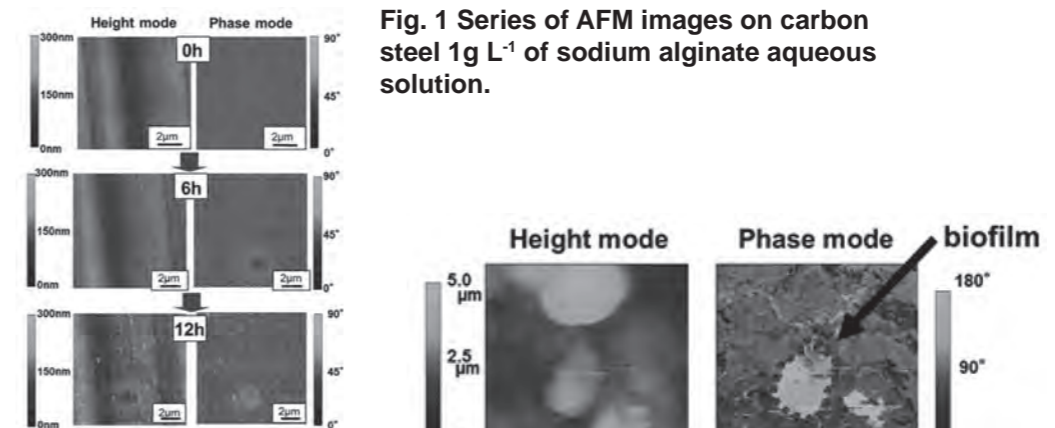


Fig. 1 Series of AFM images on carbon steel 1g L⁻¹ of sodium alginate aqueous solution.

Acknowledgments:

This work presented in this study has been partly supported by Grant-in-Aid for Scientific Research (C) (JSPS KAKENHI) Grant Number 25420795.

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2A - ORAL 11

POTENTIAL ANTIFOULING ACTIVITY OF TROPICAL MICROALGAE EXTRACTS FOR MARINE COATING APPLICATION

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BIOPAINTRIP is a multidisciplinary project with the goal of developing new environmentally friendly antifouling coatings based on biomolecules extracted from tropical marine microalgae. In this project, we study 50 microalgae species from the Western Indian Ocean. These benthic microalgae associated with various coral reefs' substrates (e.g. dead corals, reef macroalgae, turf, and sand) are of great interest for the investigation of new bioactive molecules which are potential candidates to replace the conventional chemicals.

The purification of dichloromethane-methanol extracts of microalgae via SPE chromatography yielded four fractions that are tested against pioneer bacteria from tropical and temperate zones responsible for marine biofouling, such as 4J6 (*Bacillus sp.*) 4M6 (*Paracoccus sp.*) and 5M6 (*Pseudoalteromonas sp.*).

Two *in vitro* experiments are used to evaluate the potential antifouling properties of microalgae extracts. Firstly, the bacterial adhesion on glass slides in a static system is studied. Secondly, the biofilm maturation is performed in flow cell under dynamic conditions with a constant flow of culture medium. It is applied for up to 24 hours to obtain a biofilm.

The MeOH100% microalgae extracts reveal an inhibition of adhesion and biofilm formation. Precisely, extracts of two microalgae, P-0044 (*Amphidinium massartii*) and P-0070, have a significant impact on 4J6 bacteria strains, while extracts of microalgae P-0078 (*Symbiodinium sp. clade D*) have a significant impact on bacteria 4J6 and 4M6 strains, respectively reducing 60.5% and 59.5% of their bacterial adhesion at a concentration of 50 µg/mL. The biofilm is altered also as shown in Fig 1.

Those promising extracts will be incorporated into paint formulations and into several panels that will be tested by static immersion in a photobioreactor, containing mixed biofilm forming species (microalgae and bacteria). Furthermore, an evaluation in the natural environment will be carried out according to the established method of evaluation. Those will serve as a basis for developing new antifouling coatings that can be used in temperate and tropical ecosystems.

Figure 1: Observation of 4J6 biofilm in a) standard conditions and b) with microalgae extract

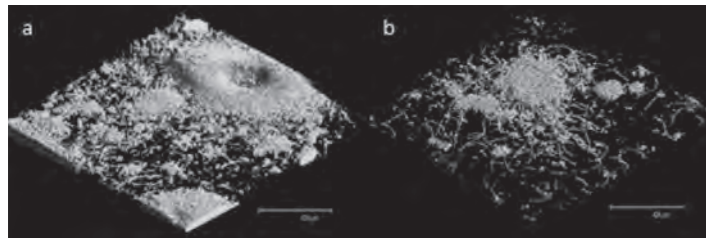


Figure 1: Observation of 4J6 biofilm in a) standard conditions and b) with microalgae extract

Acknowledgments:

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2A - ORAL 12

THE DEVELOPMENT OF DIATOM BIOFILMS ON FOULING-RELEASE COATINGS UNDER DYNAMIC CULTURE CONDITIONS

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Diatom slimes are a persistent problem on silicone-based elastomeric fouling-release coatings. Diatoms generally attach strongly to these low energy surfaces causing drag on the hulls of ships resulting in substantial economic losses. Laboratory methods to evaluate the fouling potential of diatoms on experimental coatings have concentrated on studies using single cells with short contact times (several hours) in static assays. Whilst these methods produce reliable data on cell attachment and ease of removal, the information they provide on predicting biofilm development is limited. Accordingly, a Perspex channel has been designed to enable diatom biofilms to be grown under different bed shear stresses (0-2.4Pa) on coated microscope slides. With this apparatus the adhesion of diatom (*Navicula incerta*) biofilms to PDMS has been investigated. Diatoms attached more strongly when cultured at higher shear stresses (1.3Pa). Preliminary studies indicate that biofilm development varies on different commercial silicone-based coatings. Cells form clumps on coatings that are more resistant to biofilm formation compared with a more even distribution on coatings that have inferior fouling-release efficacy. Results suggest that disruption of biofilm integrity is an important factor in releasing cells from the surfaces.

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**NEW APPROACHES FOR ANTIFOULING
SESSION CHAIR: PROFESSOR ROBERT LAMB
SURFACE SCIENCE & TECHNOLOGY GROUP, SCHOOL OF CHEMISTRY,
THE UNIVERSITY OF MELBOURNE, AUSTRALIA**

2B - KEYNOTE

SEAWATER ABUNDANT COPPER IONS - SELECTIVE AND EFFICIENT COPPER UPTAKE AND RELEASE AS A NEW ANTIFOULING MECHANISM.

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The average copper concentration in seawater is around 3 ppb¹ and up to 10 and even 114 ppb have been reported in a yacht basin in San Diego Bay² and coastal water of India³, respectively. Thus, metal contamination from antifouling coatings in marinas and harbours is of major concern.^{4,5}

Extraction of metals, especially uranium, from oceans has attracted scientific interest over the last century. Although the concentration of valuable metals in the oceans is typically very low, the vast abundance of water makes the total amount significant compared to minerals-based metals⁶.

Based on recent studies of copper selectivity and efficiency of polymer based coating materials we propose that natural abundant copper could also be the basis for a new antifouling mechanism. It is based on adsorption and release of naturally abundant copper ions. The technique comprises a coating that selectively adsorbs the naturally abundant copper and an on-demand electrochemical trigger that makes the copper release at extreme concentrations and thereby act as biocide.

Our results show that the concept holds significant promise, not only for marine biofouling prevention but also for water purification and sensing applications as well as extraction of copper from oceans.

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2BA - ORAL 1

COMPARATIVE ANTIFOULING PERFORMANCE OF SELECTED HYDROPHOBIC, SUPERHYDROPHOBIC, FLUOROCARBON AND NOVEL SURFACES

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We will present a study on the comparative performance of selected antifouling materials. Standard materials such as stainless steel, copper, glass, Teflon and commercial antifouling paints were directly compared to coatings with surface texture and chemistry specifically designed to improve resistance to marine biofouling. The advanced antifouling surfaces competitively evaluated included selected superhydrophobic, fluorocarbon, micro/nanotextured, and liquid infused porous materials. Surface energy and physical durability were used as the initial material screening criteria. Promising materials were then competitively evaluated in unfiltered seawater for resistance to marine biofouling. The initial antifouling performance of some novel polymer nanomaterial composite coatings will also be presented.

Acknowledgments:

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2B - ORAL 2

ELECTROACTIVE POLYMERS: A NEW ANTIFOULING CONCEPT FOR MARINE APPLICATIONS

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Biofouling is a natural process of colonization of any seawater submerged surfaces, involving a wide range of organisms from bacteria to invertebrates. In most marine applications, including transportation, aquaculture, offshore constructions, and *in situ* sensors, biofouling is regarded as a nuisance that needs to be eradicated or controlled. For the shipping industry, biofouling brings about high costs as it leads to increased maintenance and dry dock time as well as increased fuel consumption, which in turn cause environmental problems through increased emissions of exhaust gases. A thin slime coverage on a boat hull or an autonomous environment monitoring device can have a significant impact on the operational efficiency. Different antifouling approaches are applied to prevent and control biofouling. Techniques used or currently under development include (1) biocidal coatings [1], (2) PDMS-based fouling release coatings [2], (3) nanotextured or hierarchical slippery surfaces [3], (4) ultrasounds [4], (5) electrochemical methods, and (6) conductive coatings [6].

The aim of this research work is to develop new ecological antifouling coatings with no toxicants release. In this study, the inhibition of the adhesion of marine bacteria using poly(3,4-ethylenedioxythiophene) (PEDOT)-based coatings was studied. A laboratory assay using 96-well plates was performed to assess the activity of the electroactive coatings toward *Pseudoalteromonas* sp. isolated from the Mediterranean sea [7]. A screen-printed plate formed by 96 three-electrode electrochemical cells was used to (1) deposit the electroactive polymer by electropolymerization of 3,4-ethylenedioxythiophene on a carbon-based working electrode, (2) to record and control the redox properties of the electroactive coating during the bioassay, and (3) to carry out the anti-adhesion test and to assess the antibacterial activity of PEDOT-based coatings in the neutral state and oxidized state. First results showed a higher antibacterial activity when reversible reduction/oxidation cycles were applied.

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2B - ORAL 3

AERATION METHODS FOR IMPROVED HULL FOULING PREVENTION: USING STANDARD AIR AND LOW DOSE ELEMENTAL IODINE INFUSED BUBBLES FOR ENHANCED BIOLOGICAL INTERACTION

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Biofouling is a significant economic and ecological problem for the Navy and marine industries, impacting the functionality of vessels while underway and increasing drag, leading to increased fuel consumption and greenhouse gas emissions. Aeration is one environmentally-friendly and relatively inexpensive method for deterring the settlement of fouling organisms. This study assesses the use of standard air and iodine vapor bubbles as a method for the prevention of biofouling accumulation on vessel hulls. The inclusion of iodine vapor within the air bubbles may provide additional fouling prevention by reducing microbial counts, which are the primary fouling agents in the succession of macrofouling communities. Both aeration and elemental iodine have been shown to prevent fouling on submerged substrates; however this is the first study to combine the two methods for application in the marine environment. The efficacy of standard and iodine-infused aeration for fouling prevention will be assessed through a series of field experiments in summer 2014 in Narragansett Bay, Rhode Island using small-scale aeration system prototypes. Submerged test panels will be monitored for the establishment of biofilms and macroscopic fouling. Percent cover will be quantified by measuring the areas of fouling that accumulates on test panels over time. Preliminary results of the image analysis from the summer 2014 field monitoring will demonstrate the efficacy of both approaches by documenting the change in percent cover of biofouling over time between the two aeration systems. The goal of this research is to improve the Navy's current antifouling practices in a more cost-effective, environmentally friendly manner. Successful testing of the standard and iodine-infused aeration methods would lead to future efforts to transition from a prototype to a full demonstration scale-up on a vessel.

Acknowledgments:

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2B - ORAL 4

PHOTOSYNTHETICALLY-DRIVEN MARINE ANTIFOULING, PITTING NATURE AGAINST NATURE

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Materials that resist marine biofouling must possess a mode of action universal to all biota in aqueous environments. To date, only toxin-infused materials satisfy this criterion through the indiscriminate poisoning of all biota within its proximity. While this indiscriminate characteristic is the basis of its effectiveness, it also became the basis for extensive damage to ecosystems and its eventual ban. Current mitigation strategies have demonstrated limited success in specific conditions or against specific species, none of which exhibited broad-spectrum antifouling characteristics whilst maintaining a high degree of eco-friendliness. Here, we introduce a material that exhibits eco-friendly, broad-spectrum antifouling characteristics by harvesting and trapping photosynthetically generated air at the fluid/surface interface, thus establishing a physical barrier between aqueous biota and the surface. We demonstrate that only materials with nanoscale roughness exhibit this air harvesting and retention characteristics, which should revolutionize the design of future materials for underwater applications.

Acknowledgements:

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2B - ORAL 5

PREVENTION OF BIO-FOULING BY USING UV-LIGHT EMISSION OUTWARDS FROM THE SHIP HULL

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Anti-fouling solutions that release certain chemicals or biocides currently have a large market share. To be effective, these coatings have to provide an environment which is harsh for living creatures. A drawback is that over time – either by intended release, or by the inevitable cleaning of the surface – those chemicals are released into the water. These chemicals quite often remain active, causing adverse effects on the environment.

A fundamentally different way of preventing bio-fouling is by using UV light emission. UV light is known to be effective in de-activating or even killing micro-organisms, provided a sufficient dose of a suitable wavelength is applied. An example of such is ballast-water treatment.

We will present a new approach for anti-biofouling, in which an UV-light emitting layer is applied on the outside of the hull of a ship. The introduction of UV-LEDs as a light source enables thin, coating like structures, in which the UV light is spread evenly within the surface. Further optical design elements will ensure the light escapes more or less uniformly all over the coating layer. The UV emitting layer will make it impossible for micro-organisms to attach to the hull.

In an experimental setup, we have achieved promising results in keeping a surface free from bio-fouling for an extended period of time.



Figure 1. Three test samples. Left: sample before test. Middle: reference sample without UV light emission, after 4 weeks in water. Right: sample with UV light emission after same time period.

2B - ORAL 6

TEXTURED, BIOCIDAL ANTIFOULING SURFACES FABRICATED FROM PHOTOLITHOGRAPHY WAFERS

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Rapid prototyping methods and additive manufacturing methods were assessed with a view to producing tailored antifouling surfaces. One of the most promising of these is photolithography, which has the capacity to generate complex nano- and micro-structured patterns on a repeating or hierarchical scale. The major limitation of the technique is the restriction in size of the patterned area, which is generally restricted to less than a few cm. Nonetheless, recent investigations have focused on the up-scaling of the method to produce larger areas and reduce pattern writing times even further.

Silicon wafers (dimension: 1 mm thick and 10 cm wide) were cleaned in acetone and methanol, and deoxidized in hydrofluoric acid. They were spincoated with a hexadimethylsiloxane adhesion layer and 1.5 µm thick layer of photoresist (S1818, Shipley). The pattern was transferred using ultraviolet lithography, and the resist was developed for 60 s in Microposit MF319. The pattern was etched into the silicon substrate using SF₆/C₄F₈ chemistry in an ICP reactive ion etch (STS ASE), and the resist was removed. Finally, the wafers were coated in a monolayer of (tridecafluoro-1,1,2,2-tetrahydrooctyl)trichlorosilane by vapour-phase evaporation, to produce a non-adhesive surface.

Wafers were produced containing nine arrays of surface textures, including pillars and indents from 2-100 µm in diameter, with a pitch of between 3-6 times the diameter. An acrylic (pMMA) negative of these surfaces was produced via in-situ addition polymerization on the wafer. A set of samples was also produced containing 1% w/w capsaicin as an antibacterial additive. We will demonstrate the results from the characterization of the surfaces and the replicas, and the results from the 2014 fouling season will be discussed. In addition, the future possibilities of up-scaling this technology to larger areas will be explored, as well as the production of complex hierarchical surfaces after this proof-on-concept study.

2B - ORAL 7

ANTIFOULING PROPERTIES OF SELF-ASSEMBLED HONEYCOMB-STRUCTURED POROUS FILMS AGAINST BARNACLES

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Barnacles are popular marine sessile organisms, and they cause serious economic problems due to settle onto submerged surfaces such as ship hulls, fishnets and intake channels of power plants. Tributyltin (TBT) based antifouling paints are effective at reducing a number of barnacles settlement. However, TBT have a highly toxic to marine life. Several studies have demonstrated the antifouling potential of microstructured surfaces to the adhesion of marine sessile organisms [1]. Recently, we developed self-assembled honeycomb-structured porous films (Figure1) by casting a polymer solution of polystyrene and amphiphilic copolymer under humid conditions [2]. This is a low cost and easy method to make microstructured surfaces. In this study, we prepared the honeycomb-structured and pillared-structured surfaces, and then we investigated antifouling properties of these surfaces against barnacle in laboratory environment. In this study, we investigated the effects of microstructures against settlement of barnacles. In the results, honeycomb-structured surfaces reduced the barnacles settlements compared to flat and pillared surfaces. Furthermore, the antifouling effect of honeycomb-structured surfaces was increased with the increasing pore size of honeycomb. In pre-settlement stage, barnacle cypris larvae explore on substrates with their two sensory organs. The exploring behavior has been considered to determine the suitable substrate for their settlement. To investigate the antifouling mechanism of honeycomb-structured surfaces, we analyzed cypris exploring behavior on microstructured surfaces with image analyzing software. From the results of exploring behaviors, few exploring behaviors were found on the honeycomb surface. Furthermore, on the honeycomb surface, most of non-settled cypris quit the exploration in the early stage compared to other surfaces. The result indicates that barnacle cypris larva hard to explore on the honeycomb and consequently the honeycomb shows antifouling activities.

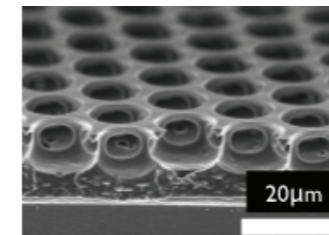


Figure 1 The SEM image of self-assembled honeycomb-structured porous film

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2B - ORAL 8

THE DEVELOPMENT AND ANTIFOULING EVALUATION OF HIERARCHICAL MACRO AND MICRO TOPOGRAPHIES DEVELOPED WITH BENCHTOP METHODS FOR MARINE ANTIFOULING APPLICATIONS

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Surface topography is one of many factors that influence the settlement trends of marine organisms. Many studies using non-toxic, chemically inert materials have investigated the efficacies of antifouling topographies; however, current topographic designs have had limited success because they are unable to deter fouling from a broad range of organisms. An analysis of the literature suggests that hierarchical topographical structures could potentially mitigate fouling from a wide array of fouling organisms. This study aims to develop and evaluate the long term, antifouling performance of hierarchical structures against fouling by a range of marine foulers. Various lithography techniques are suitable but making micro structures can be technically challenging and expensive. This research uses affordable benchtop methods to develop non-toxic antifouling topography. Hierarchical macro topographies (0.5mm – 1mm) were developed via laser ablation and direct molding. To date, hierarchical micro topographies with average widths of 50 to 100 microns were developed with several steps of photolithography, soft lithography and subsequent template replication. Photomasks were made by printing patterns onto transparency films with a high resolution inkjet printer and a fully patterned 10cm by 10cm area has been successfully developed. Observations under a light microscope and SEM showed that developed patterns exhibit an adequate degree of fidelity suitable for antifouling studies. Field tests are carried out continuously over several months at Meishan island, northeast of Ningbo adjacent to the East China Sea. Results from the field tests that compares the antifouling performance of hierarchical structures with smooth controls will be reported.

2B - ORAL 9

STUDY ON BIOMIMETIC OF SHELL SURFACE MICROSTRUCTURE FOR SHIP ANTIFOULING AND DRAG REDUCTION

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Antifouling and drag reduction of ships are two critical issues of great interest to the shipping industry, and thus advanced technologies in these areas are in great demand. There are a lot of marine organisms living in the ocean, but many marine organisms such as Crabs, Sharks, Dolphins and some kinds of *Mytilus edulis*, are rare to be adhered to shell or skin although living in sea water all day long. Therefore, it is becoming one of the future directions to develop environmental friendly antifouling technologies to study the physical morphology, microstructure and physiological status of shells or skin of these kinds of organisms, and to imitate similar surfaces. In most studies on surface microstructure of biomimetic antifouling technology, sharks have been well studied as a biomimetic object for prevention of marine biofouling. For ships, the quantity of bioaccumulation was proportional to the time of the ship in port in operation, that is, bioaccumulation would occur and fouling organisms would be gathered on the hull under static and low flow conditions, and there was little biofouling on the hull while sailing fast. Since the living condition of shells was very close to the condition of ship fouling occurrence, shells would be a perfect choice as biomimetic objects. Therefore, this study will take shell as a biomimetic object to analyze the antifouling performance of its surface microstructures, and then obtain the range of microstructure patterns and scales with antifouling performance. The numerical simulation analysis will be next adopted to investigate the drag reduction features within the range of microstructure patterns and scales rewarded with antifouling performance to determine the scale range for both antifouling and drag reduction together. The samples of the microstructure patterns and scales with both antifouling and drag reduction will be prepared using bio-replica method and coating technology respectively. Their antifouling and drag reduction performances will be verified using a series of experiments. The corresponding explanations and mechanisms will be gained and presented in the paper, which will contribute to the potential solution of antifouling and drag reduction in green ship field.

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ADVANCES IN COATING TECHNOLOGY

SESSION CHAIR: PROFESSOR DEAN WEBSTER

CHAIR, DEPARTMENT OF COATINGS AND POLYMERIC MATERIALS, NORTH DAKOTA STATE UNIVERSITY, UNITED STATES

2B - KEYNOTE

HYDROGEL-BASED FOULING CONTROL COATINGS

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Due to their very low surface energy and high elasticity, Fouling Release coatings have, historically, been based on polydimethylsiloxane binders. Additives of low surface energy polymers, such as phenyl modified polysiloxane oils were implemented to sustain the low surface-energy of the coatings and prolong the fouling release performance. However, these early Fouling Release coatings came out short against biofouling when seawater exposure exceeded one year [Yebra et al. 2004 and Yebra and Catalá 2011].

In 2008, Hempel A/S launched a hydrogel-based Fouling Release coating inspired by biomedical research. To increase biofouling resistance, these coatings contain a hydrophilic modified silicone polymer that migrates to the surface upon immersion and creates a hydrogel layer at the outermost surface of the coating. The hydrated layer of the hydrogel-polymers can be considered similar to the co-existence of water and ice at low temperature [Yebra and Catalá 2011]. Water trapped in this layer exhibits a gradient from liquid water to more gel-like, trapped water. The antifouling performance of such a surface has been proved to overperform conventional and alternative technologies significantly [e.g. Zhang et al. 2013, Zargiel and Swain 2012, Scardino et al. 2012, Zargiel et al. 2011].

Clean Fouling Release coatings are known to have improved fuel-efficiency over conventional antifouling coatings [Schultz 2007]. This is due to the smoothness and lower friction coefficient generally associated with silicone coatings [Yebra and Catalá 2010]. However, all Fouling Release systems to date tend to decline in performance over a five-year operational period to a higher or lower degree. This diminishes the overall fuel-efficiency of the silicone coatings over extended immersion periods. Further improvement of the performance has therefore been needed to prolong the fuel-efficiency.

Biocide-release from Fouling Release coatings has, until recently, not been possible because only low amounts of biocides can be used in a silicone coating in order to maintain surface smoothness, and biocides release rapidly from the silicone matrix. With the introduction of the ActiGuard® technology, it has become possible to exploit biocides in silicone-based coatings and thereby extend the fouling-free period of these types of coatings. This results in a significantly prolonged fuel-efficiency of the silicone based coatings with a minimum amount of biocide.

This presentation will give an introduction to the hydrogel-based fouling release technologies, introduced in X3 and leading up to the ActiGuard® technology. The unique features of combining hydrogels and biocides in a silicon-based coating will be disclosed together with a description of the working mechanism and performance of the technology.

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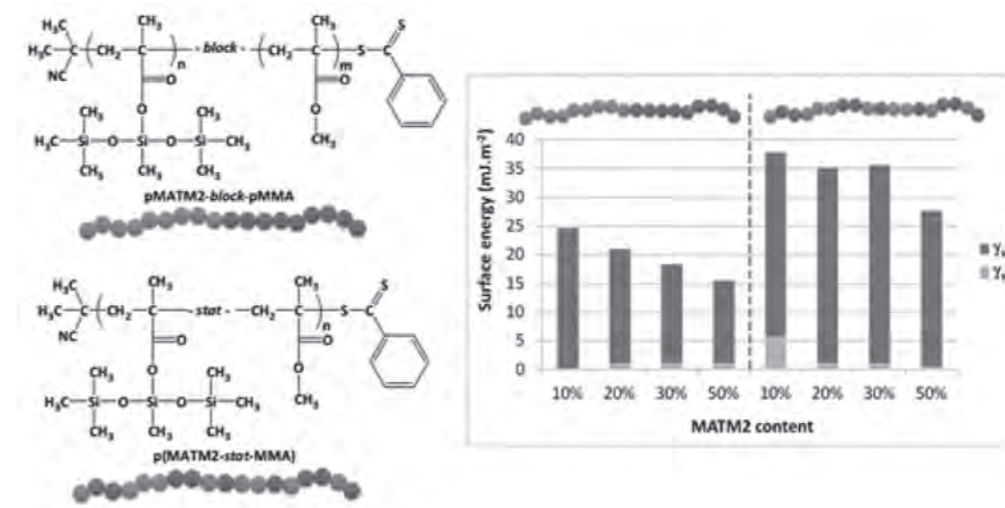
2B - ORAL 1

RAFT-SYNTHESIZED HYDROLYZABLE DIBLOCK COPOLYMERS WITH LOW SURFACE ENERGY: NEW POLYMER BINDERS FOR FRC/SPC HYBRID ANTIFOULING COATINGS

Marlène Lejars, André Margailan, Christine Bressy
Université de Toulon, Laboratoire MAPIEM, EA 4323, 83957 La Garde, France.

In this study, new polymer binders were developed based on bis(trimethylsiloxy)methylsilyl methacrylate (MATM2), a hydrolyzable monomer containing a silylester and a siloxane group. Their use in antifouling coatings makes possible to combine the hydrophobicity of polysiloxanes (used in Fouling Release Coatings, FRC¹) and a controlled erosion of the coating (like Self-Polishing Coatings, SPC²). These so-called FRC/SPC hybrid coatings enable to increase the efficiency of FRCs during idle periods and at low ship speeds and to limit the use of biocides.

Statistical and diblock copolymers based on MATM2 and methyl methacrylate (MMA) were synthesized by the RAFT process, using 2-cyanoprop-2-yl-dithiobenzoate as chain transfer agent, resulting in copolymers with predictable molar masses, closed to the targeted values, and low dispersities.³ Contact angle measurements revealed the influence of the copolymer microstructure on their surface energy, with diblock copolymers exhibiting much lower surface energies (as low as 15.6 mJ.m⁻²) than statistical copolymers. They were used as polymer binders for the development of antifouling coatings with no biocide (or low amounts). Good antifouling performances were observed after 7 months of immersion in the Mediterranean Sea.



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Acknowledgments:

The work presented in this study was funded by the French Department of National Defence.

2B - ORAL 2

FABRICATION ON AN ANTIFOULING COATING WITH LOW SURFACE ENERGY AND A BIO-INSPIRED MICROSTRUCTURE

Yunqiu Li, Chao Liang, Junyi Song, Biru Hu, Wenjian Wu

Department of Chemistry and Biology, College of Science, National University of Defense Technology, Changsha, Hunan 410073, China

In response to the great harm caused by biofouling and an urgent demand for environmental protection, we describe a new nontoxic, broad-spectrum antifouling coating.

This paper reports a novel antifouling coating combining the merits of a low surface energy and a bio-inspired surface microstructure. A novel polymer with a low surface energy was synthesized by integrating the characteristics of both silicone and fluoropolymers; its adhesion force and water resistance are improved greatly by an organic-inorganic hybrid preparation process. Then, a micro-nano binary structure was constructed on the surface of the coating by doping silica nanoparticles in the polymer. Therefore, the coating combines the advantages of a low surface energy and a microstructure, which will assist in antifouling.

The contact angle was used to characterize the surface energy of the composite coating, and its antifouling performance was determined by the seawater immersion test. The results showed that the contact angle of the new polymer was 103°, which is much higher than that normally displayed by both silicone and fluoropolymers. The composite coating possessed a still higher contact angle, up to 150°. The seawater immersion test results show the coating has excellent anti-fouling effects over short-time periods, but its application for long-term anti-fouling needs further investigation.

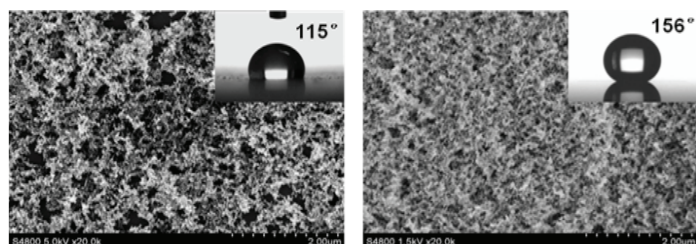


Fig.1 micro-nano binary structures of coating

Acknowledgments:

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2B - ORAL 3

SURFACE CHARGE TUNING OF LAYER-BY-LAYER ASSEMBLY FOR MARINE ANTIFOULING APPLICATIONS

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The fouling behaviours of cyprids and bacteria on the layer-by-layer (LbL) films with similar hydrophilicity and roughness but different charges were studied. Surface charge of assembled LbL polyelectrolyte films were precisely tuned based on the different ionization degree of weak polyelectrolytes at various pH values; due to the certain charge of the underling layer, the quantity of the weak polyelectrolyte deposited was adjusted by assembly pH, which determined the net charge of the fabricated LbL film. The barnacle settlement results indicated that much more cyprids settled on the negatively charged LbL film than neutral and positively charged LbL films. The cyprid footprint proteins modified colloid probe approaching test on these charged surfaces by AFM revealed that the proteins of cyprid footprint were positively charged. However, in the bacteria adhesion tests, more bacteria were observed on the positively charged surface than the neutral and negatively charged surfaces because of the negative charge from the bacterial cell wall. It seems the neutral surface with zero net charge exhibited a relatively universal antifouling effect against various foulants.

Acknowledgments:

The authors are grateful to the Agency for Science, Technology and Research (A*STAR) for providing financial support under the Innovative Marine Antifouling Solutions (IMAS) program.

2B - ORAL 4

SELF-POLISHING ULTRA LOW FOULING ZWITTERIONIC-BASED MARINE COATINGS

Shaoyi Jiang

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In this talk, I will update our efforts to study the interactions of zwitterionic-based ultra low fouling materials and surface coatings with biomolecules and microorganisms, discuss new design principles for the design of biomaterials, and introduce several new types of zwitterionic materials for biofouling control.

I will highlight our efforts towards the development of non-toxic, durable, effective, and low-cost coatings, particularly several strategies for self-polishing/nonfouling coatings. Biomolecules and marine microorganisms cannot attach onto these self-polishing/nonfouling coatings for a long period of time. These coatings are as effective as anti-fouling coatings, but do not contain or leach any metal ions or biocides while they are much more effectively than conventional fouling-release coatings, particularly at low ship moving speeds. Several formulations have been developed and tested in both laboratory and field tests. The key parameters to achieve excellent performance will be discussed.

2B - ORAL 5

NEW ZWITTERIONIC AND ION PAIR POLYMERS: SYNTHESIS TO EVALUATION AS ANTIFOULING POLYMERS IN THE MARINE ATMOSPHERE

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Ionic polymers, which could also be termed as polyelectrolyte, polyampholyte etc. are extremely important for a diverse range of applications. Application of synthetic ionic polymers include viscosity modifier, ion conducting polymers, polymeric surfactant, hydrogel, for enhanced oil recovery etc. In this present study we mainly targeted to develop nontoxic marine anti-biofouling technology and specifically in absence of commonly used toxic metallic or organic biocides in free or polymeric form. Hydrophilic ionic polymers are well known for the formation of hydration layer when present on a film surface and are reported to be antifouling towards proteins, diatom and marine spores etc. and are mostly tested in laboratory set up. However our present effort will disclose design and synthesis of some new type of zwitterionic¹ and ion pair monomers² and polymers therefrom and their evaluation in the real marine environment. Additionally other possible applications of these zwitterionic and ion pair polymers will be discussed in brief.

Acknowledgments:

This work presented here was funded by Agency for Science, Technology and Research (A*STAR), Singapore, under Innovative Marine Antifouling Solutions (IMAS) for high value applications programme. The authors gratefully acknowledge the help of Dr. Serena Lay-Ming Teo, Mr. Lim Chin Sing and Mrs. Lee Siew Chen Serina of Tropical Marine Sciences Institute (TMSI) under National University of Singapore for antifouling studies.

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2B - ORAL 6

"LOW FOULING" AND "HIGH FOULING-RELEASE" ZWITTER/PDMS MARINE COATINGS

Xuewei Xu, Yuting Li

Zwitter Technology, LLC, New Ventures Facility, Fluke Hall,
4000 Mason Road, Seattle, WA 98195-2141

A novel marine coating with both "low fouling" and "high fouling-release" properties was developed. These two properties usually compromise each other and the presence of both is difficult to achieve because "low fouling" property conventionally requires a hydrophilic surface (high surface energy), while the "high fouling-release" property usually derives from a hydrophobic surface (low surface energy). In this work, a "non-fouling" zwitterionic material, e.g., poly(carboxylbetaine methacrylate) (PCBMA), was successfully introduced into a "fouling-release" polymer, e.g., poly(dimethylsiloxane) (PDMS), to generate an integrated marine coating. The PCBMA polymers on the coating surface are able to efficiently prevent foulant settlement, leading to the "low fouling" property. At the same time, the PDMS background retains low surface energy, leading to the "high fouling-release" property. Marine laboratory tests revealed that the zwitter/PDMS coating can resist up to 80% of *Ulva* spore settlement and can release 100% under the wall shear stress of 8 Pa. Field tests showed that the pressure for the release of attached biofilm is about 60 psi, which is significantly lower than many existing "fouling-release" coatings. Field tests further showed that the zwitter/PDMS coating is able to last at least 8 and half months while remaining high "fouling-release" property. All the results have indicated that a low-cost, easy-made, durable, effective and environmentally benign marine coating with both "low fouling" and "high fouling-release" properties has been successfully achieved.

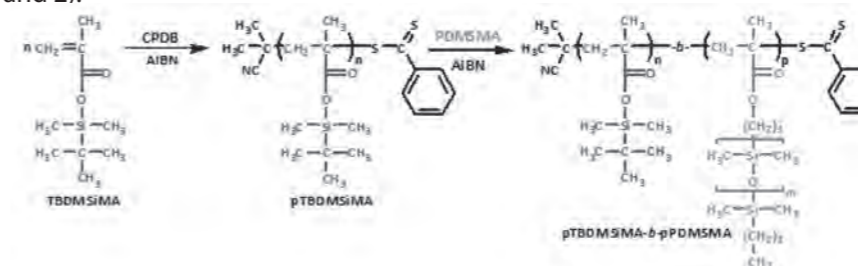
2B - ORAL 7

SEAWATER HYDROLYZABLE GRAFT AND BLOCK PDMS-BASED COPOLYMERS: HOW DOES THE ARCHITECTURE AFFECT THE ANTIFOULING PERFORMANCES OF COATINGS

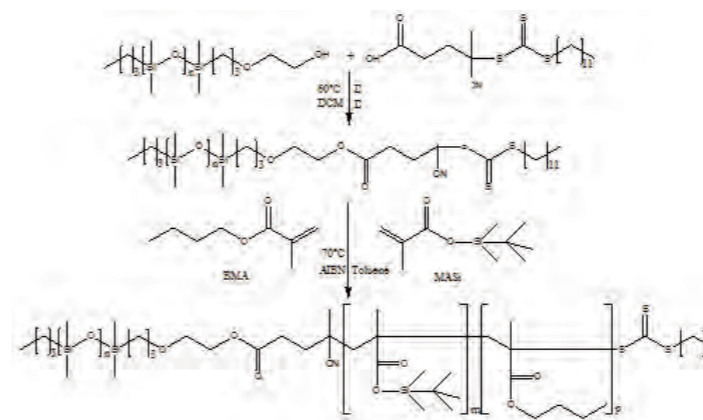
André Margaillan^a, Marlène Lejars, The Hy Duong^a, Christine Bressy^a^aUniversité de Toulon, MAPIEM, EA 4323, 83957 La Garde, France

Antifouling coatings must be applied on ship hulls to avoid their colonization by marine organisms (molluscs, algae). The most used are the Self-Polishing Coatings (SPC) whose efficacy relies on the release of toxic biocides by a controlled erosion of the surface.[1] Their polymeric binder contains hydrolyzable units such as trialkylsilyl methacrylate whose hydrolysis in seawater influences the binder solubility and consequently its erosion upon time. Emerging non-toxic coatings are the Fouling Release Coatings (FRC) based on a poly(dimethylsiloxane) (PDMS) matrix, without biocides. They limit the fouling adhesion strength owing to their low surface energy, resulting in the easy removal of fouling organisms at ship speed higher than 8 knots.[2]

In this study, FRC/SPC hybrid polymer binders, based on *tert*-butyldimethylsilyl methacrylate (SPC type) and PDMS (FRC type) have been synthesized by the RAFT process (Radical Addition-Fragmentation chain Transfer). Well-defined copolymers were prepared with controlled molecular weights and narrow distributions (PDI < 1.2). Two types of architecture were synthesised: PDMS is present in the side chain or in the main chain (schemes 1 and 2).



Scheme 1. Synthesis of pTBDMSiMA-b-pPDMSMA diblock graft copolymers by the RAFT process in the presence of 2-cyanoprop-2-yl dithiobenzoate (CPDB) as chain transfer agent, azobisisobutyronitrile (AIBN) as initiator, at 70°C, in xylene.



Scheme 2. Synthetic pathway of macro-RAFT agents and diblock copolymers, i.e. PDMS-b-P(MASi-stat-BMA)

The PDMS chains distribution, length and type of architecture were shown to be significant parameters influencing the low surface energy of the copolymers and their erosion properties in artificial seawater. These copolymers were used as binders for the formulation of environmentally friendly antifouling coatings, with no biocides.

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2B - ORAL 8

COMPARISON OF THE BIOLOGICAL PROPERTIES OF PEGYLATED AND FLUORINATED SILOXANE BLOCK COPOLYMERS DISPERSED IN A PDMS MATRIX

Elisa Martinelli¹, Brandon Wenning¹, Giancarlo Galli¹, Maureen E. Callow², James A. Callow², Alessio Di Fino³, Anthony S. Clare³

¹Department of Chemistry and Industrial Chemistry and ISTM UdR Pisa, University of Pisa, Italy, ²School of Biosciences, University of Birmingham, UK, ³School of Marine Science and Technology, Newcastle University, UK

Currently, the most successful technologies that control fouling without the use of biocides include fouling-release coatings based on polydimethylsiloxane (PDMS) elastomers.¹ Recent research has focused on improving their performance by the incorporation of oils, nanofillers, tethered antimicrobials and surface-active copolymers.²

Following this last strategy, we designed and synthesized two different classes of block copolymers by atom transfer radical polymerization (ATRP) of a hydrophilic PEGylated methacrylate and a hydrophobic/lipophobic fluorinated acrylate, starting from a polysiloxane macroinitiator (Fig. 1). The copolymers were dispersed in a bis(silanol)-terminated PDMS matrix that was then cross-linked by a sol-gel condensation reaction in order to obtain elastomeric coatings with low surface energy properties. Different proportions of the surface active block copolymer were loaded in the PDMS to tune the amphiphilic balance of the surface segregated coatings. The curing reaction was catalyzed by bismuth neodecanoate, thus avoiding toxic organotin catalysts.³

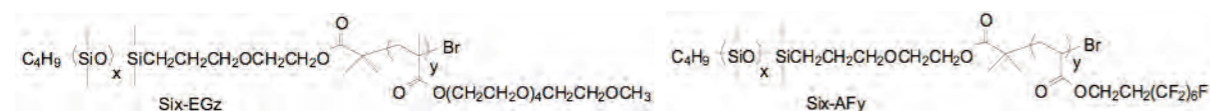


Figure 1. Chemical structures of the PEGylated (left) and fluorinated (right) block copolymers.

Laboratory bioassays showed that the incorporation of the different block copolymers into the polymer matrix resulted in distinct biological performances against the tested organisms, viz. the macro-alga *Ulva linza* and the barnacle *Balanus amphitrite*. In particular, the results highlighted the selectivity of these organisms in their preferences to interact with certain surfaces. *Ulva* sporelings were found to attach much more strongly to fluorinated siloxane surfaces, compared to the PEGylated siloxane counterparts. On the other hand, barnacle larvae were able to settle only on PEGylated surfaces, no cyprids being detected on fluorinated coatings after 48 hours. However, once the larvae became juveniles, they were removed more easily from PEGylated surfaces than the PDMS control.

Acknowledgments:

Funding of the work from the EU-FP7 Marie Curie ITN 'SEACOAT' and the Italian MIUR (PRIN 2010-11) is gratefully acknowledged.

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NEW METHODS FOR EVALUATION OF ANTIFOULING SESSION CHAIR: PROF AXEL ROSENHANN ANALYTICAL CHEMISTRY – BIOINTERFACES, RUHR-UNIVERSITY BOCHUM, GERMANY

2A - KEYNOTE

QUANTIFYING CYPRIDS' BIORESPONSE AS A PERFORMANCE-RELEVANT MEASUREMENT OF ENGINEERED SURFACES

Dr William R. Birch

Institute of Materials Research and Engineering, Agency for Science Technology and Research, A*STAR, Singapore

Cyprid settlement has been used as a targeted single-species assay, designed to measure the fouling-resistance performance of engineered surface properties. This single-parameter measurement offers a quantifiable measure of the cyprids' bioresponse that is less complex than surface colonization by multiple organisms, as generated by a marine field-test assay. The present talk will describe quantifying the cyprids' exploration walk, which is regulated by cyprid/surface interactions and thus offers insights into the evolution of a process that putatively determines their settlement. Anchoring points, formed by cyprids exploring engineered surfaces, can be imaged in a controlled environment, either under static conditions or in the controlled shear provided by a microfluidic channel. On model surface chemistries, significant variations in quantifiable step parameters correlate with the cyprids' surface affinity. Cyprids exhibit distinct preferences for the location of their anchoring points when exploring patterned microstructures, consisting of pillars with tuneable dimensions. The exposure of cyprids to ultrasound, a fouling deterrent, has been shown to significantly alter their exploration behaviour. A recent adaptation of the assay configuration for planar substrates enables the observation of cyprids exploring surfaces of widely differing wettability, either within the bulk water phase of whilst confined to the air/water interface by wetting forces. These methods quantify several performance-relevant parameters, thus facilitating a multi-faceted evaluation, to discern the engineering criteria for fouling-resistant surfaces.

This work is supported by the Innovative Marine Antifouling Solutions for High Value Applications (IMAS) Program, funded by the Science and Engineering Research Council of A*STAR.

2A - ORAL 1

A LABORATORY BASED BIOFILM ASSAY AND THE DEVELOPMENT OF ADVANCED "SLIME" RELEASE COATING TECHNOLOGIES

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The R&D cycle for new fouling control coating technologies is long and complicated and it can often take up to 10 years or more to travel from concept to commercialisation. New approaches and test methods are therefore required to allow rapid, representative and predictive screening of performance levels and lifetimes of experimental candidate materials in order to accelerate the R&D cycle.

This presentation will describe a bespoke biofilm culture method which can be used as a low cost, laboratory-based assay. The method has been used to efficiently screen several hundred candidate materials allowing down-selection of promising prototypes which were then subject to a battery of testing using more established test protocols. In doing so, biofilm release efficacy has been shown to be an indicator of effectiveness (deterrence and release) against weed and hard fouling organisms and it has additionally been proven that the short timeframe assay corresponds to long term in-field performance on in-service marine vessels.

The value and utility of the method will be illustrated by its contribution to the development of Intersleek®1100SR, a new foul release coating with enhanced micro and macrofouling release characteristics.



Fig 1. Biofilm culturing reactor

2A - ORAL 2

INTEGRATION OF AN IMAGING SPR FACILITY IN A TIRF MICROSCOPE – IMPROVED SPATIAL RESOLUTION AND COMPLEMENTARY DATA IN REAL-TIME, LABEL-FREE IMAGING OF BIOADHESION PROCESSES

Thomas Ederth¹, Samira Barhemat¹, Roni Nugraha¹, Wetra Yandi¹

¹Division of Molecular Physics, IFM, Linköping University, SE-581 83 Linköping, Sweden

Marine organisms have developed a multitude of strategies, mechanisms and chemistries for attachment to solid surfaces. Considerable efforts are made to identify and understand the processes involved in temporary and permanent adhesion to surfaces, and are motivated by, for example, a wish to reduce the use of biocides in antifouling coatings in favour of other, more environmentally benign methods, or the desire to exploit the excellent underwater performance of marine adhesives in biomedical or technological applications. Since many fouling organisms, including macrofoulers, have microscopic planktonic dispersal stages, good microscopes and microanalytical techniques are essential for these studies.

Imaging Surface Plasmon Resonance (iSPR) is a technique utilizing electronic excitations at metal-dielectric interfaces for real-time and label-free detection of distributed surface interaction or adsorption events, and has been successfully applied to studies of barnacle cyprids [1]. We have integrated an iSPR facility into a commercial Total Internal Reflection Fluorescence (TIRF) microscope, thus greatly expanding the suite of imaging methods available to complement iSPR data. TIRF and iSPR are both surface sensitive methods relying on total internal reflection, but where the former is a fluorescence method, the latter is label-free, capable of real-time imaging of surface interactions or deposition of material, as well as quantification of the deposited amounts. Beyond mere integration of iSPR with traditional imaging techniques such as phase contrast, darkfield or epifluorescence microscopy, this arrangement enables, for example, simultaneous monitoring of exploratory behaviour and localization and quantification of adhesive deposits, and subsequent *in situ* identification using fluorescent antibodies (or *ex situ* Raman or XPS analysis).

Resolution in iSPR is limited by the lateral extent of a surface plasmon (several μm), and we also demonstrate how imaging resolution can be improved by the use of surface plasmons localized to metal nanoparticles in surface arrays, where the lateral extent of the plasmons, and thus the limiting resolution, is determined by the interparticle distance.

We anticipate that this combination of methods will greatly facilitate detailed *in situ* studies of the establishment of adhesive joints, and provide tools for investigating, for example, how temporary adhesives are used to probe surface properties during exploratory behaviour, or to establish correlations between surface physicochemical properties and quantitative and qualitative properties of adhesive deposits. We demonstrate the capability of this microscope using some marine model fouling organisms.

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2A - ORAL 3**LOW EMISSION ANTIFOULING (LEAF) PROJECT: DEVELOPMENT OF AN ANTI-MACROALGAL ASSAY BASED ON ENZYME INHIBITION**

G. Id Daoud, R. Trepos, E. Beach, C. Helliou¹

¹UOP, University of Portsmouth, School of Biological Sciences, UK

Assessing the inhibition of macroalgal spores adhesion and settlement is a key stage in the search for potent antifouling (AF) compounds. However, suitable spore-producing biological material is only available during limited seasons, i.e. spring/summer in temperate regions. In addition, induction of sporulation is often unpredictable and many environmental factors can affect the yields of spores available to conduct a bioassay, which are furthermore very fastidious as they rely on spores counting. To circumvent the season-constraints and technical difficulties, we have focus on the biochemical processes involved in the adhesion mechanism that lead to the establishment of spores on surfaces. Peroxidases enzyme mediate the cross-linking of secreted phenolic polymers such as soluble phlorotannins in the presence of hydrogen peroxide and halide ions. The adhesive then results from macromolecular scaffolds between the oxidized phenolic polymers and cell wall alginates. Our work demonstrate the importance of bromoperoxidase (BPO) in the adhesion process of *Ulva linza* (Chlorophyta), *Porphyra* sp. (Rhodophyta) and *Undaria pinnatifida* (Phaeophyta), showing that this enzyme is conserved amongst taxonomic classes. Thus, a high-throughput multiwell continuous BPO kinetic analyses was set up using both the commercially available BPO (purified from *Corallina officinalis*) and BPO purified from our 4 models organisms: effects of known antifouling compounds and inhibitors of BPO were assessed. Results demonstrate a correlation between inhibition of adhesion and inhibition of BPO, thus our new develop biochemical method can be use as a new, fast, season-free and universal bioassay targeting macroalgae.

Acknowledgments:

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007- 2013) under grant agreement n° 314697.

Project name: LEAF - Low Emission Anti-Fouling project

PLENARY**PLENARY 2****DESIGNING SMALL STRUCTURES TO CONTROL MARINE CORROSION**

Dr Harvey Hack

NACE International, United States

This paper describes the important considerations for designing structures, especially small objects and mechanisms, which will be employed underwater for extended periods of time. Methods of corrosion control for underwater systems are described, including specific details for those that are of most use underwater.

These include maintenance and operation, materials selection, corrosion allowance, design considerations, environmental modification, cathodic protection, and coatings.

The underwater performance of the major metal types and the major types of hardware are also described, as are brief descriptions of performance of specific non-metals.

Finally, a series of underwater design rules of thumb are presented.

MICROBIOLOGICALLY INFLUENCED CORROSION
SESSION CHAIR: A/PROFESSOR DANIEL BLACKWOOD
DEPARTMENT OF MATERIALS SCIENCE & ENGINEERING,
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3A - KEYNOTE

POTENTIAL ENNOBLEMENT OF STAINLESS STEEL IN NATURAL SEAWATER

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Stainless steels are widely used for different applications in seawater in the oil and gas and desalination industry. It is well known that the corrosion potential of stainless steel shifts to the noble direction (ennoblement) when exposed to natural seawater. The other significant effect of the biofilm on metallic surfaces is a dramatic increase of the cathodic efficiency (e. g. cathodic reduction of dissolved oxygen), promoting the corrosion reactions and increasing the rate of corrosion propagation. Although, this has been widely studied in natural seawater at temperature ranging from 15°C to 40°C, very little is known on the effect of temperature (in a wider temperature range), dissolved oxygen content and chlorination level on the corrosion potential and the cathodic efficiency of stainless steel in natural seawater. In this paper we will report corrosion potential and cathodic efficiency of stainless steel as a function of temperature (e.g. from 5°C to 70°C), dissolved oxygen content (e.g. from 20 ppb to saturation) and chlorination level (from 0 to 10 ppm). The results will be discussed in terms of risk for crevice corrosion and bi-metallic corrosion when coupling to other materials. In addition results from exposure in tropical sea will be presented and compared to that of temperate seawater heated at the same temperature. The results will be discussed in terms of risk for crevice corrosion.

3A - ORAL 1

IS THE ENZYME ACTIVITY IN MARINE MICROBIAL BIOFILMS A RELIABLE INDICATOR FOR A TEST SYSTEM TO IDENTIFY MICROBIAL INFLUENCED CORROSION IN AN EARLY STAGE?

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A differentiation between galvanic and microbial influenced corrosion (MIC) in the monitoring of hydraulic steel structures is rare because of the lack of a low-cost and easy-to-use detection procedure. Added to this financial costs of offshore repair and maintenance are economical drivers for the early detection of MIC. Extracellular molecules are important indicators in corrosion processes of steel. Therefore it is a viable way to use the detection of these molecules for the corrosion monitoring.

Laboratory-based tests with structural steel in microcosms are used to simulate corrosive environmental conditions. Scrap samples of biofilms from immersed steel coupons were analyzed in addition to their enzyme reactions also for their microbial community by next-generation-sequencing of the 16S-DNA. Analysis of microbial community structure revealed additional insights into the physiological processes within the studied biofilms. Our analyses have shown that enzymes generally are good candidates due to their immense variety in marine biofilms. However, specific substrate reactions of our test system allow the detection of certain enzymes associated with corrosion, whereas hydrogenases, adenylyl-sulfate reductase and sulfite reductases belong to the already detectable classes.

Our findings will be discussed at the conference to give an answer to the question if the enzymatic approach could be suitable for the detection of microbial influenced corrosion.

Acknowledgements

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2A - ORAL 2

THE EFFECT OF HOST MEDIA ON THE DEVELOPMENT OF MICROBIOLOGICALLY INFLUENCED CORROSION (MIC)

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The role of microorganisms, e.g. bacteria, algae and fungi, in corrosion is a well-established field known as microbiologically influenced corrosion (MIC)¹. MIC can lead to localized material degradation with corrosion rates of orders of magnitude higher than would normally be expected from standard abiotic corrosion. MIC has been found to affect a wide range of industries such as maritime, oil and gas production and fire sprinkler water systems¹.

The existing literature on MIC is somewhat complex and confusing because bacterial activity at metal surfaces has been shown to both increase and in some cases reduce corrosion rates²⁻⁴. Many theories about possible mechanisms of MIC exist, with the process depending on both the type of microorganisms involved and the environmental conditions experienced. Metallurgical features have also been shown to play an important role in the initial attachment of microorganisms to metal surfaces and subsequent corrosion⁵.

The objective of this work was to determine the effect of different host media on the initial attachment of *Escherichia coli* bacteria and subsequent corrosion of 1010 carbon steel coupons. Nutrient broth and minimal media with different carbon sources and phosphate concentrations were used as test solutions in aerobic conditions. The results showed that initial bacterial attachment (≤ 60 min) to carbon steel coupons increased with time in all media tested. However, the rate and magnitude of attachment was medium dependent. Both short term (up to 12 h) and relatively longer term (up to 4 weeks) immersion studies showed accelerated corrosion of carbon steel coupons in all minimal media inoculated with *E. coli* compared to the sterile controls. In contrast, corrosion inhibition was observed in *E. coli* inoculated nutrient broth medium compared to the sterile controls. These trends were consistent in corresponding cell-free spent media. Mass-loss measurements were also consistent with microscopic observations of the metal surface at different time intervals, indicating that uniform corrosion had occurred. Overall, the results suggest that the host medium play a critical role in the ability of a single type of bacteria to either accelerate or inhibit corrosion of carbon steel.

Acknowledgments:

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3A - ORAL 3

CARBON STEEL CORROSION INDUCED BY A COLD-GROWING ENRICHMENT CULTURE ISOLATED FROM THE DEN HELDER HARBOR

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Microbiologically Influenced Corrosion has been traditionally thought to occur in geographical locations and/or seasons in which temperatures are temperate. Many corrosive isolates grow at temperatures between 20°C and 40°C and in fact traditional MIC test kits are incubated at similar temperatures. We have enriched a cold growing (10°C) anaerobic consortium from a static, organic rich pond filled with seawater from the Den Helder harbor. Preliminary corrosion experiments have shown enhanced corrosion activity (pitting) in carbon steel exposed to such consortium. Interestingly, the consortium showed so far no sulfate-reducing activity. The exact corrosion mechanism is currently under investigation in our lab by the use of advanced electrochemical techniques such as electrochemical noise and microscopy techniques. All in all, it can be demonstrated that the risk of MIC can be significant even in environments traditionally considered hostile for microbial growth.

Acknowledgments:

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3A - INVITED

THE CORROSION UNDER THE INFLUENCE OF BIOFILM OF MARINE ENVIRONMENTAL

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On an example carbonaceous and stainless steels it is shown, that micro fouling, developing on a surface of metals, possesses high corrosion activity and stimulates corrosion processes. In absence of microorganisms (sterile conditions) corrosion on metals in short period of time practically does not develop. We observed similar process at protective copper-contact anti-fouling coatings. Following this we mentioned that it seems possible to quantitatively estimate the destructive activity of microbial films and in general the destructive activity degree of marine environment regarding to construction materials as it is used by ISO 9223 for atmospheric environment.

Dynamics of development of a biofilm on the steel and dynamics of change of a ratio of active groups of microorganisms (aerobic and anaerobic) on a surface of the steel, participating in biocorrosion was investigated. Data on a quantitative assessment of activity of aerobic and anaerobic groups of microorganisms in a biofilm on steel were obtained. The Melchers R.E model about a crucial role of an anaerobic component of a biofilm in acceleration biocorrosion process of metals was experimentally confirmed.

The obtained experimental data by a quantitative assessment of activity of a biofilm on metals allowed to establish value pH sea water at which activity of a biofilm (A) is equal "0", that is the biofilm isn't formed. These researches found practical application at suppression of processes of biocorrosion a caisson tanks of oil-extracting platforms.

The conducted researches allow to approach further closely to development a laboratory technique of the accelerated tests of corrosion resistance of metals in the marine environment.

3A - ORAL 4

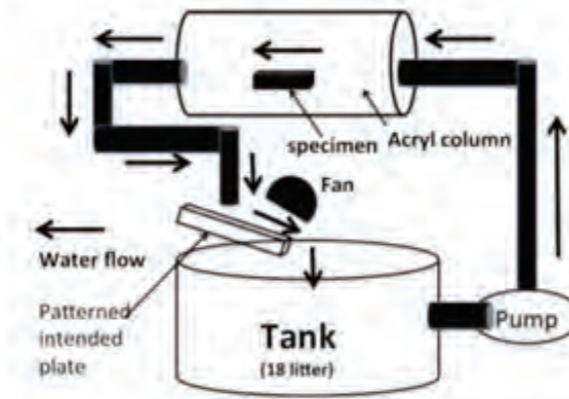
A TRIAL FOR MIC STUDY USING A CIRCULATION-TYPE LABORATORY BIOFILM REACTOR

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Akiko Ogawa¹, Takeshi Kogo¹, Yoko Miura³, Hideo Itoh¹

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One of the serious difficulties for Microbially Influenced Corrosion (MIC) study is the incoherency of laboratory scale studies with the results been not applicable to any analyses for natural phenomena. Any laboratory scale experiments have had discrepancies with the practical immersion type tests in sea water or some other practical environments. However, it would be very inconvenient for us to need the practical immersion tests, when we have to analyze and evaluate MIC phenomena at any time, since it always leads to some long duration tests and special geographical conditions. It is also true for MIC study from the viewpoint of biofilm and biofouling. We authors have been interested in corrosion phenomena, when biofilm formation is related to corrosion initiation on some metallic materials very dominantly.



To analyze and elucidate the phenomena on laboratory scale, we devised a circulation-type laboratory biofilm Reactor (LBR) based on the concept of cooling towers and tried to apply the biofilm related studies based on the apparatus to many cases so far. Fig.1 shows the basic concept for our LBR. The apparatus is basically composed of a column, water tank, pump and pipe. All of those components were connected each other by PVC pipes. The water (pure water, tap water, underground water, artificial or natural sea water) was circulated in the system by the pump. This system was not a completely closed one, strictly speaking. An intermittent plate was placed just above the tank and

the water was designed to run down on it before it was poured down into the tank. A fan was set above the plate and the ambient air was designed to blow down on it from the fan. This part of the system enabled the specimen placed in the column to form biofilm on it artificially. It means the biofilm could be formed on the specimen by ambient complicated plural germs. After the immersion, the surface of the metallic specimens was analyzed by 3D optical microscopy, SEM-EDX etc. to analyze and evaluate biofilm formation behavior on the surface of metallic materials. And in addition, electrochemical measurement system was combined to the basic apparatus. By using these apparatus and evaluation techniques, the correlation between biofilm/biofouling phenomena and MIC was investigated for steels, copper, aluminum, nickel and some alloys of them. And finally, the effectiveness of the evaluation and analysis system was discussed from the applicability to MIC.

Acknowledgments:

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3A - ORAL 5

BIOCIDAL MECHANISM OF IODINE BY IODIDE-OXIDIZING BACTERIA (IOB) ISOLATED FROM BRINE IN NATURAL-GAS RELATED FACILITIES

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At a natural gas production plant (Chiba, Japan), brine, gas field water (GFW), contains not only methane but also iodine. After methane recovery from GFW, iodine is recovered by adjusting pH by sulfuric acid and adsorbing to resin (**Figure**). Subsequently, the waste brine is reinjected into the soil as recovered water (RW). However, bioclogging and microbiologically influenced corrosion (MIC) of metal pipe occurred at the RW injection well. To examine the factors contributed to bioclogging and MIC, an on-site experiment was carried out by incubating 10 L of GFW or RW in the open air for 5 months. According to the analysis of microbial consortia, various kinds of bacteria, such as fermentative bacteria, bacteria related to sulfur cycle, iodide-oxidizing bacteria (IOB) and so on were detected¹. Among them, IOB is the bacteria which can oxidize iodide into oxidative iodine. It seems that the brine containing a high-concentrated iodide ion might affect IOB abilities, bioclogging and MIC of metal pipe. In other words, IOB is thought that it obtains the advantages in microbial consortia by inhibiting and/or damaging other populations via strongly disinfectant iodine. So far, some kinds of IOB were isolated from the brine and it was revealed that they inhibited the growth of *Escherichia coli* in the co-culture by using Marine Broth with iodide². However, the detailed biocidal mechanism of iodine under environment are still unclear. Therefore, in this study, the reactive property of iodine produced by IOB against the representative bacteria, protein, amino acids, medium and saccharide were investigated.

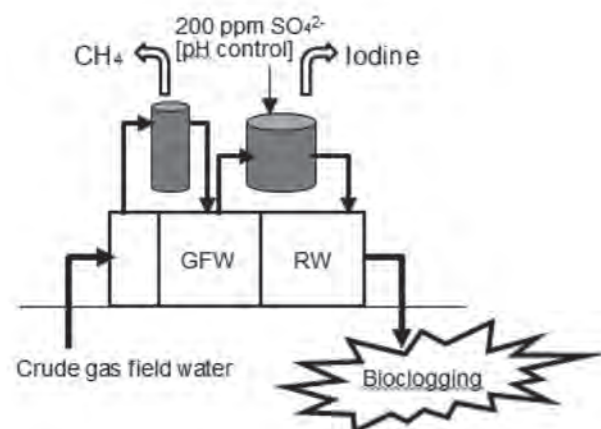


Figure Methane and iodine recovery process from brine
(GFW: gas field water, RW: recovered water)

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3A - ORAL 6

MICROBIAL CORROSION INFLUENCED BY ELECTROACTIVE BIOFILMS: RECENT PROGRESS ON ELECTROCHEMICAL AND MICROBIOLOGICAL APPROACHES

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Microbiologically Influenced Corrosion (MIC) has been found widely in natural and industry environments and many different MIC phenomena and mechanisms have been reported in references. It has been recognized that the importance of living biofilms on the surface of metal surfaces. Corrosive biofilms, as a kind of electroactive biofilms, contact electrochemically or electrically with the metal surfaces, to drive the accelerated or inhibited corrosion process. In this presentation, the electrochemical and microbiological methods will be reviewed related to the biofilm formation and electron transfer process between sulfate-reducing bacteria electroactive biofilms and electrode materials. In MIC, SRB as a kind of anaerobic biofilms, usually result in accelerated corrosion, localized corrosion and even corrosion cracking. This presentation will introduce how to judge and confirm the electroactive characteristics of the biofilms and measure the electron transfer current based on different electrochemical methods such as polarization potential, impedance, cyclic voltammograms, chronoamperometry, etc. In practice, many corrosion damages such as steel ropes, pipelines and platforms in marine environment are also contacted with the role of corrosive bacteria, microbial community analysis, culture, observation and corrosion test methods were also introduced. More commonly, the cathodic and anodic corrosion process would be changed by the aerobic and anaerobic biofilms, it is important to measure the change of the corrosion potential and corrosion rate of the electrodes, and reaction resistance and capacitance, if related to electrochemical impedance technique. It will be introduced the measure methods and discussed the mechanisms under these changes from corrosion and bio-electrochemistry view.

Acknowledgments:

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3A - ORAL 7

THE USE OF CONTINUOUS-OPTIMIZING CONFOCAL REFLECTION MICROSCOPY (COCRM) FOR STUDYING INTERACTIONS OF BACTERIAL ATTACHMENT WITH STAINLESS STEEL WELDS

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Stainless steel is a widely used industrial material due to its mechanical properties and resistance to corrosion. However, Microbiologically Influenced Corrosion (MIC) on stainless steel (SS) is reported largely and the most case of MIC of SS is involve the appearance of welded zone. Welded regions of SS are considered to be attractive to microbes because welding process alters the material surface characteristics.

In the present study, we have evaluated the influence of substratum microstructure formed by welding process, i.e. metal segregation or alternation of elemental composition on bacterial adhesion. Austenitic SS weld specimen, including minor element enriched ones (i.e. sulfur enriched weld metal), were prepared. The surfaces of these specimens were polished to mirror finish to cancel the effect of surface geometry on bacterial attachment. A natural marine water and some microbes isolated from it were used for this research and the bacterial attachment with stainless steel welds was visualized by continuous optimizing confocal reflection microscopy (COCRM).

COCRM is a technique and observation system based on confocal microscopy that can visualize everything that reflects light, unlike fluorescence microscopy. According to this observation technique, the effect of metal microstructure and minor elements on bacterial attachment was examined, and the biofilm formations depending on different microstructure and minor element segregation were evaluated.

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MARINE BIOADHESION
SESSION CHAIR: PROF JONATHAN WILKER
DEPARTMENT OF CHEMISTRY, PURDUE UNIVERSITY, UNITED STATES

3B - KEYNOTE

MUSSEL ADHESION IN A WARMER, HIGH-CO₂ WORLD: AN ECOMATERIAL APPROACH

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Mussels are key aquaculture species and often dominate temperate rocky shores worldwide, forming dense aggregations firmly tethered by byssal threads, extracellular fibers molded by the mussel foot. Field studies with *Mytilus* spp. have shown byssus strength, or tenacity, follows a strong seasonal cycle, rendering both wild and farmed populations prone to "fall-off" in late summer/early fall when increased storm activity coincides with weak attachment. Seasonal weakening is due primarily to environmentally-induced changes in the material properties of individual byssal threads. Using custom laboratory mesocosms, we quantified the effects of two common environmental stressors, elevated temperature and *p*CO₂ (= ocean acidification), on the mechanical performance of byssal threads in *M. trossulus*. Both stressors caused thread weakening and loss of extensibility, but targeted different regions of a thread. These results suggest multiple environmental stressors, including ocean acidification and warming, can combine to critically compromise the structural integrity of mussel adhesion.

Acknowledgement

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3B - ORAL 1

COMPOSITION MORPHOLOGY AND FORMATION OF CALCAREOUS SHELL OF HYDROIDES DIANTHUS AND ELEGANS AND CONTROL OF THEIR SETTLEMENT ON SURFACES

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To date, the calcareous tubes of serpulid marine worms have not been studied extensively in a biomineralization context. The structure and composition of the tube shell and adhesive cement of the marine tubeworm *Hydroides dianthus* and *elegans* were studied using a variety of characterization techniques, including powder XRD, FTIR, SEM, EDX, and AFM. The tube and cement were determined to be inorganic-organic composite materials, consisting of inorganic aragonite (CaCO₃) and Mg-calcite ((Ca_{0.8}Mg_{0.2})CO₃) crystals, and both soluble and insoluble organic matrices (SOM and IOM). SEM imaging revealed a variety of crystal morphologies. Amino acid analysis of the SOM indicated substantial amounts of acidic and non-polar neutral amino acids. Part of the insoluble organic tube lining was identified as being composed of collagen-containing fibres aligned in a criss-crossed structure. The SOM and organic tube lining were found to contain carboxylated and sulphated polysaccharides. In artificial seawater solution, the SOM and the organic tube lining mediated CaCO₃ mineralization *in vitro*. Further we show how nanostructured block copolymer thin films can control the gregarious settlement of *Hydroides* on surfaces such as glass and metal.

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3B - ORAL 2

SEA STAR TENACITY IS MEDIATED BY A PROTEIN THAT FRAGMENTS, THEN AGGREGATES

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Sea stars adhere firmly but temporarily to various substrata owing to underwater efficient adhesive secretions released by their tube feet. Previous studies showed that this material is mainly made up of proteins, which play a key role in its adhesiveness and cohesiveness. Recently, we solubilized the majority of these proteins and obtained 43 de novo-generated peptide sequences by tandem mass spectrometry. Here, one of these sequences served to recover the full-length sequence of Sea star footprint protein-1, Sfp1, by RT-PCR and tube foot transcriptome analysis. Sfp1, a large protein of 3853 amino acids, is the second most abundant constituent of the secreted adhesive. Using mass spectrometry and western blot analyses, we showed that Sfp1 is translated from a single mRNA and then cleaved into four subunits linked together by disulphide bridges in tube foot adhesive cells. The four subunits display specific protein-, carbohydrate- and metal-binding domains. Immunohisto- and immunocytochemistry located Sfp1 in granules stockpiled by one of the two types of adhesive cells responsible for the secretion of the adhesive material. We also demonstrated that Sfp1 makes up the structural scaffold of the adhesive footprint that remains on the substratum after tube foot detachment. Taken together, the results suggest that Sfp1 is a major structural protein involved in footprint cohesion and possibly in adhesive interactions with the tube foot surface. In recombinant form, it could be used for the design of novel sea star-inspired biomaterials.

Acknowledgments:

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3B - ORAL 3**BACTERIOATTRACTIVE AND BACTERIOCIDAL EFFECTS OF BARNACLE SETTLEMENT AND DISRUPTION ON SILICONE SURFACES**

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Bacteria are chemotactic to barnacle glue. Motile bacteria recruit to barnacle larval glue as soon as the cyprid becomes permanently glued to a surface. Bacteria concentrate around the primary attachment points. The bacteria nearest the antennules are killed within 24 hours of recruitment. Bacteria below the sideplates at the periphery of the baseplate are killed more gradually and eliminated as the edge of the barnacle sealed to the surface. On scratched glass coverslips, the barnacle growth is regular over the scratch and bacteria occupy the scratch. On scratched silicone-coated coverslips (PDMS and PVMS) barnacle growth is irregular. Even with abundant space between the baseplate and surface, bacteria are not present under the barnacle on silicone-coated surfaces. We hypothesize that molecules leaching from the silicone disrupts barnacle growth and prevent bacteria from colonizing the space.

3B - INVITED**HOMOLOGOUS BUT NOT SIMILAR: THE ADHESIVE PROTEINS OF STALKED AND ACORN BARNACLES**

Jaimie-Leigh Jonker, Florence Abram, Ana Varela Coelho, Ingo Grunwald, Anne Marie Power*

*Corresponding author

Barnacle adhesion underwater is an important phenomenon to understand for the prevention of biofouling and potential biotechnological innovations, yet so far, identifying what makes barnacle glue proteins 'sticky' has proved elusive. Examination of a broad range of species within the barnacles may be instructive to identify conserved adhesive domains. We add to extensive information from the acorn barnacles (order Sessilia) by providing the first protein analysis of the adhesive of *L. anatifera* (a stalked barnacle, order Lepadiformes). It was possible to separate the *L. anatifera* adhesive into at least 12 protein bands using 1D SDS-PAGE. Intense bands were present at approximately 30, 70, 90 and 110 kD. Mass spectrometry of protein bands followed by *de novo* sequencing isolated 78 peptides of 7-16 amino acids in length. None of the peptides matched published or unpublished transcriptome sequences, but some similarity was apparent between *L. anatifera* and closely-related *D. fascicularis*. Antibodies against two acorn barnacle proteins (ab-cp-52k and ab-cp-68k) showed cross-reactivity in the adhesive glands of *L. anatifera*. We also analysed the similarity of adhesive proteins across several barnacle taxa, including *Pollicipes pollicipes* (a stalked barnacle in the order Scalpelliformes). Sequence alignment of published ESTs clearly indicated that *P. pollicipes* possesses homologues for the 19 kD and 100 kD proteins in acorn barnacles. Overall, several of the proteins described in acorn barnacles appear to have homologous proteins in stalked barnacles; cp-19k and cp-100k are also found in *P. pollicipes*, while cp-52k and cp-68k appear to be expressed in *L. anatifera* adhesive tissues. Homology aside, sequence similarity in amino acid and gene sequences tended to decline as taxonomic distance increased, with minimum similarities of 18-26%, depending on the gene. A curious result was the fact that several peptides were repeatedly found in proteins of different masses but further studies will be necessary to resolve this issue.

3B - ORAL 4**NON-SPECIFIC ADSORPTION OF BARNACLE SETTLEMENT-INDUCING PROTEIN COMPLEX (SIPC) TO DIFFERENT SURFACE CHEMISTRIES, MEASURED USING SURFACE PLASMON RESONANCE**

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The settlement-inducing protein complex (SIPC) is a large, glycoproteinaceous signaling molecule essential for conspecific recognition and gregarious settlement in barnacles. Its role in the modulation of larval settlement behaviour has been studied extensively, prior even to a full characterisation of the molecule. SIPC applied crudely to surfaces will induce settlement for extended periods in the field and it has therefore been presumed that the SIPC adsorbs strongly to surfaces and resists biodegradation. The SIPC is also present in the footprints of adhesive deposited onto surfaces by exploring cypris larvae. As well as providing another possible mechanism for gregarious settlement of larvae, it has therefore been speculated that the SIPC may serve a functional role in temporary adhesion. In a series of experiments we used laboratory-purified SIPC as a proxy for temporary adhesive, in order to investigate the innate adsorbency of this molecule to different surfaces in comparison to a promiscuously adsorbent protein, fibrinogen, and a molecule that is related to the SIPC, alpha-2-macroglobulin (A2M). The nonspecific adsorption of these proteins was assessed by surface plasmon resonance (SPR) on a range of model surfaces, viz. self-assembled monolayers (SAMs) with differing end-groups (CH₃-, OH-, COOH-, N(CH₃)₃⁺-terminated) as well as a poly(ethylene glycol) (PEG) SAM. In terms of adsorbed mass, SIPC far exceeded A2M on all surfaces, except on the positively-charged N(CH₃)₃⁺-terminated SAM. It may therefore be concluded that if SIPC and A2M are closely related, SIPC must be specifically modified to enhance surface adsorption. Fibrinogen, a model protein in adsorption studies due to its high surface affinity, showed higher adsorption than SIPC to all surfaces. Nevertheless, SIPC did adsorb in measurable quantities to the PEG SAM, which is, in itself, an unusual capability - A2M did not. Investigation of the adsorption kinetics of SIPC revealed irreversible and non-cooperative adsorption to SAMs in the following order: N(CH₃)₃⁺ >> CH₃ > COOH >> OH > PEG. An overshooting effect was observed during the adsorption of SIPC to the positively-charged surface indicating temporary oversaturation, followed by conformational change and net protein desorption. In summary, these results confirm that SIPC is unusual in its ability to adsorb to a wide range of surfaces and does so even on protein-resistant PEG. If SIPC is instrumental in cyprid temporary adhesion, these results may explain the ability of cyprids to attach relatively easily to PEG-functionalised surfaces and further investigation of the molecule may yield new directions in the development of surfaces to which barnacles cannot attach.

3B - ORAL 5

SYNERGISTIC ROLES FOR LIPIDS AND PROTEINS IN THE PERMANENT ADHESIVE OF BARNACLE CYPRID LARVAE

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In the ocean, survival of encrusting sessile invertebrates depends heavily upon their ability to permanently attach and colonize substrates. Thoracian barnacles are among the most adept having evolved adhesives that can attach to surfaces with vastly different physico-chemical properties. The biophysical attributes that impart cyprid permanent adhesive the ability to attach to a great variety of surfaces are poorly understood. With the aid of multi-photon microscopy and broadband coherent anti-Stokes Raman scattering spectroscopy (BCARS), we report that the cyprid permanent adhesive is a bi-phasic system containing both lipids and phosphoproteins. The two distinct phases are contained within different subsets of cells in the cyprid cement gland. Phosphoproteins form bulk of the adhesive plaque and are found within columnar cells constituting majority of the cement gland volume. Whereas the lipidaceous granules are contained only in cells present basally in close proximity to the medial cement collecting duct. These two phases work synergistically throughout the delivery and the adhesion processes. Lipids secreted first, displace water from the surface interface and create an anhydrous environment for introduction of phosphoproteins. The lipidaceous phase protects the phosphoproteins from biodegradation whilst limiting their excessive spreading. The unique bi-phasic approach to adhesion implies far greater complexity than was previously realized. The long-standing presumption that proteins alone are instrumental in underwater bio-adhesion seems to be over-simplification, and knowledge of a lipid contribution will surely inspire development of novel synthetic bio-adhesives as well as environmentally inert antifouling coatings.

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3B - ORAL 6

PROTEOMICS OF BIOLOGICALLY ACTIVE ODORS FROM BARNACLES AND OYSTERS

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Gregariousness in barnacle and oyster settlement is mediated chemically. Experimental evidence for peptide involvement in gregariousness, specifically the role of the carboxyl terminal region has been reported for about 30 years. Evidence that peptides with the same kinds of carboxyl terminal regions have multiple specific functions as pheromones, kairomones and signals in marine systems has accumulated for over 4 decades. Here we report the sequences of peptides from barnacle and oyster odors. The peptides were isolated from 10,000 liter odor preparations by bioassay-directed purification using predatory snails. Purification was by macro-reticular aliphatic resins and liquid partition chromatography with volatile buffers. Identification was accomplished after reduction, alkylation and treatment with either; no added enzyme, trypsin (R&K) or *S. aureus* V8 protease at pH5.0 (Q&N). Samples were subjected to nanoscale capillary liquid chromatography coupled to high-resolution accurate-mass tandem mass spectrometers (LC/MS/MS). Sequences were determined by automated searches of LC/MS/MS data against public protein sequence databases (NCBI, UniProt etc.). We show that one pure peptide from barnacle odor induces barnacle settlement and a mixture of peptides found in oyster odor generated from trypsin hydrolysis of ubiquitin induce metamorphosis in oyster larvae. Both sources of peptides induce shell investigation behavior in hermit crabs. All are active in the 0.1 nM concentration range. Most of the peptides from very biologically active preparations have sequences found in vertebrate α -collagens which function in bone mineralization. Although our original goal was the identity of biologically active peptides, the most intriguing discoveries are those associated with protein relationships discovered in the peptide mixtures.

3B - ORAL 7

UNDERSTANDING OYSTER CEMENT:
SIMILARITIES AND DIFFERENCES COMPARED TO OTHER BIOADHESIVES

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The oceans are home to a diverse collection of animals producing adhesive materials. Mussels, barnacles, oysters, starfish, and sea grasses are examples of the organisms generating adhesive matrices for affixing themselves to the sea floor or ship hulls. Our laboratory is characterizing these biological systems and then using the information we discover to develop surfaces for repelling bioadhesion. In the case of mussel adhesive, we are seeing that the shellfish use iron and oxygen cross-linking reactions to form their adhesive matrix. For oyster cement, less information is known and ongoing efforts are working at more basic, less chemical levels. Microscopy studies are revealing that oyster cement is a composite material comprised of both inorganic (CaCO₃) and organic species. The organics appear to be partitioned such that they make interfacial contact between the cement and substrate. Inorganics fill the remaining space. The resulting adhesive system is a biological, organic-inorganic composite. These findings, along with other recent results, will be discussed and placed within the context of emerging themes in bioadhesion.

Acknowledgment:

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**ADVANCES IN ANALYSIS OF CORROSION
SESSION CHAIR: PROF HIDEYUKI KANEMATSU
DEAN, DEPARTMENT. MS & E., SUZUKA NATIONAL COLLEGE OF
TECHNOLOGY, SUZUKA, JAPAN**

3A - KEYNOTE

THE EFFECT OF BIOTIC COMPONENTS ON CORROSION: CURRENT ADVANCES AND
FUTURE PERSPECTIVES

Professor Iwona Beech

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Significant progress has been made in understanding the effect biological component exerts on marine corrosion of metallic materials.

With unprecedented developments in mass spectrometry, as well as imaging and surface analytical techniques, direct in-situ observations of structures and chemical functions at micron and sub-micron resolutions are now within grasp. However, demonstrating spatial and temporal relationship between biological activity and electrochemical events on surface of bio-fouled materials still presents a major challenge. Current developments in the fields of nucleic acid-based technologies, in particular the rapid expansion of affordable techniques facilitating metagenomic and meta-transcriptomic analysis, allows simultaneous characterization of taxonomic composition, metabolic content and, more importantly, gene expression within biofilm communities. The above techniques, when coupled with proteomics and metabolomics, including metabolomic imaging, offer great promise in understanding the role biotic components play in corrosion. Examples are presented to demonstrate progress made in elucidating biodeterioration of iron and ferrous alloys in marine environments under oxygenated and anoxic conditions. Emphasis is placed on discussing aspects of corrosion that require additional investigations, e.g. biotically-mediated electron transfer processes, and the effect of organic compounds on the rate of cathodic (reduction) reactions.

3A - ORAL 1

EVALUATION OF DIAGNOSTIC METHODS FOR MICROBIOLOGICALLY INFLUENCED CORROSION

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Involvement of microorganisms in corrosion is referred to as *microbiologically influenced corrosion* (MIC). Although MIC is suspected at various industrial facilities, causative microorganisms are difficult to identify because systematic methods for MIC diagnosis have not been established. Traditionally, a culture-based method has been used for the MIC diagnosis. Recently, molecular techniques involving metagenomic analysis and specific-gene detection have been developed. Here, we conducted a combinatorial test of culture-based methods (lab scale cultivation and monitoring of the corrosion rate) and molecular methods (microbial community analysis and detection of a specific gene) in order to evaluate their reliability.

The corrosion test was performed on bottom water from oil storage tanks in Japan. Because coworkers isolated an iron-corrosive methanogen from bottom water of another tank in the same facility, we collected bottom water from 3 oil storage tanks (KTD1, KTD2, and KTD3). Judging by the release rate of ferrous/ferric ions from metallic Fe, accelerated corrosion was only present in the KTD1 sample supplemented with an artificial sea water medium. A PCR test using a gene-specific primer set did not detect the known iron-corrosive methanogen in the corroded sample. On the other hand, denaturing gradient gel electrophoresis (DGGE) analysis of a gene fragment of 16S rRNA showed that the microbial community of the corroded sample differed from that before the cultivation and from uncorroded samples. In the corroded sample, we found that an *Acetobacterium* sp. bacterium was enriched. After 2 rounds of batch cultivation, this enriched culture showed an iron-corrosive ability and the same DGGE profile.

Thus, we found a novel corrosive microorganism, *Acetobacterium*, by means of both culture-based and molecular genetic techniques. If we had conducted a stand-alone diagnostic test, for example, detection of a specific gene of a known corrosive microorganism, we would have overlooked this possibility of a novel corrosive microorganism. Therefore, a stand-alone diagnostic test is insufficient for accurate assessment of the risk of MIC. We propose the combinatorial method of culture-based and molecular genetic assays as a reliable and systematic diagnostic test for MIC.

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3A - ORAL 2

QUANTITATIVE ANALYSIS OF INITIAL STAGE OF BIOFOULING USING QUANTITATIVE PCR TARGETING BACTERIAL 16S rRNA GENE

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At the Initial stage of microbiologically influenced corrosion (MIC), it is known that biofilm is formed and the trend of biofilm formation influences biofouling. Therefore controlling biofilm formation is important technique to prevent iron and steel materials from MIC caused by biofouling. In order to analyze the biofilm formation on the materials under the sea, visual monitoring is a good way but difficult one. On the other hand, it is known that the amount of microorganisms is related to the degree of biofilm formation. Our previous study reported that we developed a laboratory biofilm reactor (LBR) and we succeeded in accelerating biofilm formation on several materials at our laboratory. In addition, we quantitatively measured the amount of biofilm formed on the glasses by the two methods: the one was measurement of the absorbance using Giemsa stain, by which Giemsa positive bacteria is dyed, and the other one was measurement the dirt of the glasses by visible light transmittance. It was revealed that the amount of microorganisms was related to the degree of dirt and we successfully proposed the easy method for quantitative analysis of biofilm. However, this method cannot be applied to non-transmissive materials such as steels. In this study, we proposed the other quantitative analysis of initial state of biofouling using quantitative polymerase chain reaction (PCR) targeting bacterial *16S rRNA* gene to measure the amount of total bacteria. Some silicon-coated and non-coated glasses were fixed in the LBR where clear water was circulated (at 30 °C) in order to form biofilm. After one week, biofilm formed glasses were taken out, measured by visible light transmission and observed with an optical microscope. Next, the biofilm on the glass was collected by pipetting using DNA-extracting buffer then collected biofilm was performed DNA purification using Extrap Soil DNA Kit Plus ver.2 (Nippon Steel & Sumikin Eco-Tech Co.) Purified DNA was used for quantitative PCR targeting bacterial *16S rRNA* gene. Silicon-coated glass had a lot of bacteria and we could observe the biofilm on the surface. On the other hand, non-coated glass did little of bacteria and we could not observe the biofilm. When silicon-coated glasses were modified, the amount of bacteria varied. Additionally, the amount of bacteria was related on the decrease in the transmittance. These results indicate that quantitative PCR targeting bacterial *16S rRNA* gene can be effective method for quantitative analysis of initial biofouling, i.e., microfouling.

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3A - ORAL 3

APPLICATION OF TRIPLE COMPOSITE FUZZY FUNCTIONS IN PREDICTING SSRT
BEHAVIOR OF CARBON STEEL IN ENVIRONMENTS CONTAINING SULPHATE REDUCING
AND IRON REDUCING BACTERIAL SPECIES

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Fuzzy logic and calculations have been used in many fields of science and engineering such as corrosion. Microbial corrosion (or as more officially known, microbiologically influenced corrosion abbreviated as MIC) has also been the subject of some studies using fuzzy logic especially due to the uncertainties involved coming from chemical as well as biological factors. In addition, steels and especially carbon steel and stainless steel are among materials that have always become a choice in engineering applications especially in marine applications from subsea pipelines to the seafloor installations. This paper will address a prediction model constructed based on fuzzy logic to assess the performance of carbon steel and stainless steel 316L in environments containing corrosion-related bacteria. To achieve this goal, a composite fuzzy function model was developed to predict the corrosion resistance of carbon steel in three environment containing single-type and mixed cultures of corrosion-related bacteria such as sulphate reducing bacteria and iron reducing bacteria. Based on this model, it was predicted that the fuzzy probability of corroding carbon steel in the mixed environment is higher than that of the single-type environments and that this fuzzy probability for the single-type environments is almost equal. To validate the model, stress corrosion testing (slow strain rate test) was conducted on carbon steel in these environments. The obtained results validated the predicted results by the model as measured by change of important mechanical features of carbon steel in these environments.

Key Words: Corrosion-Microbiologically Influenced Corrosion (MIC) - Steel- Fuzzy Composite Functions- Bacteria.

BIOLOGY OF FOULING ORGANISMS
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3B - KEYNOTE

THE BIOLOGY OF FOULING ORGANISMS: A FIELD PERSPECTIVE

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Understanding the biology of fouling organisms is fundamental to the management and development of strategies and methods for the control of biofouling. There is a wealth of knowledge on the subject. This talk will review past and present research in terms of what, where, when and how fouling becomes established. Fouling is initiated from propagules present in the water column, whose presence is determined by spatial and temporal variation. Their choice of substrate, however, is controlled by sensory receptors that can respond to both environmental and substrate conditions. Once settled, growth rates, competition and predation will play a role in determining the final community structure. From a management perspective this knowledge can help optimize ship and structure cleaning schedules; locate the placement of seawater intakes and other critical components; understand the potential for introducing non-indigenous species; and identify the locations and times of year when biofouling control is required. The development of novel methods to prevent fouling will benefit from a detailed knowledge of the morphology, physiology and behavior of the propagules. Finally, this knowledge may also be used to re-establish benthic communities in areas that have been impacted by anthropogenic activities.

3B - ORAL 1

AN OVERVIEW OF FOULING SEDENTARY POLYCHAETES

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Sedentary polychaetes are conspicuous with numerous species in marine environments. They can also be a major component of fouling communities. As fouling organisms they can be divided into four families (Serpulidae, Spirorbidae, Sabellidae and Terebellidae) with a total of 53 species identified, of which the dominant species are *Hydroides elegans*, *H. ezoensis*, *H. diramphus*, *H. norvegicus*, *H. operculatus*, *Pomatoleios kraussii*, *Serpula vermicularis*, *Spirobranchus polytrema*, *S. tetracerus*, *Ficopomatus enigmaticus* and *Thelepus cincinnatus*.

Sedentary polychaetes usually live in tubes, which they themselves secrete. Tubes are either attached to surfaces or to each other forming tangled batches; such tubes are difficult to remove even when the occupying worms have died. Their larvae can settle on various underwater man-made substrata and post-settlement tube growth may cause serious impairment problems such as adding weight to buoys, decreasing ship speed (more fuel consumption, so increasing CO₂ emissions), blocking seawater pipelines and aquaculture nets.

The fouling sedentary polychaetes are widely distributed in tropical, subtropical and temperate waters. However, they are not homogeneously distributed over the different biogeographical regions. In the Pacific Ocean the common species are *Hydroides ezoensis*, *H. centrospina*, *H. longistylaris*, *H. multispinosa*, *H. prisca*, *Serpula cf. hartmanae* and *S. tetratropia*. Whereas *Hydroides minax*, *H. heterocerus*, *Spirobranchus semperi* and *Ficopomatus uschakovi* are only found in Indian Oceans and *Hydroides brachyacanthus*, *Serpula concharum*, *Spirobranchus lamarcki*, *Pseudovermilia occidentalis* and *Sabella spallanzanii* mainly occur in the Atlantic Ocean.

Fouling sedentary polychaetes range from shallow coastal habitats to deep water. However, most previous work is restricted to coastal waters as studies in the deep ocean are rare. Moreover, different species prefer particular substrata. For example *Pomatoleios kraussii* and *Hydroides operculatus* tend to settle on the hulls of ships, whereas *H. ezoensis* and *H. diramphus* are generally abundant on quay and aquaculture equipment. Understanding their settlement processes is likely to contribute to the development of novel antifouling technology.

Sedentary polychaetes are appropriate representative animals to evaluate the impact of environmental factors on marine ecological systems and from the viewpoint of antifouling studies they are also ideal testing models. Therefore, further work should be focused on the aspects of larval development and settlement mechanisms of the dominant species. Moreover, with the increase in oceanic development and utilization activities, more man-made facilities now occur in deeper and colder waters. Lack of information on fouling sedentary polychaetes in such environments means urgent further studies are now necessary.

Due to the limitations of traditional taxonomic methods it is sometimes difficult to identify related polychaete species effectively. Modern genetic technology should provide the answers. Furthermore, some sedentary polychaetes can be easily transported by ship to new environments. As such alien invasive species they can cause serious ecological problems. Based on the reasons mentioned above future work should address the issues of taxonomy and invasive species.

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3B - ORAL 2

THE EFFECT OF CUES AND CONDITIONING ON THE SETTLEMENT OF MARINE MACROFOULING AND COMMUNITY DEVELOPMENT

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Physical, chemical and biological cues may stimulate or deter the settlement of macrofouling organisms. Responses of larvae to physical cues such as light, hydrodynamics and topography, and to biochemical cues associated with conspecifics, prey/food and competitors/predators are well documented. Recent efforts to identify the chemicals responsible for larval settlement responses and an increased awareness of the importance of biofilms and conditioning films have focused research on how cues and conditioning affect where larvae settle and how that effects community structure. This presentation will highlight the results of recent research on the effects of prior conditioning of surfaces on subsequent fouling. This will be put into context of how cues and conditioning both deter settlement for potential novel antifouling technology and encourage settlement for aquaculture.

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3B - ORAL 3

THE EFFECTS OF FEEDING LEVELS AND TEMPERATURE ON GROWTH AND ADHESIVE PRODUCTION IN BALANUS AMPHITRITE

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The barnacle *Balanus amphitrite* is a model species for fouling-release (FR) studies. Although a model species, there is no consensus about larval culture conditions and different laboratories use different protocols. The effect of changing temperature and food availability on barnacle growth and moulting has long been understood. However the effect on adhesive production has not been studied, although a temperature study has been undertaken to investigate temperature effects on critical removal stress (CRS; Johnston 2010). This study considered growth and adhesive ring formation of *B. amphitrite* at four temperatures (15, 19, 22 and 28 °C) and two feeding regimes. Barnacles were grown individually on flexible plastic coverslips to allow all the parameters to be linked to each individual. Moults and growth were noted from settlement and once a set size had been attained, adults were removed from their substratum and their bases stained. The adhesive was stained and the number of rings, area of cover and width of bands evaluated. Growth levels were found to be higher in all treatments than those reported in earlier investigations for this species. Moults and basal growth were closely linked, as had been found in the past. Barnacle moulting was not linked to temperature when food resources were limited. An adhesive ring was, however, produced for each moult produced. Moreover, average coverage of the basis with adhesive increased with both increasing temperature and increasing food availability. The mean width of the adhesive rings did not differ, however, between feeding treatments, but did increase with increasing temperature. Barnacles grown on an inferior FR coating (T2) showed a strong negative correlation of CRS to temperature, as in the previous study (Johnston 2010). The study shows the importance of environmental factors, temperature and food availability on growth and adhesive production in *B. amphitrite*. The results show the difficulty in direct comparisons of CRS between laboratories using different growth protocols and further shows a commonly used growth temperature may not be ideal.

3B - INVITED

CHEMICAL AND VISUAL CUES FOR GREGARIOUS SETTLEMENT IN BARNACLES

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Selection of suitable settlement sites in larvae of sessile marine invertebrates is a crucial process for survival and reproduction. In many barnacle species, gregarious settlement is also essential to ensure that mating neighbors are sufficiently close one the individual becomes an adult. How barnacle larvae settle gregariously?

Since the 1950s, response of cyprids, the settlement stage larvae in barnacles, to chemical cues from conspecifics have been thought to be one of the most important mechanisms leading to conspecific gregarious settlement in barnacles, and two types of proteinaceous settlement cues have been purified from the adult barnacle, *Balanus (Amphibalanus) amphitrite*. One is the substratum-bound pheromone, settlement-inducing protein complex (SIPC), and the other is the waterborne pheromone. SIPC is a high-molecular mass, previously undescribed glycoprotein but shares a 25% sequence homology with the thioester-containing family of proteins that includes the α 2-macroglobulins. SIPC was also detected in "footprints" of cyprids, suggesting involvement of SIPC in both adult-larva and larva-larva interactions during settlement. The waterborne settlement pheromone of 32 kDa protein is suggested to be released into seawater and attracts cyprids. These chemical cues are definitely important in the settlement of barnacle cyprids although their receptors in the larva have not been identified. However, it has been suggested that they only work over relatively short distance, indicating possible involvement of other species-specific signals in their gregarious settlement. How about visual signals?

Interestingly, the cyprid has one pair of compound eyes that appear only at the late nauplius VI and cyprid stages, but the function(s) of these eyes remains unknown. We recently showed that cyprids of *B. amphitrite* can locate adult barnacles even in the absence of chemical cues, and prefer to settle around them probably via larval sense of vision. We also show that the cyprids can discriminate color and preferred to settle on the red surface. Moreover, we found that shells of adult *B. amphitrite* emit red auto-fluorescence and the adult extracts with the fluorescence as visual signal attracted cyprid larvae to settle around it. To examine molecular mechanisms, two barnacle opsin genes, named *Ba-op1* and *Ba-op2*, expressed in the larval stage of *B. amphitrite* were cloned, sequenced and characterized in expression profiles. The results suggested that the cyprids discriminate red fluorescence signal in adult shells by using the long wavelength sensitive opsin, *Ba-op1*, expressed in their compound eyes.

We propose that the perception of specific visual signals can be involved in behavior of zooplankton including marine invertebrate larvae, and that barnacle auto-fluorescence, as well as settlement pheromones, may be a specific signal involved in gregarious larval settlement.

3B - ORAL 4

A NEW METHOD TO COMPARE THE POTENTIAL TOXICITY OF FOULING RELEASE COATING LEACHATES ON AMPHIBALANUS AMPHITRITE LARVAE

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Nowadays, among all the low environmental impact antifouling solutions, Fouling Release Coatings (FRC or silicone coatings) represent one of the most promising approaches to cope with biofouling problems in the maritime field. These coatings are based on silicone elastomers, produced from poly-dimethylsiloxanes (PDMS), that, thanks to their low surface energy, minimize the adhesion strength between organisms and surface. Silicone coatings are declared not to release any chemical as their antifouling activity is based just on surface physical properties, and, for that, they should not represent a risk for the marine environment. In spite of this assumption, different Authors highlighted some toxicity of silicone coatings elements. In order to predict antifouling paint potential environmental impact, ecotoxicological bioassays are commonly used to evaluate paint leachates toxicity. Standardized methodologies to obtain leachates are designed for traditional biocide-based paints, but usually they are not able to highlight any effect of FRC leachate. The aim of this work was to develop a new experimental approach to compare the potential toxic effect of different FRC leachates. Five different commercial FRC were aged in a flow through system with natural seawater and leachates were collected and tested after different ageing times: 0-7-14-30-60-90 days. As regards leachates preparation, the methods were similar to standard ones (72 hours of leaching time) but the ratio between coated surface and seawater volume was modified drastically in order to maximize the concentration of potential leaching products in the seawater. At each aging time leaching products were tested on II stage nauplii of *Amphibalanus amphitrite* and mortality and swimming speed alteration, an extremely sensitive sub-lethal end-point, were evaluated after 24 and 48 hours of static exposition to leaching products. All silicone coatings leachates showed a toxic effect at 0 days (after 72 hours of leaching in seawater) and, in general, the toxicity (both acute and sub-lethal) seemed to decrease with increasing ageing time. However, results allowed us to appreciate differences among the formulations: for three out of the five tested coatings any toxic effect was detected after 7 days of ageing, while the other two products exhibit toxicity until 14 and 30 days of ageing. The method developed proved to be an efficient tool to compare silicone coating formulations, providing information that, coupled with the antifouling performance evaluation, can be important for the design and optimization of new and existing formulation of FRC.

3B - ORAL 5

INSTANTANEOUS FLOW STRUCTURES AND OPPORTUNITIES FOR LARVAL SETTLEMENT:
BARNACLE CYPRIDS SWIM TO SETTLEAnn I. Larsson^a, Lena M. Granhag^{a,b} and Per R. Jonsson^a^aDept. of Biological and Environmental Sciences, University of Gothenburg, Tjärnö,
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Water flow affects settlement of marine larvae on several scales. At the smallest scale local flow regime may control the probability of adhesion to the substrate. Our aim was to mechanistically understand the transition from suspended to attached larvae in turbulent flow. Recently it was proposed that opportunities for larval settlement in turbulent boundary layers depend on time windows with suitable instantaneous flow properties. In flume flow we characterized the proportion of suitable time windows in a series of flow velocities with focus on the near-bed flow. The change in the proportion of potential settling windows with increasing free-stream velocities was compared to the proportion of temporary attachment of barnacle cyprids at different flow velocities. We found large instantaneous flow variations in the viscous sublayer where attachment took place in all tested flows. The probability of temporary attachment in cyprids declined with local flow speed and this response was compatible with a settling window lasting at least 0.1 s with a maximum local flow speed of 1.9 - 2.4 cm s⁻¹. Cyprids swam against the near-bed flow (negative rheotaxis) and the swimming speed (1.8 cm s⁻¹) was close to the critical speed that permitted temporary attachment. We conclude that temporary attachment in barnacle cyprids requires upstream swimming to maintain a fixed position relative to the substrate for at least 0.1 s. This behavior may explain the ability of barnacles to recruit to high-flow environments and give cyprids flexibility in the pre-settlement choice of substrates based on flow regime.

3B - ORAL 6

EFFECT OF LECTINS ON CONSPECIFIC SHELL EXTRACT-INDUCED SETTLEMENT OF
LARVAE OF THE PACIFIC OYSTER CRASSOSTREA GIGAS

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Larvae of the Pacific oyster *Crassostrea gigas* are induced to settle by a glycoprotein from shells of conspecifics. In the course of our study to characterize the nature of the settlement inducing compound in shells of conspecifics, we conducted preliminary experiments to select a suitable substrate for settlement assays. Furthermore, we investigated the effect of lectins on the induction of settlement by the glycoprotein from shells of adult conspecifics.

Larval settlement on four substrates: plaster plate, nitrocellulose membrane paper, GF/C filter paper and glass were investigated. In addition, settlement of larvae on these substrates when extract from shells of conspecifics (OSE or oyster shell extract) were added at different concentrations to them were also tested. Larvae were then placed in multiwell plates with either shell chips of adult *C. gigas* (SC) or GF/C filter papers containing OSE (100 mg SC eq per GF/C; OSE paper) and their settlement in the presence of different concentrations (0, 0.5, 5 and 50 µg mL⁻¹) of the lectins: lentil lectin (LCA), concanavalin A (ConA), soybean lectin (SBA) and wheat germ agglutinin (WGA) were investigated. OSE papers and pediveligers were separately treated in different concentrations of WGA for 2 h, and the effects of the treatments on larval settlement were also investigated. Furthermore, the inhibiting effect of 50 µg mL⁻¹ of WGA on larval settlement on OSE paper was also investigated in the presence of different concentrations (10⁻⁴, 10⁻⁵, 10⁻⁶ M) of N-Acetyl-D-glucosamine (GlcNAc). SC and OSE on GF/C filter paper were also dyed using fluorescein isothiocyanate conjugated WGA (FITC-WGA) and then observed under a fluorescence microscope.

C. gigas larvae did not settle on any of the substrates tested. With OSE added to the substrates, larvae settled differentially on them, show highest settlement on GF/C filter paper. Almost no settlement was observed on SC and OSE papers in the presence of LCA, ConA and WGA at concentrations of 5 µg mL⁻¹ and higher, but at 0.5 µg mL⁻¹, WGA effectively inhibited larval settlement. Treatment of the OSE paper with WGA reduced settlement in a manner dependent of the WGA concentration. Treatment of the larvae with 5 µg mL⁻¹ of WGA also reduced larval settlement on the OSE paper. The inhibiting effect of WGA was cancelled by GlcNAc, resulting in settlement that was at the same level as that on OSE paper without WGA. A WGA-binding sugar compound in SC and OSE was visualized with FITC-WGA. Thus, a WGA-binding sugar moiety of the glycoprotein in shells of conspecifics may mediate the settlement of *C. gigas* larvae on conspecifics.

3B - ORAL 7

THE EFFECT OF SILVER NANOPARTICLES ON BIOFILM COMMUNITY COMPOSITION AND MUSSEL PLANTIGRADE SETTLEMENT

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Silver nanoparticles (AgNPs) have good antimicrobial activity, which lead to a range of medical environmental application. However, the knowledge of interactions between AgNPs and biofilm community composition and mussel settlement remains unknown. In the present study, we investigated bacterial communities in biofilms developed on PDMS decorated with AgNPs (PDMS@AgNPs) by 454 pyrosequencing, relationship between biofilm community composition and plantigrade settlement of the mussel *Mytilus coruscus*, and the effect of PDMS@AgNPs on plantigrade settlement. PDMS@AgNPs had no any effect on plantigrade settlement. Except young biofilms (7 d), old biofilms developed on PDMS@AgNPs reduced plantigrade settlement comparing biofilms on controls (Glass and PDMS). The dry weight, bacterial and diatom density and chlorophyll a concentrations of biofilms on PDMS@AgNPs were significantly reduced. Pyrosequencing via 454 revealed that the bacterial phylum Proteobacteria was the first dominant group in Glass (59.7%) and PDMS (71.1%) communities. In contrast, Proteobacteria only represented 0.9% of total reads and Firmicutes was the first dominant group in PDMS@AgNPs (98.8%) communities. Bray-Curtis analysis showed that there was only 1% similarity between libraries of PDMS@AgNPs and controls. Thus, AgNPs affected the composition of bacterial community in biofilms, and subsequently this variation in bacterial community may explain the discrepancy of their corresponding inducing activities on plantigrade settlement of *M. coruscus*.

Acknowledgments:

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RISK MANAGEMENT IN MARINE CORROSION

SESSION CHAIR: DR BRENDA LITTLE

SENIOR SCIENTIST, NAVAL RESEARCH LABORATORY, STENNIS SPACE CENTER, UNITED STATES

3A - KEYNOTE

SEAWATER NUTRIENT POLLUTION AND THE LONG-TERM IMMERSION CORROSION OF STEELS

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Structural steel is used widely for major infrastructure in or around seawater harbours, for shipping and for offshore structures. Protection using coatings or cathodic protection systems or both can be effective if properly maintained. However, some infrastructure is unsuited to such protective measures and reliance is then placed on a sacrificial corrosion allowance. A variety of data show that corrosion loss for steel in marine exposure conditions is not a simple linear function of time and that it is influenced by many factors, principally seawater temperature and microbiologically influenced corrosion (MIC). Recent studies have shown that in seawater MIC mainly is the result of elevated concentration of dissolved inorganic nitrogen (DIN). Two developments are reviewed in this paper. The first is the construction of model for the long-term corrosion of steel in DIN nutrient-polluted seawater using data from a variety of field exposure programs. The simplified model is shown to asymptote the long-term part of the previously proposed bi-model model for marine corrosion. The second considers the phenomenon of accelerated low water corrosion and that this also is correlated with DIN nutrient concentration. The results allow for average seawater temperature and also for the variability in observed corrosion losses. The models permit prediction of long-term corrosion loss in waters polluted with DIN and of known average temperature. The results of example applications suggest that anthropological pollution of seawater potentially is a major hazard for corrosion of steel infrastructure.

3A - ORAL 1

AN UNDERSTANDING OF ENVIRONMENTAL FACTORS CAN IMPROVE CORROSION RISK ASSESSMENT IN NATURAL WATERS

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In general, an understanding of factors involved in corrosion greatly improves corrosion risk assessment and management. Although the primary environmental factors affecting corrosion in aquatic environments are widely known, the effects of salinity and sunlight have not been adequately explored. Further, combinations of two or more environmental factors have also not been fully taken into account. This paper addresses the variable effects that salinity, sunlight and biofilms can have on the active/passive behaviour of stainless steels (SSs) in natural waters. Particular focus is made on how combinations of the above factors can lead to anomalous test results and how an understanding of these factors can improve corrosion risk assessment. Examples and case histories are drawn from the author's recent work illustrating salinity dependence of SS under passive as well as active conditions, and the increased biocorrosion risk for SS in low salinity waters over that in full-strength seawater. It is also explained how misleading the careless use of the term "marine" can be while referring to estuarine and/or brackish water situations. Illustrations are also cited on a totally lower risk of SS corrosion due to sunlight. The mechanisms by which photons influence the physicochemistry of surface passive films, biofilm activities and cathodic kinetics—all at the same time—are presented. It is believed that these fresh data will enhance the prediction of corrosion risks in natural waters, including estuarine and marine conditions, thus contributing to better corrosion management.

Acknowledgements:

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3A - ORAL 2

PREDICTING THE RISK OF MICROBIOLOGICALLY INFLUENCED CORROSION: A STATE OF THE ART REVIEW

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6528 Alakoko Drive
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Abstract for IBBS-16 in Lodz, Poland, 3rd - 5th September 2014

Risk can be defined as probability multiplied by consequence. Increasingly, owners, operators and insurers are requiring design engineers to quantify probability of microbiologically influenced corrosion (MIC) for new and existing construction in marine environments, e.g., pipelines, bridges and harbor infrastructure. Expected rates of corrosion are essential for specifying corrosion allowances and for estimating safe operational lifetimes. To-date, however, there are no direct measurements of numbers and types of microorganisms that can be used to predict corrosion rates resulting from their presence. In most cases the occurrence of MIC is considered an upset condition, rather than a predictable phenomenon. Several new approaches have been proposed, including quantification of microbial activities, e.g., sulfide production and/or the environmental constraints on an activity, e.g., temperature, nutrients or oxygen. The presentation will provide an overview of current models being used to assess MIC probability in specific marine applications and the likelihood that more generalized models can be developed.

3A - ORAL 3

COMPOSITE COATING TO CONTROL BIOFILM FORMATION AND MIC

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The mechanism for Microbially Influenced Corrosion (MIC) has been discussed and debated in these relatively long years. Some researchers attribute the main reason to a certain bacteria's unique metabolism such as SRB. Others insist that biofilm would play an important role for MIC. We authors support the involvement of biofilm at the beginning stage of MIC, even though we don't deny the correlation between MIC of metallic materials and the chemical reactions as metabolism. We already confirmed the concavo-convex biofilm profile formed on materials surfaces would lead the corrosion initiation, since oxygen concentration cells could be formed due to the geographical profile of biofilm. If the mechanism of MIC could be attributed to biofilm to a greater or lesser extent, we could assume that the substrate's capability for biofilm formation would be one of the controlling factors against MIC. Therefore, it should be an effective countermeasure to control biofilm. Many possibilities and approaches for the purpose would be considered. In this experiment, we focused on the surface finishing, treatment or modification.

Iron and steel which have been used in many industries including shipment, marine structures etc. tend to attract lots of bacteria on them. Whatever the reason might be, the dissolution of iron or steel and the formation of iron ion in the vicinity of surface would be one of the key roles to increase bacterial number on the material surface. In this experiment, some composite coatings were applied on metallic materials such as steel, copper, nickel aluminum and their alloy specimens as well as glasses. Their biofilm formation capabilities were measured, compared each other, using a specially devised Laboratory Biofilm Reactor (LBR)⁽¹⁾. Then the biofilm was observed and evaluated by a 3D optical microscope, a low vacuum SEM-EDX, UV-VIS etc.⁽²⁾, and the results were compared each other and the mechanism was discussed from various viewpoints. And the tendency of biofilm formation on those material surfaces and their changes

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SHIP HYDRODYNAMICS AND ENERGY EFFICIENCY

SESSION CHAIR: DR ANDREW SCARDINO

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION, AUSTRALIA

4A - KEYNOTE

THE EFFECT OF ANTI-FOULING PAINTS ON LONG TERM HYDRODYNAMIC PERFORMANCE OF SHIPS RELATED TO ENERGY EFFICIENCY

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There are many different types anti-fouling paint systems currently applied on ships in the market. However, the effect of these paints on the ship hydrodynamic performance is complex and not easy to evaluate accurately. This is based on the fact that the ship's hydrodynamic performance will be affected by not only the weather such as wave, wind and current but also rather complex and unpredictable bio-fouling and ageing effect of the hull roughness and propeller. In this lecture, the recent research works related to this area will be reviewed and a practical prediction method for the long period ship performance will be introduced by taking into account the roughness and bio-fouling effect. The reflections on the recently introduced IMO criteria for the energy efficiency will be discussed.

4A - ORAL 1

FOULING AND VESSEL PERFORMANCE ON AN ALUMINIUM HULLED PATROL BOAT OPERATING IN TROPICAL WATERS

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The Royal Australian Navy's aluminium hulled patrol boats operate predominately in tropical waters and face severe biofouling pressure as they can remain alongside in port for extended periods which can result in sub-optimal performance of the fouling release coatings. This presentation outlines various ship trials conducted to assess the hull and propeller fouling penalties on one patrol boat instrumented with torsionmeters to the propeller shafts to record torque and shaft power. Regular hull and propeller fouling inspections have mapped the rate of calcareous fouling over a number of years. Controlled steady steaming trials have been conducted under a range of vessel fouling conditions including fouled hull, clean hull and newly painted hull. Attempts have been made to determine the penalty of fouled propellers by examining trials with polished, painted and fouled propeller conditions. Significant increases in shaft power and fuel consumption at fixed speeds have been recorded. Issues encountered with measuring performance penalties on an operational vessel are outlined. Options for protecting vessels from fouling when in port are also described.

4A - ORAL 2

FOULING-RELEASE PROPELLER COATINGS: EFFICACY AND DURABILITY ON A US NAVY LSD-CLASS VESSEL

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Accumulation of roughness elements, including hard fouling and mineral deposits, on propeller blades significantly degrades ship fuel efficiency. Coated propellers may improve the roughness condition of propeller blade faces and by that reduce propulsive fuel use and maintenance costs (avoid diver cleanings). In 2008 a silicone fouling-release coating was applied to the propellers of a US Navy Landing Ship Dock (LSD) 41-class vessel. Observations indicate 1) accumulation of biofouling during the ship's inactive periods, 2) sloughing of accumulated biofouling during underway periods, 3) control of accumulation of mineral deposits where the coating remains intact, and 4) physical coating degradation especially along blade edges and on the suction faces. Hard fouling sloughing has been complete on the blade suction faces, and nearly complete on pressure faces where retained fouling (<1% cover after extended operations) was mainly limited to the area near the blade root. Coating physical degradation has occurred along blade leading edges and is normally to bare metal. On blade faces coating physical degradation is a mix of topcoat and full system loss, and is mainly associated with the effects of cavitation, although strike damage and loss associated with blistering and chipping have also been observed. After more than 4 years of service, approximately 70% of the coating remains intact on propeller suction faces, while the coating is more than 90% intact on pressure faces, and there is substantial variation among and across propeller blade faces. Despite coating physical degradation, roughness associated with biological and mineral deposits remains well controlled. Predictive models based on the Rubert roughness scale were used to estimate propulsive fuel savings associated with biofouling and mineral deposit reduction alone. Savings approaching 2% were estimated compared with uncoated blades. Recent data may suggest these estimates were conservative. Future work will focus on accounting for the effects on ship performance due to the roughness that develops over time as the coating degrades, and on identifying coatings that are more durable and/or more effectively release hard fouling accumulations.

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4A - ORAL 3

LONG TERM DRAG PERFORMANCE OF HULL COATINGS FOR OCEAN GOING VESSELS

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Fuel efficiency is often assessed via skin friction measurements of fouling control coatings in clean condition or in between static immersion cycles. These conditions inadequately represent the ocean-going fleet, so better prediction tools are needed.

The skin friction of hull coatings change over time so the initial friction properties of freshly applied coatings are therefore insufficient to accurately estimate the fuel efficiency of a hull over a typical dry-docking period. Furthermore, it is well-known that static immersion compared to dynamic immersion leads to more fouling and as a consequence static immersion leads to a higher skin friction. Hence, the ability of a fouling control coating to protect against fouling under varying immersion conditions is of high importance when determining the most fuel efficient fouling control solution for a given end-application.

In response to this, an experimental protocol is presented in this paper. The protocol has been designed to measure skin friction of fouling control coatings over an extended time period and under conditions mimicking the vast majority of ship profiles (speed and activity) in today's market. The experimental procedure consists of two parts; an aging setup and a laboratory scale rotor capable of measuring skin friction on coated cylinders. Four hull top-coats were exposed for 25 weeks in Roskilde fjord, i.e. relatively cold brackish water, during early May to late November. The immersion conditions consisted of 5-week cycles with 2 weeks of static immersion followed by 3 weeks of dynamic immersion, all in natural seawater. The dynamic immersion consisted of spinning coated cylinders at a speed of 8.1 knots. It was found that the skin friction increased significantly more during the static immersion periods compared to the dynamic periods. It was, furthermore, found that the fuel efficiency of the investigated top-coats increased in the following order: fluorinated fouling release coating (worst), silylated-acrylate self-polishing co-polymer coating and hydrogel-based fouling release coating, and hydrogel-based fouling release coating containing biocides (best). However, the difference in skin friction between silylated-acrylate self-polishing co-polymer coating, hydrogel-based fouling release coating, and hydrogel-based fouling release coating containing biocides is small. The immersion conditions consisted of 40 percent of the time being static which potentially could give biased favor of skin friction for either fouling release coatings or the silylated-acrylate self-polishing co-polymer coating.

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4A - ORAL 4

HYDRODYNAMIC PERFORMANCE EVALUATION OF FDR-SPC (FRICTIONAL DRAG REDUCTION SELF-POLISHING COPOLYMER)

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The reduction of frictional drag of turbulent boundary layer is of great importance for the fuel economy of ship. The fuel consumption of global ocean shipping in 2003 was estimated 2.1 billion barrel/year (Corbett and Koehler, 2003), which corresponds to approximately 200 billion US\$/year. Thus, 10% reduction of frictional drag would lead to saving of 16 billion US\$/year. Recently, there have appeared several kinds of low-frictional AF coatings based on diverse physical mechanism of skin friction reduction. One of such examples is a PEO-containing AF paint by Yang et al. (2014), who reported the release of PEO, the well-documented drag reducing agent leading to Toms effect, from the surface of coating. It was found that the PEO-mixed paint exhibited significant drag reduction efficiency in excess of 10% from various lab tests. In their paint, however, the PEO powders were physically mixed with the paint matrix, thereby giving rise to an increase in surface roughness and rapid release associated with the solubility of PEO in water. These factors may be detrimental to the longevity of drag reduction performance.

With a view to overcoming the drawbacks of the PEO-mixed paint in the previous research, a novel FDR-SPC is first synthesized in this study. The drag reducing functional radical such as PEGMA (Poly(ethylene) glycol methacrylate) has been utilized to participate in the synthesis process of the SPC. The types of the baseline SPC monomers, the molecular weight and the mole fraction of PEGMA were varied in the synthesis process. The resulting SPCs were coated to the substrate plates for the subsequent hydrodynamic test for skin friction measurement. In a low-Reynolds number flow measurement using PIV (Particle Image Velocimeter), a significant reduction in Reynolds stress was observed in a range of specimen, with the maximum drag reduction being 15.9% relative to the smooth surface. In the high-Reynolds number flow measurement with a flush-mounted balance and a LDV (Laser Doppler Velocimeter), the skin friction of the present FDR-SPC is found to be smaller than that of smooth plate throughout the range of Reynolds number, with the average drag reduction efficiency being 13.5% over the smooth plate. These results strongly support that the present FDR-SPC gives rise to the Toms effect based on chemical reaction at the surface of the coating.

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4A - ORAL 5

A NUMERICAL TOOL DEVELOPMENT ON THE EFFECT OF COATING AND BIO-FOULING ON THE MARINE PROPELLERS

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Unpredictable fuel prices and environmental requirements in recent years have forced the maritime community to reduce fuel consumption of ships by improving their propulsive efficiency. In order to improve the propulsive efficiency of a ship it is important not only to keep the hull free from bio-fouling, but also its propeller. Mossad (1986) stated that the effect of the propeller surface condition could be less important than the hull condition, but it would be significantly more important in terms of energy loss per unit area. In economic terms, high return on a relatively cheap investment can be obtained by a properly set propeller maintenance strategy. Coatings of propellers can avoid or reduce not only fouling growth, but also galvanic corrosion of ship hull as well resist to cavitation erosion.

Within the frame of propeller, Atlar et al. (2002) and Atlar et al. (2003) showed that anti-fouling coatings which give a surface finish equivalent to that of a new or well-polished propeller can display up to 6% gain in the efficiency against the surface represented by Rubert E. This highlights the importance of the roughness characteristics affected by the coating on the blades. As the continuation of the development of numerical tool on the effect of coating and bio-fouling on the marine propellers in Newcastle University this paper aims to present the development of an algorithm to formulate the effect of coating roughness and bio-fouling on a full scale and integration with a state-of-the-art lifting surface propeller analysis program to predict the effect of coating and bio-fouling on the propeller performance. To investigate the effect of coating and bio-fouling on the propeller performance two cases for the "good" and "poorly" applied new foul release coating conditions and three for "light slime", "heavy slime" and "small calcareous" fouling conditions are considered on a 95000 DWT Tanker propeller.

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4A - ORAL 6

PREDICTION OF THE EFFECT OF HULL FOULING ON SHIP RESISTANCE USING CFD

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The development of marine biofouling on ships' hulls induces added resistance, which may cause a drastic increase in fuel consumption and greenhouse gas (GHG) emissions. Despite the existence of various antifouling systems, which may suppress the accumulation of biofoulers to a certain degree, it is still impossible to eliminate biofouling completely. It is therefore critical to be able to predict the effect of hull fouling on ship resistance from both economic and environmental points of view, particularly considering the recent attention directed towards NO_x, SO_x and CO₂ emissions from shipping.

In this study, the effect of hull fouling on ship frictional resistance is predicted using a computational fluid dynamics (CFD) software (STAR-CCM+). Initially, the standard wall function of the software is replaced by a wall function which shows appropriate roughness function behaviour for fouling in both transitionally rough and fully rough flow regimes. Afterwards, a case study is carried out using a flat plate of ship length, since hull fouling is assumed to affect the frictional resistance only. Therefore, a flat plate, which represents a handymax tanker, is chosen and CFD simulations are performed. A range of fouling conditions is considered at different operational speeds, and the frictional resistance coefficients of the plate are evaluated for each case. Finally, the results are presented in both graphical and tabular forms and discussed in detail.

Acknowledgments:

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4A - ORAL 7

AN INVESTIGATION INTO DIFFERENT SKIN FRICTION ANALYSIS METHODS FOR COATINGS WITH DIFFERENT ROUGHNESS RANGE

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New generation of foul control coatings will replace 80% of existing coatings. There are two types on the market, which can keep a ship free from fouling for 5 years namely: Tin free Self-Polishing Copolymer's and Foul Release coatings. These two coatings, which were commercially introduced into the antifouling market in the mid-1990s, offer antifouling performance over the same time period. However, the working principles of the aforementioned fouling control coatings are different. The former use a chemical and hydrolysis based control system; the latter use a rather physical and low surface energy based defence system. In the past limited research that was undertaken on these coatings have shown that Foul Release Systems may have lower drag characteristics. However more data are needed using scientific approaches to compare systematically the roughness and drag characteristics of these coatings, at least, in laboratory conditions.

Collecting data on the roughness and drag characteristics of coatings can be achieved utilizing the most reliable and scientific methods available, e.g. laser based roughness analysis and boundary-layer analysis based skin friction analysis. Accordingly boundary-layer and roughness data can be collected on the same flat panels that can be coated with different range of coatings. It is important to point out that roughness ranges of coated surfaces can be different from each other even for the same type coating application apart from the fact that different coatings will present different roughness ranges. It is concluded that one should show great care in the determination of the coatings' skin friction characteristics based on the boundary-layer analysis methods, as most of the methods can be applicable to rougher or smoother surfaces only .

In Emerson Cavitation Tunnel of Newcastle University, an ideal boundary layer measurement set up has been developed for coating performance tests. In this facility many types of commercial and experimental coatings have already been tested including a number of replicates over the recent years. To the Authors knowledge there are not many studies available on multiple replicates of specific coatings. As a result, there is a respectable amount of data collected on roughness as well as the boundary-layer characteristics to make a comprehensive evaluation of these characteristics.

Within this framework, the main objective of this paper is to review the roughness and skin friction data of the selected panels coated with various foul control coatings making use of different analysis methods for the roughness and skin friction.

4A - ORAL 8

BOUNDARY LAYER AND ROUGHNESS CHARACTERISTICS OF HULL COATINGS

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²Maritime Technology Division, Ghent University, Belgium*

This study presents an experimental investigation conducted at the Emerson Cavitation Tunnel (ECT) of Newcastle University to investigate the boundary layer and surface roughness characteristics of three commercially available hull coatings: a tin-free SPC, a new generation Foul Release coating and a novel nanostructured coating. In addition, two coatings that have been artificially roughened by mixing in sand grit during application were included in the study. These coating were roughened in order to mimic either hull surfaces that have been a while in service or poor quality coating applications.

In order to examine the boundary layer characteristics of the coatings, a large flat plane model with interchangeable test sections was used. A two-dimensional DANTEC Laser Doppler Velocimetry (LDV) system was used to collect the boundary layer data of each coating.

The measurements provided critical parameters including local skin friction coefficients and roughness functions. The surface roughness of the tested coatings was analysed using both a non-contact laser profilometer and a stylus instrument.

The tests and subsequent analysis allows to compare the hydrodynamic performance of these antifouling. The measured boundary layer data were analysed by using different analysis methods to predict and compare the skin friction characteristics of these coatings.

Acknowledgments:

The work presented in this study was partially funded by International Paint and partially by Dredging International nv.

4A - ORAL 9**HULL AND PROPELLER PERFORMANCE MEASUREMENT FOR VESSEL IN SERVICE**

*Andreas Krapp
Jotun A/S, Sandefjord, Norway*

Given the considerable impact of hull and propeller surface degradation on a ship's overall efficiency, a practical method is needed to measure changes in hull and propeller performance for a vessel in service. It is only with a clearly defined and commonly accepted method that hull and propeller performance become manageable, also including situations where the party paying for measures (the vessel owner typically) is not identical with the party profiting from the potential fuel savings (e.g. the charterer).

This presentation will give an overview over existing proposals on the market and report on the status of the work on an ISO standard on «Measurement of Changes in Hull and Propeller Performance» (ISO 19030). Furthermore, a practical method to measure changes in hull and propeller performance over a docking interval will be discussed in detail with reference to numerous real life examples.

MARINE CORROSION - MATERIALS AND COATINGS
SESSION CHAIR: DR DOMINIQUE THIERRY
FRENCH CORROSION INSTITUTE, BREST, FRANCE

4B - KEYNOTE**METALS AND THEIR CORROSION BEHAVIOUR IN SEAWATER - AN ENGINEERS OVERVIEW**

*Mrs Carol Powell
Marine Specialist to Copper Development Association¹ and Nickel Institute²
¹Copper Development Association, Hemel Hempstead, UK. ²Nickel Institute, Brussels, Belgium 1210.*

There are many different alloys available to engineers for structures, systems and components for use in sea water. These include steels, stainless steel and alloys of copper, nickel, aluminium and titanium. Good performance relies on an understanding of their corrosion behaviour and a requirement that they are selected and designed to their strengths and not their weaknesses. Many systems are mixed metals and knowledge of the compatibility of alloys in contact with each other is also crucial.

Different alloy groups have different methods of corroding depending on the sea conditions. Flow, temperature, stagnation, pollution, applied stresses and aeration can all produce a different response. Some alloys can show uniform thinning while others may show localised corrosion which can include corrosion at crevices, pitting, stress corrosion and corrosion of preferential phases.

This Keynote presentation provides a brief overview of the world of metals and their response to one of the most corrosive environments there is, giving examples of the types of corrosion which can occur and how to avoid them.

4B - ORAL 1

STUDY OF PHYSICO-CHEMICAL AND MICROBIOLOGICAL TESTING PARAMETERS IN RELATION TO MARINE CORROSION

SA Wade^{1,2}, D. Miller³, H. Lawn³, Y. Lizama^{1,2}, PR Stoddart^{1,2}, SL McArthur^{1,2}

¹*Biotactical Engineering, IRIS, Faculty of Science, Engineering and Technology, Swinburne University of Technology, Australia* ²*Defence Material Technology Centre (DMTC), Melbourne, Australia* ³*ASC Pty Ltd, Osborne, SA, Australia.*

The corrosion of metals immersed in seawater can create costly problems for a wide range of maritime infrastructure (e.g. ships, ports, desalination facilities). Designers and engineers typically provide tolerance values for corrosion to allow for degradation, at a rate designated in a relevant standard¹. These tolerance values are loosely based on field-based corrosion tests, which have provided basic information on the importance of a range of environmental parameters^{2,3}. There are difficulties however in using field trial data to gain an understanding of the relationship between corrosion and relevant seawater properties. This includes how to account for the fact that the properties of interest typically fluctuate over time and commonly only limited (often one-off) information on physico-chemical data is provided. Alternatively, laboratory-based tests with set values of relevant parameters can be performed⁴, but then difficulties in replicating field conditions (e.g. using artificial solutions) tend to arise, typically resulting in a poor correlation between field and laboratory measurements.

In this work, periodic measurements of the physico-chemical and microbiological properties of seawater were performed and were compared with laboratory-based corrosion tests undertaken using seawater sampled at the same time. The testing was performed over a 10 month period at two test sites located several thousands of kilometers apart. The aims of the work were to evaluate the relative importance of individual physico-chemical parameters involved in the corrosion process of steel immersed in seawater, and to improve the understanding of one of the less well known corrosion mechanisms, that being microbiologically influenced corrosion.

The results obtained show that significant and relatively rapid changes in physico-chemical and microbiological readings can occur over time, which has implications for interpreting corrosion trials and the development of testing programs. Despite differences between the seawater properties at the two test locations and over time the individual corrosion rates determined in lab tests showed relatively little variation. A significant difference however was observed between the corrosion rates of samples tested in the field and in the lab.

Acknowledgments:

The authors would like to acknowledge the support of the Defence Materials Technology Centre (DMTC). The DMTC was established and is supported under the Australian Government's Defence Future Capability Technology Centres Program.

References:

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4B - ORAL 2

CORROSION PERFORMANCE OF 25%CR SUPERDUPLEX STAINLESS STEEL FOR DIFFERENT SEAWATER APPLICATIONS

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Keywords: Crevice and Pitting corrosion, superduplex stainless steel, natural seawater, crevice geometry

The utilisation of 25%Cr superduplex stainless steel for seawater applications is sometimes controversial since contradictory corrosion results can be found in the literature from both field and laboratory studies. The same high alloy stainless steel may resist localized seawater corrosion for a given application or in a given study, and may be shown to fail for other applications or studies. It is clear that the nature of crevice corrosion of stainless steel is stochastic, which might partially explain some contradictory results, but for most cases, the specific characteristics of the seawater applications including confined zone geometries (e. g. nature of the gaskets, surface treatments, contact pressure, threaded connections, etc.), service conditions (e. g. seawater renewal, seawater treatment, heat flux transfer, etc.) and/or the product form (e. g. wrought or cast alloys) are sufficient to explain discrepancies of the results regarding corrosion resistance. Several studies on the seawater corrosion resistance of high alloy stainless steels were performed in our laboratory. The present paper reviews some results of 25%Cr superduplex stainless steel which was evaluated for different seawater applications such as tube heat exchangers, subsea umbilicals, fitting devices on base materials and welded assemblies. Corrosion resistance for both natural and chlorinated seawater was investigated, at different seawater temperatures and considering the specific characteristics of the final application. The results of the 25%Cr superduplex stainless steel are compared to other high alloy stainless steels and are correlated with the specificity of each tested application. The paper confirms that the limits of utilization of superduplex stainless steels in seawater are highly dependent on the crevice geometry and/or the service conditions of each specific application.

4B - ORAL 3

LOCALIZED CORROSION OF 316L STAINLESS STEEL IN SINGAPORE SEAWATER

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Biologically induced corrosion of 316L, stainless steel was investigated at three different test sites off the northeast and south coasts of Singapore. By inspection of fouling species on the coupons with up to 30 months of exposure, it was found that the fouling species varied with location with different fouling species having influences on the metallic corrosion, which was microscopically examined. The manner of the localized corrosion appeared to be related to shape of the barnacle base, with most of corrosion sites were found under dead barnacles located at the edge of the colony and with sizes around 8-12mm. On some specimens serve localised corrosion was observed that appeared to be initiated by oysters or green mussels. Although the extent of the attack on the surface looked low, below long tracks (centimetres) of internal corrosion that could penetrate 2 mm thickness inside 12 months developed.

Acknowledgments:

This work was jointly funded by Defence Science & Technology Agency (POD 0411835) and the US Office for Naval Research (N00014-04-1-789).

INDUSTRY SESSION**SESSION CHAIR: MR JOHN LEWIS****SENIOR ASSOCIATE, ES LINK SERVICES, AUSTRALIA****4B - KEYNOTE****CONVENTIONAL AND INNOVATIVE ANTIFOULING TECHNOLOGIES IN INDUSTRIAL COOLING WATER SYSTEMS***Dr Sanjeevi Rajagopal^{1,2,*}*¹*Department of Animal Ecology and Ecophysiology, Institute for Wetland and Water Research, Radboud University Nijmegen, Heyendaalseweg 635, 6525 AJ Nijmegen, The Netherlands*²*Institute for Marine Resources and Ecosystem Studies (IMARES), Wageningen University, Ambachtsweg 8A, 1785 AJ Den Helder, The Netherlands***E-mail: s.rajagopal@science.ru.nl*

Chlorination is the most commonly used chemical antifoulant in industrial cooling water systems. The most important criteria deciding the chlorine dosing frequency are intensity of fouling at a given location, cost and environmental discharge specifications. Accordingly, different types of dosing regimens are employed such as intermittent, continuous, semi-continuous, pulsed etc. Recent data indicate that newer methods of chlorine administration may help reduce the chlorine inventory and thereby reduce the environmental burden caused by discharge from power plant cooling systems.

As biofouling essentially is an interfacial problem, the required biocide concentrations must be available at the water-substratum interface, rather than the bulk water. Therefore, we have attempted to test the use of porous surfaces as a biocide delivery vehicle using dynamic experimental system. The logical approach is to deliver the right concentration of biocide at the very interface, so that effective concentration is maintained at the actual site of fouling, leaving the bulk water concentrations largely negligible. Our results indicate that chlorine reduction to the extent of about 70% can be easily achieved by using porous ceramic surfaces in place of conventional bulk water continuous chlorination for controlling mussel fouling.

Carbon dioxide (CO₂) has the potential to be utilised as a molluscicide for control of mussel fouling. The synergetic effect of chlorine (commonly used antifouling chemical) and CO₂ to most important fouling mussel species would be desirable, because any reduction in chlorine inventory used for fouling control will preserve the environment of the receiving waters. An attempt has also been made to estimate the economic considerations of CO₂ in combination with sodium hypochlorite, by applying the present results in industrial cooling water systems.

New methods such as microencapsulated pellets (commercially known as BioBullets) and biological agents (pathogens, parasites, predators or competitors that reduce populations of the target species) have also been investigated. Environmental and cost factors will play very important roles in deciding whether some of these technologies will be finally accepted by utilities as a replacement of chlorination. It is, therefore, necessary that emphasis may continue to be placed on research aimed at development of environmentally benign biofouling control technologies.

4B - ORAL 1**THE BURDEN OF BIOFOULING: WHAT DOES IT WEIGH?***John A Lewis**ES Link Services Pty Ltd, Castlemaine, Vic 3450, Australia*

Biofouling can adversely affect the performance and integrity of offshore structures by increasing structural loading, promoting corrosion, impairing visual inspection, and adding weight. Added weight is generally not an issue for fixed structures, but can be on floating structures at the surface or suspended mid-depth. The weight of an attached biofouling organism in water is a function of its volume and density relative to the surrounding seawater, and therefore varies with the external and internal composition and structure of the organism. Commonly referenced values for the specific gravity (SG) of biofouling are 1.4 for hard fouling and near 1.0 for soft fouling. These numbers trace back to Woods Hole (Marine Fouling and its Prevention, 1952). The SG value of 1.4 for hard fouling was recently questioned during a study on offshore fouling rates because the SG of calcite, the predominant form of calcium carbonate in hard fouling shells, is 2.7. To investigate this anomaly, the specific density of a range of organisms sampled from offshore structures in the Timor Sea was determined by measuring the volume and weight of individual organisms. From these measurements and calculations, the average specific density for hard shelled biofouling organisms was found to be 1.74, which is significantly higher than the Woods Hole value. The average SG for soft fouling was 1.06, and therefore near past estimates.

4B - ORAL 2**PREVENTING THE ESTABLISHMENT OF INVASIVE PESTS IN A MARINE CONSERVATION AREA THROUGH EFFECTIVE MARINE BIOSECURITY**

*Simon McKirdy and Johann van der Merwe
Chevron Australia Pty Ltd, 18 Mount St Perth, Australia, 6000*

Construction of the Chevron-operated Gorgon Project commenced in 2009. The Project is being constructed on Barrow Island, a 23 567 ha island around 60 kilometres off the northwest coast of Western Australia. The water surrounding Barrow Island is a marine conservation area.

A comprehensive Quarantine Management System (QMS) was developed prior to the commencement of the Project. In relation to marine pests, the key objective of the QMS was to prevent the introduction of marine pests. To achieve this, all vessels mobilising to the island must be free of secondary biofouling prior to commencing work and must exit Barrow Island waters within defined timelines. In addition, three risk management zones were established that restricted vessel movements and length of stay. The range of vessels visiting the island during construction has included offshore support vessels, landing craft tankers, dredges, tugs, barges, utility vessels, module carriers, heavy lift vessels and crew transport vessels. The vessels originated from intrastate, interstate and international ports.

All vessels mobilising to Barrow Island must adhere to strict dry docking, cleaning and anti-foul coating requirements. Coupled with these requirements are mandatory under water inspections in lieu of dry docking.

As the Project nears the start of operations and a significant decrease in vessel mobilisations, this paper presents the challenges and successes of implementing a marine biosecurity system to prevent the introduction of invasive pests to a marine conservation area. An analysis of anti-foul coating applied to different vessel types and duration of mooring in high risk waters is included. The paper particularly focusses on the success of this marine biosecurity system in preventing the introduction of the Asian Green Mussel to Barrow Island and the waters of Western Australia.

The Gorgon Project is operated by an Australian subsidiary of Chevron and is a joint venture of the Australian subsidiaries of Chevron (47.3 %), ExxonMobil (25 %), Shell (25 %), Osaka Gas (1.25 %), Tokyo Gas (1%) and Chubu Electric Power (0.417 %).

4B - ORAL 3**EFFECT OF PARTICLE SIZE OF COPPER PYRITHIONE ON LEACH RATES FROM ZINC ACRYLATE ANTIFOULING COATINGS**

*Paul Kappock
Lonza Microbial Control*

Copper pyrithione is the leading co-biocide used in antifouling coatings with over 50% market share globally. It is manufactured by several suppliers with varying particle sizes and particle size distributions. The effect of particle size on leach rates is important. For solid low water solubility biocides, the antifouling coatings can be formulated to vary the leach rate for a given particle size biocide, but the particle size of the biocide and the concentration of biocide will also contribute to the rate of leaching from the paint film. Water temperature, pH, salinity, hull shape, and sailing pattern of the ship will also be a factor in biocide leach rates. There are several methods for measuring the leach rate. Although the ISO standard is considered to overstate the actual leach rate, it is nonetheless a good tool for comparison purposes. This paper will discuss the effect of the particle size of copper pyrithione on the leach rate of biocide from a zinc acrylate self polishing antifouling paint.

4B - ORAL 4**MICROBIOLOGICALLY INFLUENCED CORROSION RISKS IN THE INTERIOR OF OFFSHORE WIND MONOPILES**

*Felipe Leon¹, Nanni Noel¹, Anouk Bruin¹, Axel Homborg²
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The use of monopiles is still popular in shallow waters such as those found in the North Sea or the Baltic Sea. Monopile foundation corrosion, especially internal corrosion is one important aspect that has been largely ignored in corrosion guidance. Interiors of monopiles have in general not been included in corrosion allowance and also are often not protected. Engineers assume an air-tight environment in which corrosion will be irrelevant once oxygen is depleted. This has not been the case in practice and many installations show signs of unexpectedly high corrosion. It is still a matter of debate the role of MIC but as experienced in this work, it could be an important aspect to take into account. We investigated reported physicochemical and biological aspects of environments typical of actual wind monopile installations. In addition, we did laboratory investigations on a model monopile foundation (with unprotected interior) using natural entrapped seawater. The water, which was sporadically exchange remained largely anoxic during the test period. In such conditions, we observed comparable microbial numbers inside and outside the monopile, for an observation period of up to 1 year. Internal corrosion rates of unprotected steel reached up to 0.28 mm/y and did not go below 0.1 in the gas/liquid interface. Corrosion rates in deeper parts of the monopile foundation (close to seawater/sediment interface), where lower but mass loss continued during the whole observation period. Our research has found that the risk of internal corrosion (including MIC) can increase with the exchange of seawater from below the monopile which in turn, depends on intrinsic permeability characteristics and organic load of marine sediments. Also the corrosion risk in the liquid/gas interface remains relatively high even if the entrapped seawater remains with low levels of dissolved oxygen.

Acknowledgments:

The work presented in this study has been funded within the DOWES (Dutch Offshore Wind Energy Services) project.

4B - ORAL 5

EVALUATION OF ANTIFOULING PAINTS AND DEVELOPMENT OF BIVALVE MOVEMENT SENSOR FOR BIOFOULING CONTROL IN COOLING WATER SYSTEM OF TWO NUCLEAR POWER PLANTS AT KALPAKKAM, INDIA

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Biofouling is a significant issue in the cooling water systems of coastal power plants. Madras Atomic Power Station (MAPS) which has been operating since 1983 faces fouling problem and a Prototype Fast Breeder Reactor (PFBR) which is under construction at Kalpakkam is expected to encounter the same. Despite of chlorination, various screens (trash rack and intake gates) located at intake, to act as barrier for organism's entry, are fouled severely due to the very location of the chlorine injection lines and the inward flow direction rendering the chlorination ineffective there. Thus, either application of antifouling paint or physical cleaning is the plausible method of biofouling control at this location. Similarly, during transition period between readiness of cooling water system and non-availability of chlorination plant makes the cooling water tunnel susceptible to fouling even leading to subsequent ineffectiveness of chlorination. In view of this, a study was carried out to evaluate six different commercial paints (Nukote, International paint, Sigma Glide, Fluglide, Polyglass and Biofoul) for their biofouling control potential. These paints were exposed to coastal waters for about 4 months. Results showed that, Nukote, Fluglide and Polyglass paints were more prone to biofouling as compared to International paint, Sigma Glide and Biofoul. The growth on panel coated with Sigma Glide was easily removable without any damage to the base coating. However, barnacles penetrated International paint coating after 3 months. Sigma Glide showed a unique behavior of easy detachment of organisms as compared to the other two paints. Sigma Glide antifouling paint is planned to be studied further coupled with flow for assessment of bio-growth self removal. Biofoul coating was also found to be efficient to control biogrowth during the exposure period. Initially barnacles and hydroids settled on Biofoul coated panels, however, they never grew to adults stage. It is understood that Sigma Glide is a low surface energy silicon based paint, whereas, Biofoul is a copper based paint. Green mussel the climax community, was the main fouling organisms at this location. In order to control them, a unique intermittent biocide dosing system based on magnetic reed-relay sensor principle has been developed in-house and experiments are being conducted. Finally, it may be possible to dose biocide in tune with mussel valve opening using this system thereby reducing operational cost and environmental problem. The paper also discusses usefulness of experimental results from a Ti plate heat exchanger loop setup for PFBR.

SHIP HULL MANAGEMENT
SESSION CHAIR: PROF GEOFFREY SWAIN
DIRECTOR, CENTRE FOR CORROSION AND BIOFOULING CONTROL,
FLORIDA INSTITUTE OF TECHNOLOGY, UNITED STATES

4A - KEYNOTE

HULL EFFICIENCY: A REVIEW OF 100 INWATER HULL CLEANINGS AND THEIR IMPACT ON REDUCING FUEL CONSUMPTION AND EMISSION ON OCEAN GOING VESSELS

Mr Daniel Kane

Propulsion Dynamics, United States

Through utilization of a hull efficiency analysis technology named CASPER® the audience will be presented with case studies on 100 inwater hull cleanings on tankers, bulkers and containerships and the corresponding reductions in fuel consumption and emission. Underwater photos before and after hull cleanings will be presented along with precise speed and fuel consumption analysis. In addition, separating the effects of hull fouling from propeller roughness and long term hull coating performance after the inwater cleanings will be discussed.

The International Maritime Organization [MEPC 63/23] has determined that hull condition an important factor in the Ship Energy Efficiency Management Plan and the International Standards Organization has established a working group [ISO-TC8-SC2WG7] to develop a standard for hull and propeller performance monitoring.

KEY WORDS: Hull efficiency, hull resistance, Biofouling, hull and propeller performance monitoring; ship

4A - INVITED

MANAGING UNDERWATER HULL PERFORMANCE

Dr Raouf Kattan

Safinah Ltd, UK

This paper will provide an overview of the factors that owners should consider to optimise hull performance to reduce drag and hence achieve fuel savings.

It will consider issues at the design and new building stage, including coating specification that are increasingly overlooked and then look at factors to be considered once the vessel is in service and the options that are available to the owners for managing the underwater hull and the impact of speed and fuel penalties.

The work will draw on established research and experiences from work carried out by Safinah Ltd.

4A - ORAL 1**DATA MASHING, BIG DATA AND MULTIVARIATE MODELLING TO PREDICT COATING PERFORMANCE***Jeremy C Thomason¹ and Richard Ramsden²**¹Ecotecnica SCP, AP #88, Administración Siglo XXI, Mérida, Yucatán, CP 97111, México and ²International Paint Ltd, Stoneygate Lane, Felling, NE10 0JY, UK*

Predicting the performance of coatings on ships is time consuming and costly, involving the use of broad scale testing on in-service vessels. If the coating is successful it will have sufficient life to enable the company to collect data about its performance across a whole variety of vessels. Indeed this has been happening since 1974 for one company's products and the results collated into one database. Since 2003 we have been carefully analysing this database. We reported the initial logistic predictive models at the ICMCF in Rio de Janeiro and subsequently the more refined structural equation modelling approach in ICMCF Gateshead. The conclusion then was that latent variables contribute considerably to the errors and that more data were required. Accordingly we have sourced an array of data from various satellite systems and commercial maritime databases and mashed these with the ship performance database to give an analytical database which can be questioned to give historical and predictive coating performance for in-service vessels

4A - ORAL 2**THE EFFECTS OF GROOMING ON COPPER ABLATIVE COATINGS: A SIX YEAR STUDY***Melissa Tribou**Florida Institute of Technology, 150 West University Blvd*

Greater than 90 percent of US Navy ships are coated with copper ablative paint. These ships may spend long periods of time pier-side. This makes them vulnerable to fouling and the development of a leached layer which reduces the effectiveness of the paint. Hull grooming has been proposed as a means to keep the coatings in an active and fouling-free condition. This study investigated the effect of grooming on a US Navy qualified copper ablative coating exposed statically for six years. Grooming was performed weekly or monthly with controls left ungroomed. The fouling community was visually assessed and dry film thickness (DFT) measurements were taken to monitor coating loss. It was found that weekly grooming reduced or prevented fouling, monthly grooming reduced fouling, and the ungroomed surfaces became fully fouled. There were only small differences observed in the reductions in DFT for weekly, monthly and ungroomed surfaces. This demonstrated that grooming did not remove excessive amounts of coating. The results presented suggest that grooming is a viable method to keep copper ablative coatings in a fouling-free condition without increasing copper output.

4A - ORAL 3**MANAGING IN-WATER HULL INSPECTIONS, CLEANING AND OTHER TREATMENTS TO REDUCE BIOSECURITY RISK AND BIOLOGICAL ROUGHNESS: THE EXPERIENCE AT SINGAPORE***Robert Hilliard¹ and Derek Tan²**¹Intermarine Consulting Pty Ltd, Darlington, Perth, Western Australia 6070**²Leading Marine Technology Pte Ltd, Choa Chu Kang Central Post Office, PO Box 210, Singapore 916837*

As the world's busiest port in terms of annual shipping arrivals (>2.3b tonnes), Singapore transships ~20% of all shipping containers and handles nearly half the annual supply of seaborne crude. It is also the world's busiest maritime hub in terms of ship bunkering, supplies, maintenance and repairs. With nearly 140,000 vessel arrivals per year and over 2000 movements per day, much of this traffic occurs within the port's 34 designated anchorages that are administered by the Maritime Port Authority (MPA). In-water inspection, cleaning and repair activities are permitted in 10 of these, with over 15 diving companies offering such services as a regular part of their commercial operations. While most shipyards will allow diving inspections on vessels at maintenance berths, in-water cleaning is normally banned to maintain berth integrity and operational safety.

Demand for in-water inspections and hull cleaning at Singapore has steadily risen in recent years, both from the increasing attention being paid to fuel saving measures by trading ship operators, and the need for vessels engaged to port or offshore development activities in Australia and New Zealand to undertake pre-departure inspections and, where appropriate, to undergo remedial cleaning, other treatments or dry-docking, so as to meet the biosecurity requirements set by the charterer and/or states within these countries.

This paper reviews and highlights some of the key advances, pitfalls and other salient experiences that the authors have gained over this period from advising, guiding and supervising these in-water operations for a large and wide variety of vessel types in the anchorages and dockyards of Singapore. Their combined experience pool that forms the basis of this review presently covers over 500 vessels, from 2007 to present.

Acknowledgments:

Much of the work and some of the equipment described in this review has been actively supported and facilitated by APL (Singapore) and Master Tech Diving Services Pte Ltd (Singapore).

4A - ORAL 4**DRYDOCK COATING INSPECTION METHODOLOGY AND SHIP HULL MANAGEMENT**

Abhishek Koka, Geoffrey Swain
Center for Corrosion and Biofouling Control
Florida Institute of Technology,
Melbourne,
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Outer ship hull coatings have been identified by the International Maritime Organization (IMO) as a major contributor to ship performance and are now included in the Energy Efficiency Design Index (EEDI), for new ships, and the Ship Energy Efficiency Management Plan (SEEMP) for all ships. With increasing fuel prices and stringent emission norms, there is a need to improve coating performance through coating selection, application, quality control and maintenance. This paper presents methodology that has been developed to use during drydocking. It includes the measurements relative to existing coatings, procedures for surface preparation, new coating application and the condition of the ship at out docking. The purpose of the method is to improve quality control, provide a baseline of information to the owner and data that can be analyzed for future coating selection.

FOULING IN AQUACULTURE
SESSION CHAIR: DR BELINDA YAXLEY
PETUNA AQUACULTURE PTY LTD

4B - KEYNOTE

CHALLENGES AND OPPORTUNITIES FOR UNDERSTANDING AND MANAGING
BIOFOULING IN MARINE AQUACULTURE

Dr Oliver Floerl
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The development of biofouling assemblages on aquaculture infrastructure or on culture organisms themselves poses considerable challenges to the industry. Aside from impacting farming operations, biofouling can affect stock health and quality, and contribute to depletion and deposition impacts of aquaculture farms. Aquaculture farms can also provide habitats and dispersal pathways to non-indigenous biofouling species. Unfortunately, neither the finfish nor shellfish aquaculture industries have found fully reliable and sustainable solutions to prevent or manage the unwanted development of biofouling. However, because marine aquaculture is a rapidly growing global industry expected to play an increasingly important role in providing food security, it is imperative to strengthen our efforts at finding solutions and best-practice management for biofouling on farm surfaces. To start off the session for Biofouling in Aquaculture at the 2014 ICMCF I will provide a broad overview of biofouling in finfish and shellfish farming, and of its known and potential impacts on the industry and the environment. While doing so I will highlight our most critical knowledge gaps and provide suggestions for R&D priorities that will help us minimize the unwanted consequences of aquaculture biofouling.

4B - ORAL 1

BLUE MUSSEL (*MYTILUS GALLOPROVINCIALIS*) OVER SETTLEMENT ON NEW ZEALAND'S GREEN-LIPPED MUSSEL (*PERNA CANALICULUS*) FARMS

*Javier Atalah*¹, *Grant Hopkins*¹ and *Barrie M Forrest*¹
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The indigenous green-lipped mussel, *Perna canaliculus*, forms the backbone of the New Zealand aquaculture industry, with annual exports earnings equating to \$US218M. Like many mussel growing regions around the world, crops are susceptible to the detrimental effects of fouling pests (e.g., pre-emption of space, overgrowth and dislodgement, food competition). In the Marlborough Sounds, the largest mussel farming area in New Zealand, the invasive blue mussel (*Mytilus galloprovincialis*) is considered to pose one of the greatest fouling threats to the industry as it can result in considerable crop losses. The New Zealand Marine Farming Association has been monitoring blue and green-lipped mussel spat for almost 40 years on settlement arrays deployed throughout the region. The goal of this project is to use these data to identify patterns that could be exploited to avoid blue mussel over-settlement. Preliminary analyses revealed large inter-annual and spatial variability in the settlement of both mussel species, with distinct seasonal and depth patterns. Relationships between spat settlement and environmental conditions, such as water temperature, salinity, primary productivity and Southern Ocean Oscillation Index, have been explored. In addition to identifying seasons and growing areas less prone to blue mussel over-settlement, this work will also help to identify new sites appropriate for green-lipped mussel spat collection.

Acknowledgments:

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4B - ORAL 2

THE ROLES AND DYNAMICS OF CALCIUM ION AND GLW-AMIDE PEPTIDES IN SETTLEMENT AND METAMORPHOSIS OF ACTINULA LARVAE OF MARINE HYDROID TUBULARIA MESEMBRYANTHEMUM

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Along the Japanese coasts, dense colonies of the marine hydroid *Tubularia mesembryanthemum* can be observed on the artificial substrata used in aquaculture or in cooling water systems of power plants. *T. mesembryanthemum* produces the unique-shaped larvae, actinulae in their life cycles. Actinula larvae demonstrate two forms of attachment to substrata: temporary attachment by the nematocyst discharge from the tentacle tips, and permanent settlement by cement secretion from the basal protrusion.

We examined the exogenous and endogenous factors affecting the settlement and metamorphosis of actinula larvae. The temporary attachment and settlement of actinulae were strongly promoted by tactile stimuli resulted from the water motion using new stirring assay. The mechanosensitivity of actinulae increased rapidly following the larval liberation from the maternal gonophores. The temporary attachment and mechanoresponse of actinulae were inhibited reversibly by decrease of external Ca^{2+} concentrations or addition of gadolinium ion in artificial seawater. A simultaneously transitory surge of $[Ca^{2+}]_i$ was observed in the tentacle tips during the nematocyst discharge, using visualization of intracellular Ca^{2+} levels by fluorescent calcium indicator (fura-2) and image-analyzing system. During settlement and metamorphosis of actinulae, the intracellular Ca^{2+} concentration increased specifically in the tentacle ring and the basal protrusion.

The effects of peptidic neurotransmitters were examined on the actinular settlement, together with the dynamics of the immunoreactive neurons during the actinular development. GLWamide peptides clearly induced the settlement and metamorphosis of actinulae. As the results of immunocytochemical labeling, GLWamide immunopositive reactions were detected in neurosensory-like cells of the tentacle tips and nerve fibers along the tentacles in competent larvae, while not in young larvae.

These results suggest that an influx of external Ca^{2+} via mechano-sensitive cationic channel activation play important roles in the larval mechano-reception, and internal Ca^{2+} and GLWamide peptides control the settlement and metamorphosis of actinula larvae as the internal signals.

4B - ORAL 3

ARE SALMON FARMS PROPAGULE RESERVOIRS FOR MARINE BIOFOULING ORGANISMS?

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Biofouling is one of the great challenges for salmon farming in Norway since it can negatively impact fish health, cleaner fish behaviour and cage stability. Common antifouling treatments such as copper coatings are not sufficient to prevent growth on nets and therefore are combined with regular high-pressure cleaning. However, current cleaning practices may facilitate biofouling growth at the farm site as they lead to the release of large numbers of larvae and possibly viable organisms into the environment.

To investigate whether the release of biofouling material during net cleaning promotes biofouling development at fish farms, recruitment rates to experimental panels were compared between two fish farms and two reference sites over two net cleaning cycles spanning a period of 3 months. In our experiment, the density of recruits did not differ between cleaning and non-cleaning periods, suggesting that the release of larvae during net cleaning has no effect on biofouling intensity. However, we found surprisingly large differences in recruitment between farm and reference sites. Propagule counts at the farm sites (72 ± 10 per $0,032 \text{ m}^3$, mean \pm CI) were on average 5 to 26 times higher than at the reference sites (6 ± 1). A potential explanation for substantially higher recruitment at farm sites is the availability of extensive artificial substrates other than cage nets, which are seldom or never cleaned. Haphazard sampling of structures such as moorings, bottom rings and collars showed significant amounts of biofouling organisms that may function as biofouling reservoirs and supply larvae independent of cleaning cycles. Further implications for salmon farms as biofouling reservoirs are discussed and relevant research questions and knowledge gaps pointed out.

POSTER SESSION

PO - 1

DETERIORATION OF ELASTOMERIC GASKET BY HYPOCHLOROUS ACID

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Biofouling is a severe problem in heat exchange systems using seawater as the coolant. The fouling deposits consist of a variety of organic substances, microorganisms (bacteria, algae), and macro-organisms (mussels, barnacles, etc.). Sodium hypochlorite (NaOCl) has been widely used to inactivate and remove the organisms attached on heat exchange plates and pipe-line. However, periodic or frequent cleaning using NaOCl often causes the deterioration and damage of elastomeric gasket, leading to the decrease in the sealing ability. For the maintenance of the stability and duration of gasket, it is necessary to clarify the mechanism of the deterioration of gasket by NaOCl. In this study, the deterioration of carbon black-filled ethylene propylene diene terpolymer (EPDM) in NaOCl solution was studied as a function of pH. Free available chlorine (FAC) exists in two forms, i.e., undissociated hypochlorous acid (HOCl) and hypochlorite ion (OCl⁻), depending on the solution pH. Electron probe microanalysis showed that the permeation of FAC into EPDM was accelerated in the acidic pH region and it depended on the concentration of HOCl in the NaOCl solution. It was also found that carbon black stimulated the diffusion of HOCl inside the EPDM. The tensile strength of EPDM decreased with the increase in the degree of HOCl permeation. As a result of immersion of EPDM in NaOCl solution of pH 4.5, at which FAC mainly exists as HOCl, surface morphological change became remarkable and corrosion pits, blisters, and cracks were formed on the HOCl-diffused EPDM surface. X-ray photoelectron spectroscopy (XPS) analysis showed that C-Cl, C-O, C=O, and COO groups were formed on the surface. These results indicated that chlorination, hydroxylation, oxidization, crosslinking and chain scission reactions occurred between HOCl and EPDM. On the basis of the above data, we proposed deterioration processes of EPDM by HOCl.

PO - 2

AMPHIPHILIC ACID FUNCTIONAL SILOXANE POLYURETHANE COATINGS

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Amphiphilic coatings are a current area of investigation as a possible solution to combat marine biofouling. Due to the diverse adhesion profiles of more than 4000 different marine fouling organisms, coatings with absolute hydrophobic or hydrophilic surfaces may not provide suitable fouling-release performance to a broader spectrum of organisms. The first generation acid-containing amphiphilic siloxane-polyurethane coatings showed improved diatom and bacteria release, however they impaired green macroalgae and barnacle removal. Thus, in order to fine tune the surface composition, a series of amphiphilic siloxane-polyurethane coatings were prepared from blending aminopropyl terminated acid functional polydimethylsiloxane (APT-PDMS-A) with polydimethylsiloxane (APT-PDMS) in the polyurethane system. Coating surfaces were characterized by contact angle, surface energy, and X-ray photoelectron spectroscopy (XPS) measurements to explore the self-stratification of acid groups. Laboratory biological assays for bacteria (*Cytophaga lytica*), algae (*Navicula incerta* and *Ulva linza*), barnacles (*Amphibalanus amphitrite*), and mussels (*Geukensia demissa*) were used to evaluate the fouling release performance of these coatings.

PO - 3

ANTIFOULING EVALUATION OF POLYMER COATED SURFACES IN SEA

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Finding ways to endure the performance and life of manmade materials immersed in water particularly in the marine environment is one of the hot topics of research. Such structures, if not protected suitably, harbor a diverse variety of organisms. This causes a range of problems from enhanced emission of green house gases to species invasion quite apart from compromising the integrity of immersed surfaces. As heavy metal based formulations as well as those based on biocides are considered hazardous to human beings and marine organisms, environmentally benign solutions are sought to tackle the problem of fouling. Polymers are used in various forms in everyday life and have become an inherent part of human life in the space age. Because of their ability to cover surfaces and thereby influence surface characteristics, polymer coated surfaces are widely used as performance materials. As an extension, polymer coated surfaces have also been explored and in some instances used as environmentally acceptable alternatives to tackle the problem of fouling.

This talk will summarize our efforts in the design and synthesis of various monomers and polymers. Specialty monomers bearing tertiary nitrogen atoms capable of forming quaternary ammonium salts were synthesized through various chemical transformations. Polymers which can be classified as hydrophilic, hydrophobic and those grafted with pendant heterocyclic units were also synthesized. Glass vials were coated with these polymers and were evaluated for anti-settlement of cyprids and toxicity, at first, in the lab. Subsequently, coated, rectangular glass slides were immersed in the sea to study the effect of various polymers in preventing fouling of marine organisms. As majority of antifouling studies involves settlement of early stage organisms under controlled conditions in the lab, the field antifouling evaluation being proposed to be discussed could add vital knowledge and enrich the area of polymer based antifouling research.

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PO - 4

MOLECULARLY ENGINEERED MULTIFUNCTIONAL SURFACES TO COMBAT MARINE BIOFOULING

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Stainless steel (SS) is widely used in the construction of marine ship hull and underwater structure due to its high mechanical strength and corrosion resistance. Continuous exposure in the marine environment renders it susceptible to biofouling, leading to serious device failure and economic loss. Despite high efficacy in biofouling mitigation, coatings that release metal or organic biocides are exhausted overtime and under environmental scrutiny. There has been an increasing interest in the development of non-released antifouling coatings as an environmentally-friendly alternative. Through molecular engineering, dopamine as mussel-mimic adhesive can be beneficially used for surface modification to combat marine fouling and biofouling. The catechol groups of dopamine can spontaneously form bidentate complexes with the metal center of SS. Antifouling copolymer of dopamine methacrylamide and poly(ethylene glycol) methyl ether methacrylate (P(DMA-co-PEGMEMA)) and amino-rich branched polyethyleneimine (PEI) can be assembled sequentially on the SS surface *via* catechol-amine reaction in a layer-by-layer (LbL) manner. Dopamine methacrylamide can be combined with oligopoly(ethylene glycol)/N-hydroxyethyl acrylamide and N-(3-aminopropyl)methacrylamide hydrochloride to make antifouling dopamine-mimetic terpolymers, which are readily deposited on SS surface. Despite the simplicity of the coating processes, direct functionalization with anchorable and hydrophilic polymers are effective in preventing bacterial adhesion, biofilm formation, microalgal attachment, and barnacle cyprid settlement.

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PO - 5

POLYMER BRUSH COATINGS FOR REDUCING MARINE BIOFOULING AND BIOCORROSION

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Current marine antifouling technology based on self-polishing or controlled-depletion coatings and paints is under environmental scrutiny. Non-biocide-releasing functional polymer brushes and coatings with tailored anti-fouling, anti-microbial and/or anti-adhesion properties represent an environmentally-benign alternative. Benefiting from recent advances in controlled radical polymerizations and 'click' chemistry, polymer brush coatings have been designed to inhibit molecular fouling, microfouling and macrofouling through incorporation or inclusion of multiple functionalities. The 'beneficial' application of barnacle cement as a biological anchor for antifouling and antimicrobial polymer brushes can be compared directly to that of dopamine, a marine mussel inspired biomimetic anchor widely used in surface-initiated controlled radical polymerization. The environmentally-friendliness of the surfaces was further enhanced by coupling of natural biocides, such as lysozyme and chitosan. The direct application of barnacle cement as surface anchor for 'clicking' of antifouling and antimicrobial polymer brush coatings can be readily demonstrated. Synthetic biomimetic anchors, such as poly(dopamine acrylamide)-co-poly(propargyl acrylamide) copolymers, can also be coupled to a metal surface via coordination interaction of the catechol moieties, yielding a functionalizable metal platform containing 'clickable' alkyne groups on the surface for incorporation of azide-labeled antimicrobial and anti-fouling moieties. Surfaces functionalized with hydrophilic, hydrophobic, cationic, anionic and zwitterionic polymer brushes exhibit different efficacies in preventing protein adsorption, bacterial adhesion and settlement of barnacle cyprids. Finally, imparting of metal surfaces simultaneously with inorganic coatings (e.g. from sol-gel processes) and antimicrobial functionalities effectively inhibits biofilm formation and biocorrosion in seawater.

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PO - 6

SELF-HEALING COATING BASED ON DIISOCYANATE LOADED IN GLASS BUBBLES

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Encapsulating of very reactive healing agents with ease of processing to realize rapid or even instant repair of damage in coatings is a big challenge to advance the self-healing materials. In this study, glass bubbles (GBs) with micro-through-holes were etched with diluted 1 wt% hydrofluoric acid (HF) in a specially designed device. The etched GBs was infiltrated with a very reactive diisocyanate, toluene diisocyanate (TDI), using a vacuum-assisted device. Self-healing coating was formulated by integrating 15 wt% TDI loaded GBs (TDI-GBs) in a UV-curable adhesive, which was coated on carbon steel. Excellent self-healing anti-corrosive performance was observed for this coating when the manually scratched specimens were immersed in 1 M NaCl solution for up to 7 days. The polarization resistance tests for the specimens after corrosion tests were carried out, revealing the steel substrate was well-protected by the polymeric barrier formed from the released TDI in the scratch.

Keywords: self-healing coating, glass bubbles (GBs), toluene diisocyanate (TDI)

PO - 7

ELECTROLYTIC DEPOSITED COPPER METAL AT PROPELLERS- AN EFFICIENT METHOD FOR PREVENTION OF BARNACLE GROWTH AT YACHT PROPELLERS.

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Introduction. Barnacle growth on propellers is a well-known phenomenon among owners of small yachts as well as medium sized ships. Yacht propellers, with a layer of barnacle may lose over 80 % of its propulsion efficacy as early demonstrated in test-bed experiments (<http://www.vastkustkretsen.se/>). The cumulative increase in combustion gas, as a result of low efficient barnacle colonizing yachts propellers may cause unwanted increase of combustion gasses in the marine environment. This may be a serious and increasing marine environment problem. The increase in fuel consumption may also be a problem for the yacht-owners beside its effects on impairing the safety and sea worthiness of the yacht. Brass-metal (copper containing alloy) is usually used in yacht propellers. The commonly use of scarifying anodes, to prevent the corrosion at adjacent stainless steel materials, also result in an inhibited emission of copper ions from the propeller blades. This condition makes the copper metal inefficient to prevent colonization of barnacle at the propeller blades. In this investigation we have tried to coat the propeller blades of some 30 yachts, with electrolytic deposited 60 micron layer of pure copper metal that is expected to leach a high amount of biofouling active copper ions. We also recommended the Yachts owners to remove the scarifying anodes from the propeller axis. The **Results** of those experiments clearly indicated that the exposed pure copper metal at the propeller blades was very efficient in preventing barnacle growth, in combination with removal of the scarifying anodes. However, there was also indication of that the absence of scarifying anodes might have caused some unwanted corrosion problems at the stainless steel but this problem seems to be less important compared to the increase in propeller efficacy.



Typical appearance of a Yacht propeller at the west coast of Sweden after three summer month. Note the dense growth of barnacles at the propeller-blades.



Removal of a copper coated propeller from the electrolytic bath



Photograph of a copper-coated propeller after three summer month deployment at the west-coast. Note the absence of barnacle growth at the propeller blades. Also note the presence of barnacles at the propeller axis.

PO - 8

MAIN CHAIN DEGRADABLE SILYL ACRYLATE POLYMERS FOR MARINE ANTI-BIOFOULING

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Marine biofouling is a sticky problem. Development of environment-friendly anti-biofouling systems is a challenge. Here, we present a novel polyurethane with poly(ϵ -caprolactone) (PCL) segments in the main chain and poly(triisopropylsilyl acrylate) (PTIPSA) side chains, where the former are able to degrade in marine environment due to the attack of seawater and microorganisms whereas the latter have been commercially used in self-polishing coating. The self-polishing rate of the surface constructed by the polyurethane determined by degradation and hydrolysis can be regulated by varying its composition. Moreover, the introduction of the biodegradable PCL into the silyl acrylate polymers can also improve the dissolution of the hydrolytic moieties without the help of shear force, which facilitates the anti-biofouling in static state. We have examined the enzymatic and hydrolytic degradation of the polymers in seawater and the anti-biofouling by marine field tests. Our studies show that the degradation and hydrolysis of the polyurethane in seawater can be well controlled. Marine field tests reveal that the polyurethane has good antifouling ability due to its self-renewing property. Moreover, the polyurethane can serve as a carrier and release system of organic antifoulant, and the combined system exhibits much higher antifouling performance even in a static marine environment (Figure 1). Such systems are promising in marine anti-biofouling.

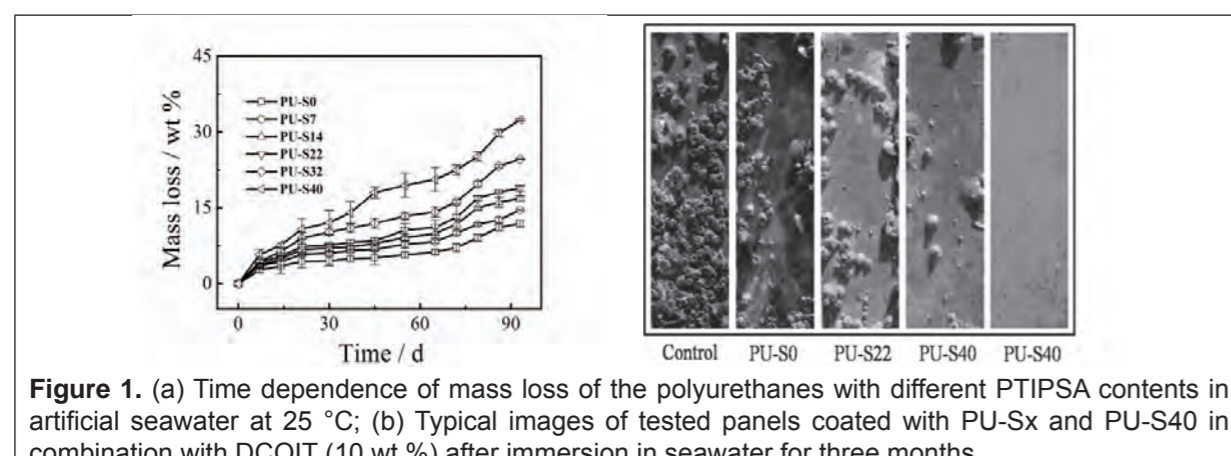


Figure 1. (a) Time dependence of mass loss of the polyurethanes with different PTIPSA contents in artificial seawater at 25 °C; (b) Typical images of tested panels coated with PU-Sx and PU-S40 in combination with DCOIT (10 wt %) after immersion in seawater for three months.

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PO - 9

BIOFOULING FIELD SURVEYS OF ENVIRONMENTALLY FRIENDLY BIOCIDES IN U.S. NAVY SONAR DOMES

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Marine biofouling of the outer surface of SONAR domes and acoustic windows is a major environmental factor responsible for degrading the performance of surface ship and submarine mounted SONAR systems. Vinyzene-Max (4,5-dichloro-2-n-octyl-4-isothiazolin-3-one, "DCOIT") is an environmentally benign antimicrobial agent that has been proposed as an alternative to globally banned tri-butyl tin (TBT)-based biocides for preventing biofouling on the surfaces of critical-use elastomers. To assess the antifouling performance of Vinyzene-Max-protected surfaces, the extent and composition of biofouling communities present on rubber transducer boots was examined during multiple in-water surveys of U.S. Navy submarines in 2013 and 2014. Several test locations were selected for long-term monitoring including submarine bases in Pearl Harbor, Groton, and San Diego using qualitative and quantitative photographic assessments and biofilm sample collections. Sediment and water samples were also obtained to determine if any measurable quantities of Vinyzene-Max and/or its breakdown products can be detected in the submarine base seafloor sediments or surrounding waters. Preliminary visual analysis of the digital images revealed less overall percent cover of fouling organisms on all Vinyzene-Max protected rubber boots compared to unprotected boots and the remainder of the hull. Marine growth on the rubber boots consisted primarily of biofilm including filamentous algae, with hard fouling (calcareous tube worms) along edges and seams of rubber boots. Biofilms were composed of marine algae (predominantly pennate diatoms), with no indications of microfouling organisms, including bacteria. Additional surveys are planned for 2014 at the same submarine bases to gain a better understanding of how the antifouling performance changes over time.

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PO - 10

POLYMER BINDERS, COMMERCIAL BIOCIDES AND IMMERSION SITES: ALL INFLUENCE MACROFOULING ASSEMBLAGES ON CHEMICALLY-ACTIVE ANTIFOULING COATINGS

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From an environmental purpose, there is a need to reduce the amount of biocides from antifouling coatings in the marine environment as these biocides can cause severe damages on the marine life. The ECOPAINT PACA project (2007-2011) aimed at developing chemically-active paints with a long-time efficiency and limiting toxic products. Chemically-active paints are currently designed to release biocides from the coating surface and thereby create a hostile environment for marine organisms which could colonize ship hulls [1]. Knowing that the antifouling efficiency of these coatings depends on several parameters (diffusivity of water, solubility of the polymer matrix and/or the biocidal molecule, diffusion, etc), two types of polymer matrix (solvent-based and aqueous-based matrices) have been used. 6 biocides have been studied: DCOIT (Sea-Nine™ 211N and Rocima™ 200), dichlofluanid (Preventol® A4-S), zinc pyrithione, copper pyrithione, tralopyril (Econea™) and Zineb. All these compounds have been submitted to the European Biocidal Product Directive (BPD) 98/8/EC. Field immersion tests were performed on two different sites in terms of water quality (Atlantic ocean and Mediterranean sea) for paints containing 3 wt.% of biocides. Results, including multidimensional analyses, showed significant variations of the macrofouler groups [2] and richness depending on the two sites of immersion, and whatever the biocide. All biocides reduce significantly the density of macrofoulers settled on coatings excepting Zineb in a solvent-based coating in the Mediterranean sea. The structure of macrofouler assemblages was also affected by the biocide nature. Zinc pyrithione had the highest activity in the Mediterranean sea, whatever the polymer matrix, whereas Copper pyrithione affected similarly the density of macrofoulers in all conditions. Econea™ exhibited the best performance for aqueous-based coatings in Atlantic ocean.

[1] Bressy C. *et al.* "Tin-free self-polishing marine antifouling coatings" in *Advances in Marine Antifouling Coatings and Technologies*; Woodhead Publishing: Cambridge, UK, 2009.

[2] Bressy C, Briand J-F, Compère C, Réhel K (2014) Laboratory assays and field test evaluation method. In *Biofouling Methods*, Williams D, Thomason J, Dobretsov S (eds), Wiley-Blackwell, in press.

PO - 11

PERFORMANCE ASSESSMENT OF MARINE PAINT FORMULATIONS ACTING THROUGH THE RELEASE OF ANTIFOULING AGENTS: EVALUATION OF LEACHING AND ECOTOXICITY

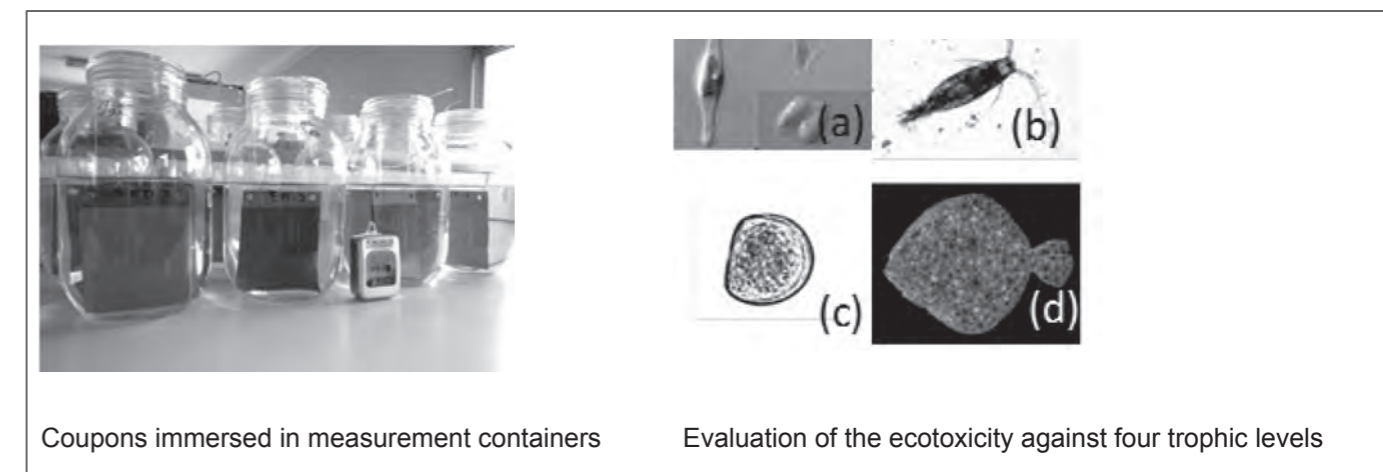
Lydia Horatius¹, Gérald Culioli¹, Françoise Quiniou², Romain Davy², Sandra Couteau¹, Chantal Compère², Christine Bressy¹
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Within the framework of the ECOPAINT research program dealing with the development of alternative and non-toxic antifouling coatings, the ecotoxicity of several marine paint formulations have been assessed. In this work, a commercial formulation (reference) and two self-polishing coatings developed in our lab were studied through the evaluation of the leaching rate of their antifouling agents (Cu- and Zn-based compounds, Sea-Nine™ 211N and dichlofluanid) and the ecotoxic effects of their leachates.

The first step of the study was to determine the leaching rates of the biocides. For this purpose, test cylinders were coated with the assayed marine paints and immersed in a storage tank filled with artificial sea water (ASW). At selected periods, the cylinders were hauled out of the tank and subjected to rotation (1h, 60 rpm) in a measurement container filled with ASW (1.5 L). Concentrations of the biocides in the container were hence determined by ICP-OES (for Cu and Zn) and LC-MS (for Sea-Nine™ 211N and dichlofluanid). These data allowed optimizing the surface of the coupons and the volume of immersion in the measurement beaker so as to obtain accurate concentrations of leachates for the subsequent evaluation of their ecotoxicity.

In a second step, optimized coupons were immersed in the selected conditions and ecotoxicity of the obtained leachates was evaluated against four trophic levels, including (a) planktonic microalgae (*Phaeodactylum tricornutum*), (b) copepods (*Acartia tonsa*), (c) larvae of bivalves (*Crassostrea gigas*), and (d) fishes (*Psetta maxima*).

Finally, the results showed that all the leachates were significantly toxic against several trophic levels. Nevertheless, the two coatings developed in our lab were found to be less toxic than the reference.

**Acknowledgments:**

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PO - 12

THE EFFECTS OF NONIVAMIDE ON LARVAL SETTLEMENT OF *BALANUS RETICULATUS*,
PINCTADA MARTENSII AND *CHLAMYS NOBILIS* AND SPORE GERMINATION OF *ULVA*
LINZA, *U. LACTUCA* AND *GRACILARIA TENUISTIPITATA*

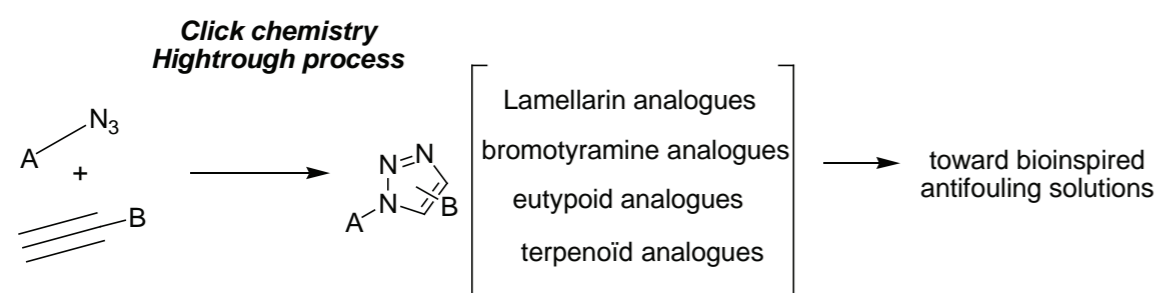
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Marine fouling is a major economic and technical problem around the world. With the development of the marine fouling prevention and the increasing awareness of environmental and human health concerns, to develop novel, non-toxic and effective anti-fouling methods have been become more and more important. Nonivamide is N-(4-Hydroxy-3-methoxybenzyl)nonanamide, which might be a potential antifouling agent. In this study, the effects of Nonivamide on larval settlement of acorn barnacle *Balanus (=Amphibalanus) reticulatus*, pearl oyster *Pinctada martensii* and scallop *Chlamys nobilis* and spore germination of algae *Ulva linza*, *U. lactuca* and *Gracilaria tenuistipitata* were assessed. As the result, it is showed that no larval settlement or spore germination occurred at the dose of 100 $\mu\text{g cm}^{-2}$. Both larval settlement and spore germination were significantly inhibited by nonivamide at doses of 10 $\mu\text{g cm}^{-2}$ for *B. reticulatus* and *U. linza*, 0.1 $\mu\text{g cm}^{-2}$ for *C. nobilis* and *U. lactuca*, and 0.01 $\mu\text{g cm}^{-2}$ for *P. martensii* and *G. tenuistipitata*. It could be concluded that Nonivamide may be an effective antifouling agent with a broad spectrum of activity against a range of marine sessile organisms including macroalgae and invertebrates, and the practical application of Nonivamide would be studied in the next step.

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PO - 13

ANTIFOULING TESTS OF LEAF PROJECT IN TROPICAL WATERS

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Since the banishment of TBT paints, scientists and industries have been investing on search of new compounds or formulations less toxic and more sustainable for marine natural ecosystem. LEAF project, Low Emission Antifouling, focus on the development of environmentally friendly antifouling paint based on post settlement inhibition. After several months of research, LEAF staff formulated four new coatings (#3.0 #4.0 #4.1 #4.1N) to be submitted in antifouling tests and compared to commercial compositions (#STD, #STD+). These formulations should be test in different marine waters around the world. Tropical tests are going on in Brazil, at two sites: Farol Island (FI), municipality of Arraial do Cabo and Guanabara Bay (GB), municipality of Rio de Janeiro; both in Rio de Janeiro State. FI is a protected area, characterized as unpolluted and GB is a very impacted area, which receives waste discharge, intense traffic vessel and other anthropic interferences. We used 4 panels of each formulation, totaling 24 panels per study area during 12 weeks. After 7 weeks, we made the first measure of the antifouling performance based on percentage of coverage (% total and % barnacle) using photo registration analyzed with Coral Point Count with Excel extensions (CPCe) software. Biofilm were observed in panels from Arraial do Cabo with high percent cover, while hydroids and serpulids were the most common in Guanabara Bay. Considering total coverage percentage, #STD and #STD+ formulations were more efficient than LEAF formulations in panels from IF (Anova/ Tukey's test: $F_{(5,17)} = 21.91$, $p < 0.01$). Although in GB these differences were not verified (Anova: $F_{(5,18)} = 1.61$, $p = 0.20$). However, if we consider only percent cover of barnacle, LEAF formulations were so efficient as commercial formulations except by #4.1N in GB, which showed higher barnacle coverage (IF Anova: $F_{(5,17)} = 0.93$, $p = 0.48$ and GB Anova/Tukey's test: $F_{(5,18)} = 6,30$, $p < 0.01$). General conclusion can be made that LEAF formulations are showing barnacle protection, which is the main problem faced by antifouling coatings.

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ANTIFOULING ACTIVITY OF N-BUTYL ALCOHOL EXTRACT FROM GORGONIAN CORAL SUBERGORGIA RETICULATA ON THE ACORN BARNACLE BALANUS RETICULATUS AND ALGAE ULVA LINZA, U. LACTUCA AND GRACILARIA TENUISTIPITATA

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The fresh minced gorgonian coral *Subergorgia reticulata* were extracted with ethanol:dichloromethane (2:1) three times at room temperature. Then the solvent in the extractant was evaporated *in vacuo*. The residues were mixed in H₂O and then extracted with ethylacetate and *n*-butyl alcohol in sequence for three times each, respectively. The resulting *n*-butyl alcohol extract was combined, reduced its volume *in vacuo* and stored at 5°C for antifouling assays. Five dosages of the extract, i.e. 100 µg cm⁻², 10 µg cm⁻², 1 µg cm⁻², 0.1 µg cm⁻² and 0.01 µg cm⁻² were tested in Falcon Petri dishes. Results showed that the larval settlement of acorn barnacle *Balanus reticulatus* for a test period of 120 h was significantly inhibited by the extract at all dosages mentioned above and no larval settlement occurred at the dosages of 10 µg cm⁻² and 100 µg cm⁻² (P<0.05). The zoospore germination of the green algae *Ulva linza* and *U. lactuca* was significantly inhibited by the extract at dosages > 1 µg cm⁻² (P<0.05). The carpospore germination of red alga *Gracilaria tenuistipitata* was significantly inhibited by the extract at dosages > 0.1 µg cm⁻² (P<0.05). It could be concluded that the *n*-butyl alcohol extract from gorgonian coral *S. reticulata* contains bioactive substances with a broad spectrum of activity against barnacle larval settlement and algal spore germination.

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ANTIFOULING ACTIVITIES OF PALMYRA FRUIT (BORASSUS FLABELLIFER) EXTRACT

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Terrestrial plants offer promising leads for the development of natural products with medical and industrial applications. In this study, anti-microfouling effect of palmyra fruit extract was assessed by *in vitro* and *in vivo* bioassays such as antibacterial activity, anti-adhesion assay, and short term field trail in the coastal waters. The palm fruit extract showed inhibitory activity against biofilm forming bacteria. The result of anti-adhesion and bacterial attachment assays showed a significant variation between control and experimental slides. In the short term field trails, the fiber plates coated with extract mixed epoxy resin prevented the settlement of microfoulers than the control plates. The toxicity of the extract was determined by calculating the LC₅₀ value against *Artemia salina*. The responsible bioactive compound present in the extract was separated by thin layer chromatography (TLC) and purified by high performance liquid chromatography (HPLC). The purified compound was partially characterized by fourier transform infrared (FT-IR) analysis. Based on the findings of this study, further antifouling assays and characterization of the active compound could lead for the development of a novel natural product antifoulant.

Keywords: Natural product; Biofouling; Antifouling; Adhesion

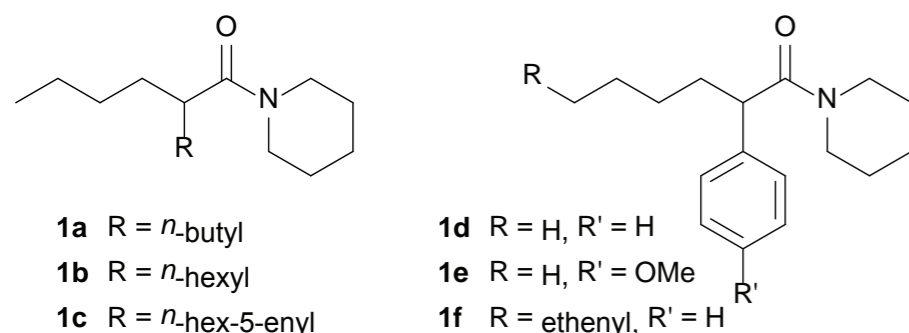
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GOING GREEN FOR MARINE: DEVELOPMENT OF ENVIRONMENTALLY FRIENDLY ANTIFOULING ADDITIVES FOR MARINE COATINGS

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Marine bio-fouling refers to the undesirable growth of marine organisms (e.g. barnacles, algae and slime) on submerged surfaces such as jetty pylons and ship hulls. Fouling on the hulls of ships leads to increased hydrodynamic drag, reducing the fuel efficiency, speed and manoeuvrability of the vessels. The search for the next generation of metal free, fully biodegradable antifouling agents for the maritime industry has begun. In a project funded by the A*STAR, NUS and the Maritime Port Authority of Singapore, scientists from ICES have been working to develop environmentally benign anti-fouling agents for applications in marine coatings.

We have identified a series of piperidiny amides which show excellent anti-settlement activity, and are expected to biodegrade easily.^{1,2} Recently we have investigated the potential for scaling up the synthesis of these amides, in aid of demonstrating the manufacturability of these potential biocidal additives. This presentation will focus on route selection and optimisation of the chemistry required.



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NEW CHARACTERIZATION METHODS IN LOW EMISSION ANTIFOULING COATINGS DEVELOPMENT

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Present biocide-based antifouling strategies are based on a continuous exposure of biocides at the film/water interface and consequently release into the environment if the antifouling efficacy is to be maintained. Such biocide-based solutions can therefore not be regarded as sustainable. The aim of the LEAF project is to develop antifouling coatings based on a new strategy. Instead of releasing the bioactive molecule into the water the biocide will be "entrapped" in the paint matrix and it first after stimuli by organism interaction with the paint surface intoxication will take place.

This new route of intoxication leads to different requirements on the paint matrix. For example, the coating must be sufficiently soft and resilient to allow post-settlement penetration of target organisms. The distribution of the biocide in the coating is important when the transfer of the biocide from paint layer to organism takes place directly when in contact with the coating and not via solubilisation in the water phase. Large aggregates and steric compartmentalization of the biocide could reduce the bioavailability. Understanding how biocides distribute and aggregate in the coating is a major technical challenge. It is also quite difficult to study the structure and dynamics of molecules in the dried film in a non-invasive manner and one is often left with studying macroscopic effects such as release of bioactive substances and swelling of the paint film on the supramolecular level and upwards. Moreover, as release of the biocide is not necessary for antifouling efficacy erosion of the paint binder can be minimized.

The new demands on the coating required new methods to be developed for characterizations. For example, mechanical analysis such as Buchholz hardness of the coatings resembling the action of barnacles on coatings, where introduced. Distribution of paint components and biocides were directly visualized in microtomed cross-sections of the dry paint film using fluorescence microscopy, scanning electron microscopy (SEM) and Time of Flight Secondary Ion Mass Spectroscopy (ToF-SIMS). For coating stability and erosion, both dynamic methods as the rotating drum and static accelerated test methods were employed. Characterization results including biocide release and antifouling efficacy will be presented.

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 Project name: LEAF - Low Emission Anti-Fouling project



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COLONIZATION AND SUCCESSION OF MARINE BIOFILM-DWELLING CILIATES IN RESPONSE TO ENVIRONMENTAL VARIATION

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Despite high abundances in marine biofilms, influences of protozoa on the structure and function of biofilms is poorly understood. There is however increasing evidence that the presence of protozoa can influence both biofilm structure and population dynamics. We investigated the temporal composition of ciliate assemblages in biofilms, and how they are influenced by seasonal variation and aspect (North/South alignments) during the fouling process. Biofilm ciliate communities were studied in temperate Australian waters (Williamstown, Victoria) over two distinct seasons during 2012-2013. Artificial substrates were colonized at 1 m depth and sampled bi-weekly during three week deployment periods. The results showed that the assemblage was similar on both aspects, although many species were observed earlier on the north facing aspect. A total of 16 ciliate genera were identified using both live observation and silver impregnation staining techniques. Sessile ciliates were represented by species of the order Peritrichida, and vagile forms belonged primarily to the orders Hypotrichida, Pleurostomatida and Scuticociliatida. The peritrich *Zoothamnium* spp. was the most dominant species across all samples. Vagile ciliates had low abundance in comparison however accounted for the majority of the species diversity. Multivariate analysis revealed significant differences in proportions of functional groups and colonisation/growth rates confirming that aspect can differentially influence abundance and taxonomic structure of ciliate communities. The colonization and succession dynamics of biofilm-dwelling ciliates investigated here emphasizes the need for a refreshed view on the role of ciliates in the fouling process. Further investigation will be required to develop a more comprehensive understanding of the ecology of biofouling.

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THE EFFECT OF PDMS DECORATED WITH CNTS AND TiO₂ ON BIOFILM COMMUNITY COMPOSITION AND MUSSEL PLANTIGRADE SETTLEMENT

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PDMS is a model fouling-release coating and can mediate the settlement of fouling organisms. The anti-macrofouling activities using PDMS decorated with CNTs (PDMS@CNTs) or TiO₂ (PDMS@TiO₂) has been reported in the lab. However, the effect of PDMS@CNTs or PDMS@TiO₂ on biofilm community in the marine environment remains unknown. In addition, the knowledge of interactions between PDMS@CNTs or PDMS@TiO₂, biofilm community composition and mussel plantigrade settlement is limited. In the present study, we investigated bacterial communities in biofilms developed on PDMS@CNTs or PDMS@TiO₂ by 454 pyrosequencing, the relationship between bacterial community and plantigrade settlement of the mussel *Mytilus coruscus*, and the effect of PDMS@CNTs or PDMS@TiO₂ on plantigrade settlement. Both PDMS@CNTs and PDMS@TiO₂ had no any directly effect on plantigrade settlement. Except young biofilms (7 d), old biofilms developed on both PDMS@CNTs and PDMS@TiO₂ reduced plantigrade settlement comparing biofilms on Glass and PDMS. PDMS@CNTs reduced diatom density and chlorophyll a concentrations of biofilms. PDMS@TiO₂ did not reduce dry weight, bacterial and diatom density and chlorophyll a concentrations in biofilms. 454 pyrosequencing revealed that Proteobacteria and Bacteroidetes were the two dominant group in Glass (88.6%), PDMS (88.9%), PDMS@CNTs (96.8%) and PDMS@TiO₂ (88.1%) communities, but the substantial differences in percentages of each phylum existed. Proteobacteria was the first dominant group in PDMS@CNTs (49.6%) and PDMS@TiO₂ (63.1%) communities, while Bacteroidetes was the first dominant group in PDMS (52.3%) communities. Bray-Curtis analysis showed bacterial communities in biofilms between PDMS@CNTs and controls or PDMS@TiO₂ and controls showed variability of 23% and 29%, respectively. CNTs or TiO₂ affected the biofilm community composition, and subsequently this variation in bacterial community may lead to the discrepancy of their corresponding inducing activities on plantigrade settlement of *M. coruscus*.

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PLANTIGRADE SETTLEMENT OF THE MUSSEL MYTILUS CORUSCUS IN RESPONSE TO SHEWANELLA SP. 1 BIOFILMS TREATED BY DIFFERENT ENZYMES

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Shewanella sp. 1 biofilm (BF) showed the highest inducing activity of larval settlement of the mussel *Mytilus coruscus*. In the present study, we investigated that the effects of *Shewanella* sp. 1 BF on plantigrade settlement of *M. coruscus* and plantigrade settlement in response to *Shewanella* sp. 1 BF treated by commercial enzymes. Protein changes of *Shewanella* sp. 1 BF with and without Alcalase treated were also analyzed. Plantigrade settled in response to *Shewanella* sp. 1 BF and the maximum inducing activity of 78% was observed. The percentages of plantigrade settlement on *Shewanella* sp. 1 BF was significantly reduced when *Shewanella* sp. 1 BFs were exposed to eight enzymes. After exposure to eight enzymes, the total bacterial densities of *Shewanella* sp. 1 BFs decreased significantly. Except Lipolase, other seven enzymes including Alcalase showed good removal effects of bacterial adhesion. Alcalase showed the most effective bactericidal activity and the mortality of bacterial cells was > 40%. SDS-PAGE revealed that some protein bands decreased. The intensity value of all proteins were quantified by densitometry showed that three protein bands were disappeared (the loss of band intensity, >80%), 20 protein bands were reduced (the loss of band intensity, 21-79%), and 5 protein bands showed few changes (the loss of band intensity, <20%). Thus, these enzymes are effective in removing adhered bacterial cells and bactericidal activity of *Shewanella* sp. 1 BF, which led to the decrease in inducing activities on plantigrade settlement of *M. coruscus*.

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THE CORROSION OF ZN ANODE IN AMPHORA-CONTAINING SEAWATER

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Microalgae can cause damages to the marine engineering material by adhering to the surface of the material. In this study the adhesion of Amphora to Zn sacrificial anode was investigated. Amphora from Huanghai and Bohai Sea was identified by molecular biology techniques. The growth curve was researched by using spectrophotography. The results showed that the Amphora growth curve was divided into three phases: adjustive phase, exponential growth phase and decay phase. Effects of Amphora on corrosion of Zn anode were investigated by using potentiodynamic polarization, electrochemical impedance spectroscopy (EIS), scanning electron microscopy (SEM), fluorescence microscopy and energy dispersive spectrometer (EDS). The electrochemical results showed that corrosion potential for samples exposed to the f/2 culture solutions containing Amphora was higher than that for samples exposed to the sterile culture solutions from exponential growth phase in which Amphora start to mushroom. The EIS studies showed that Rct value in f/2 culture solutions with Amphora was lower than that of anode in the sterile culture solutions. The kind of attached algae, Amphora, which can adhere to specimen producing large of oxygen and metabolites, reduced self-corrosion potential and make the corrosion current increasing. SEM results showed that: localized corrosion occurred on the anode surface in the solutions with Amphora and a number of alga can be seen in the corrosion area. All these results provide a basic knowledge on the influence of microalgae on the corrosion of Zn sacrificial anode. This is meaningful for interpreting microbiologically influenced corrosion in situ for further.

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CHEMICAL MEDIATION BETWEEN THE MEDITERRANEAN BROWN ALGA TAONIA ATOMARIA AND THE BACTERIAL COMMUNITY ASSOCIATED TO ITS SURFACE

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In the marine environment, all submerged surfaces are rapidly colonized by bacteria and other microorganisms, resulting in the formation of complex three-dimensional structures called biofilms. This step could be followed by the attachment of macro-colonizers. Nevertheless, a number of marine organisms, such as macro-algae, appeared to be relatively free of epibionts at a macroscopic scale although they harbor surface biofilms^{1,2}. In this study, a Mediterranean alga (*Taonia atomaria*) was selected for its ability to keep its surface free of macrofoulers. However, microscopic techniques allowed the observation of a diversified biofilm on the surface of the thalli.

The purpose of this work was to understand how this alga could interact with its associated bacteria using chemical ecology approaches^{3,4}. Therefore, the surface metabolome of *T. atomaria* was studied. A specific extraction protocol was optimized for the surface compounds using a dipping technique in organic solvents associated with the control of the integrity of algal cell membrane. Sampling was carried out monthly at Carqueiranne (North Western Mediterranean Sea, France) during the period February-July 2013.

The first results showed the presence at the algal surface of a major molecule identified as a known sesquiterpenoid. Anti-adhesion capacity against reference bacterial strains was noticed for this compound, while it remained inactive against strains isolated from the algal surface. This specificity was never observed for commercial biocides nor other molecules purified from crude algal extracts of *T. atomaria*. Then, changes in surface extracts and associated bacterial surface communities were monitored using metabolomics (LC-MS) and DGGE, respectively. Seasonal fluctuations for the two parameters could be reported without any evident correlation between them. The occurrence of the major molecule throughout the seasonal monitoring was also noticed together with its capacity to diffuse in the marine environment.

In conclusion, *T. atomaria* could control at least partially the biofilm at its surface using specific metabolite(s).

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EARLY BIOFILM DEVELOPMENT AND DIVERSITY ON GRAPHENE HONEYCOMB FILMS

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Recently, free-standing graphene honeycomb films with the ability to incorporate functionalized nanoparticles have shown broad-spectrum antibacterial activity against model pathogens in laboratory assays (Yin et al, 2013). The goal of this project was to characterize the growth of bacterial biofilms on these graphene films within a natural fouling seawater environment in order to assess this novel surface's antifouling capabilities. Early biofilm development was analysed over several time points for up to a week. Bacterial density and biofilm thickness was analysed via confocal laser scanning microscopy (CLSM) and scanning electron microscopy (SEM). Bacterial community diversity was fingerprinted via terminal restriction fragment length polymorphism (TRFLP), whilst a snapshot of other microbial community members was obtained by production of a limited plasmid library. The effect of graphene honeycomb films on biofilm development in seawater and the potential applications for these films in marine applications will be discussed.

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GROWTH OF MICROBIAL BIOFILM ON GLASS SURFACE IMMERSSED IN THE SEA OFF SHIN-NAGASAKI FISHING PORT, NAGASAKI, JAPAN

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Microbial biofilms are the primary colonizers of almost any surface in the marine environment. Although marine microbial biofilms are thought to be involved in the settlement of various marine benthic invertebrates, their growth is still poorly understood. In the present investigation, we investigated the growth of microbial biofilm on a glass surface immersed in the sea off Shin-Nagasaki Fishing port, Nagasaki, Japan. We also investigated the seasonal succession and growth of periphytic diatoms in the microbial film.

Clean glass slips (26mm x 35 mm, glass slides cut into half) were immersed in the sea from a pontoon bridge adjacent to Nagasaki Prefectural Institute of Fisheries, Taira-Machi, Nagasaki, Japan for different periods from July 2010 to October 2012. At regular time intervals, microbial films on the glass slips were brought to the laboratory for measurement of biofilm dry weight and microscopic observations of the taxonomic classification and densities of diatoms in the microbial biofilm. Chlorophyll c contents of the biofilms were also measured according to the estimation method by Jeffrey and Humphrey (1975). Seawater temperatures were also recorded during the investigation.

In general, glass slips immersed in the sea were fouled, the amount increasing with the length of immersion period. During the period between May and September, attachment of barnacles and polychaetes were observed on glass slips immersed for 2 to 4 weeks. As to glass slips that were not colonized by macrofoulers, microbial biofilm dry weight reached 1.2 mg/cm² in January 2011 but ranged from 0.4 to 0.8 mg/cm². *Navicula* sp., *Nitzschia* sp. and *Cocconeis* sp. were the dominant diatom species. Diatom density ranged from 2.4 to 5.3 x 10⁵ cells/cm², while chlorophyll c content was constant at about 0.34 µg/cm², except for a peak measurement of 0.8 µg/cm² in January. Seawater temperatures were 12°C to 15°C between December and March and ranged from 25°C to 30°C between July and September.

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3-D IMAGING PROVIDES A NOVEL APPROACH FOR ANALYZING BIOFOULING

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Quantifying the abundance of fouling organisms on ships' surfaces—as well as the species composition of the fouling community—is of interest for a number of reasons, for example, to determine when hull cleaning is warranted so that drag is minimized while vessels are underway (and, by extension, fuel consumption is reduced) and to evaluate the success of newly developed anti-fouling or fouling release coatings. Here, a novel approach for determining the fouling burden on surfaces is presented: a 3-D camera imaging system with fine (5-µm) resolution. Panels immersed in a eutrophic estuary on the southwest coast of Florida, USA were imaged using this system, and the data were used to quantify seasonal changes in the surface topography of the biofouling community. Test panels, which were submerged in seawater for up to one year, were analyzed before and after gentle scrubbing to quantify the biovolume of the total fouling communities (i.e., soft and hard organisms) and the hard fouling communities, respectively. The biovolume of loosely attached, soft fouling organisms was estimated as the difference between the biovolumes measured before and after brushing. Total biofouling, measured as the biovolume per unit area, ranged from 0.01 to 1.16 cm³ cm⁻² throughout the immersion period. Soft fouling, which consisted of loosely attached organisms (eg, algal biofilms), constituted 22-87% of the total biovolume, with minimum and maximum contributions in June (seven-month immersion) and January (one-month immersion), respectively. In the future, 3-D profiles of natural fouling communities may be used to inform numerical models of fluid-surface interfaces. Likewise, this approach, with its high resolution, could be used to evaluate the success of newly developed anti-fouling or fouling release coatings. Strategies to analyze a single panel repeatedly over time, rather than destructively sampling multiple panels, would allow for observations of fouling dynamics with high spatial resolution. These and other approaches to fully utilize 3-D data sets are anticipated.

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SURFACE WETTABILITY AND THE EXPLORATORY BEHAVIOUR OF BARNACLE CYPRIDS AT THE AIR/WATER INTERFACE

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The air/water interface lies at the root of a persistent query: are cyprids trapped at the water surface lost to the cyprid settlement assay? In a sessile drop configuration, patterns of settled cyprids on hydrophobic surfaces show a significant proportion at the periphery of the drop, where it meets the solid surface at the three-phase line. In contrast, settlement on surfaces with high wettability occurs uniformly over the area of contact between the water drop and the solid surface, probed by the cyprids. The present study utilizes an apposing surface geometry to generate a water column with a predominantly vertical air/water interface. The cyprid's putatively hydrophobic carapace may dewet, thus forming a finite contact angle that confines it to the air/water interface. Cyprid exploratory behavior at the air/water interface was compared with that of cyprids in the bulk water phase, using substrates with wettabilities ranging from highly hydrophilic to hydrophobic. These data were correlated with capillary force calculations, using the substrate surface wettability and the contact angle of the cyprid's carapace. The latter was estimated from images of a cyprid using temporary anchoring points to pull away from the air/water interface. Finally, cyprid settlement patterns are compared with the capillary interaction between the meniscus formed by a cyprid trapped at the air/water interface and the meniscus formed by the water column, as it approaches the three-phase line.

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LARVAL ABUNDANCE AND THEIR RELATION WITH MACROFOULING SETTLEMENT IN THE COASTAL WATERS OF KALPAKKAM, SOUTHEAST COAST OF INDIA -A SEASONAL PERSPECTIVE

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The coastal water of Kalpakkam is used for cooling the condenser and other auxiliary systems of Madras Atomic Power Station (MAPS), where biofouling is an operational problem. A new nuclear reactor under construction is also going to use the coastal seawater for the same purpose. Macrofouling, the benthic invertebrates, exhibit a complex life cycle especially, planktonic larval stage and the benthic adult phase. Metamorphosis and settlement are the linking processes between these phases of development. Hence, considering the importance of benthic life cycle in the process of biofouling, a study was carried out to assess the availability of larval abundance and their relation with adult macrofouling settlement in the coastal waters of Kalpakkam, Southeast coast of India. Results revealed that salinity, temperature and food availability were the essential factors controlling the larval abundance and subsequently settlement of macrofouling community in this coastal water. Qualitative and quantitative results showed that late post-monsoon and pre-monsoon periods were found to be suitable for larval growth, development and survival to adult stages for most of the organisms. Among all major groups, bivalves found to establish a good relationship between its larval abundance and adult settlement. Clustering of physico-chemical and biological (including larval and adult availability) data yielded two major clusters; one formed by northeast monsoon months (October-January) and the other by post-monsoon/ summer months (February- May), whereas, pre-monsoon period (June-September) was distributed between the two clusters. Principal component analysis indicated a good association of bivalve larvae with polychaete larvae and adult bivalves with adult barnacles. However, biotic interactions between ascidians and bryozoans were found throughout the study period. Results of the present study, first of its kind from this locality, indicate that variations in larval abundance are likely to play a significant role in the formation and development of fouling community.

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THE RESPONSE OF HYDROIDES ELEGANS LARVAE TO METAL PYRITHIONE IS RELATED TO LARVAL AGE

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The effective ecotoxicological evaluation of the increasingly antifouling alternatives of organotin is a critical issue nowadays. *Hydroides elegans* usually dominates the fouling communities in some tropical and subtropical seas^[1-2]. The rapidly accumulated calcareous tubes adversely affect the efficient operation of ships and aquaculture infrastructure. In addition, the sensibility to toxin, the short reproduction cycle and accessibility of the larvae in the laboratory make *H. elegans* an ideal candidate as an animal model for ecotoxicity test of antifoulant^[1,2]. However, few researches addressed the impact of larval age on the response to antifoulants. In this experiment, we compare the response of 24-hour trochophore and 72-hour metatroch larvae to CuPT and ZnPT within 24 h and 48 h exposure period, respectively. For 24-hour larvae the values of LC₅₀ for CuPT were 8.64 µg/L (24 h) and 6.73 µg/L (48 h), the values of LC₅₀ for ZnPT were 10.95 µg/L (24 h), 7.64 µg/L (48 h); while for 72-hour larvae the values of LC₅₀ for CuPT were 9.87 µg/L (24 h) and 7.67 µg/L (48 h), the values of LC₅₀ for ZnPT were 11.17 µg/L (24 h) and 8.19 µg/L (48 h). The results showed that the values of LC₅₀ for both CuPT and ZnPT were significantly lower ($p < 0.05$) for 24-hour trochophore than those of 72-hour metatroch larvae either within 24 h or 48 h exposure. In addition, the values of LC₅₀ for CuPT were significantly lower ($p < 0.05$) than those of ZnPT for both 24-hour and 72-hour larvae. So it is recommended to consider the larval age of *H. elegans* on the design of ecotoxicological evaluation experiments and interlaboratory comparison.

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INFLUENCE OF SURFACE CHEMISTRY ON FOOTPRINT PROTEIN SECRETION AND SETTLEMENT BEHAVIOUR OF BALANUS AMPHITRITE AND B. IMPROVISUS CYPRIDS.

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Barnacles are considered to be one of the major marine fouling organisms. Their settlement behaviour has been investigated using mainly *Balanus amphitrite* as a model organism. To better understand the mechanisms involved during the colonisation of surfaces by cypris larvae we have investigated another species, *B. improvisus*, which is reported to have different surface preferences compared to *B. amphitrite*. This study aims to unravel the effects of surface physicochemical cues, in particular surface free energy (SFE) and surface charge, on the settlement of cyprids of both species. The use of well-defined surfaces under controlled conditions further facilitates comparison of the results with *B. amphitrite*. Furthermore, since this phase of pre-settlement behaviour is characterised by temporary adhesive (footprint) deposition, considered to be fundamental to surface exploration and surface discrimination by cyprids, some of the chemistries used for the settlement assays were used to investigate temporary adhesive-surface interactions.

Cyprids were exposed to a series of model surfaces, namely self-assembled monolayers (SAMs) of alkanethiols with varying end-groups, homogeneously applied to gold-coated polystyrene Petri dishes. The settlement response was significantly higher on negatively charged SAMs and lower on positively charged surfaces, while intermediate settlement occurred on neutral SAMs. Furthermore, no effects were observed when data were plotted against surface free energy after 48 hr of exposure. Temporary adhesive on SAMs was investigated using imaging ellipsometry and atomic force microscopy. Relatively thick footprints with low wetting were found on positively charged surfaces. Settlement of both species was also low on these surfaces. Footprints were thinner and spread more on hydrophobic surfaces. The adhesion force of temporary adhesive measured with functionalised AFM tips was higher on hydrophobic and negatively charged surfaces for both species.

We conclude that cyprid settlement behaviour of both species is influenced more by surface charge than SFE under controlled conditions. The temporary adhesives (footprints) of the two species had a stronger affinity for hydrophobic surfaces. Contrary to previous reports, therefore, the settlement preferences and adhesive secretion of these two species are similar. This finding will be important for understanding the mechanism of surface selection by cyprids and for the development of future antifouling technologies.

Acknowledgements:

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BIOFOULING DIVERSITY AND COMMUNITY DEVELOPMENT ON STATIC IMMERSION PANELS IN MAJOR PORTS OF SOUTH EAST ASIA AND INDIA

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Our limited knowledge of marine biodiversity and challenges in species identification hinder effective biodiversity management for safeguarding South and Southeast Asian marine coastal environment against the threat of invasive species transfer through shipping. A baseline study of sessile marine biofouling organisms occurring in South East Asia ports is currently lacking. Under the auspices of the ASEAN-India Cooperative Project on Extent of Transfer of Invasive Species by Shipping in South East Asia, a static immersion study in Southeast Asia and India was carried out using polyvinylchloride (PVC) panels as a means of gathering information on biofouling community development and diversity in major port areas. We present an overview of the occurrence of biofouling organisms and patterns of fouling in Muara (Brunei Darussalam), Goa (India), Jakarta (Indonesia), Vientiane (Lao PDR), Kertih (Malaysia), Yangon (Myanmar), Manila Bay (The Philippines), Singapore (Singapore), Songkhla (Thailand) and Haiphong (Vietnam). Not surprisingly, the study revealed that overall, fouling patterns differed between ports possibly as a result of dissimilar hydrographic conditions, but there were underlying similarities that reflect a regional uniformity in the composition of fouling communities. The alien Caribbean bivalve *Mytilopsis sallei* was only detected in Manila Bay and Singapore.

Keywords: South East Asia, India, biofouling, invasive species, marine biodiversity

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FOULING IN YOUR OWN NEST: VESSEL SOUND PROMOTES SHIP FOULING

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Recent ecological research indicates that underwater sound plays an important ecological role in the settlement behaviour of many coastal organisms. Laboratory and field experiments have shown that some types of underwater sound triggers a more rapid settlement response in a wide range of species, including biofouling organisms. Large steel hulled vessels are well known to be a major source of underwater sound in the marine environment and are noted for their propensity to accumulate marine fouling, mostly from the settlement of invertebrates such as crustaceans (barnacles), cnidarians (anemones), ascidians (sea squirts) and algae. Many millions are spent each year on methods attempting to control the fouling on commercial marine vessels.

The basis of this research was to test the hypothesis that the fouling of vessels by marine invertebrates was greatly enhanced by the underwater sound the vessels emit while in port. Three experiments were designed to test this hypothesis;

1. In the laboratory, mussel larvae were exposed to pre-recorded generator noise emitted by large steel hulled ships whilst in port. Results indicated a significant increase in settlement and metamorphosis of larvae when subjected to vessel noise.
2. In the field, clean settlement plates were deployed in a harbour (free of vessel traffic) and subjected to pre-recorded vessel noise. Levels of biofouling and species diversity were significantly higher on the plates which had been exposed to the pre-recorded vessel noise compared with silent controls. Furthermore, the growth rate of newly-settled biofouling was enhanced by the presence of vessel noise.
3. In the laboratory, ascidian larvae were exposed to pre-recorded generator noise from domestic fishing vessels. Larvae exposed to the loudest noise (i.e. recordings taken closest to the generator) settled and metamorphosed significantly faster than larvae which were exposed to a lower intensity (quieter) noise (i.e. recordings taken on the opposite side of the vessel or the stern. These results were also further substantiated by an assessment of the level of biofouling and species diversity on the vessel hulls.

Overall, these results indicate that underwater vessel noise plays an important role in stimulating biofouling. These novel findings have potentially important and wide ranging implications for controlling biofouling on vessels, marine biosecurity and vessel-mediated spread of invasive species.

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PROJECT "MANAGEMENT AND INFORMATION CONTROL OF BIOFOULING AND BIOINVASION (GEBIO)": AN EFFORT TO MINIMIZE BIOINVASION OF FOULING SPECIES IN THE BRAZILIAN COAST

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Global commerce through shipping activities have increased exponentially in the last decades and represent a risk of invasive marine species transportation by ballast water and/or biofouling. Concerning biofouling colonization in ship hulls and other structures, although anti-fouling systems and other measures have been applied, marine bioinvasions caused by biofouling transferring were reported worldwide. In Brazil, a cooperation between Brazilian Navy and PETROBRAS (oil company) resulted in the project GEBIO, a novel initiative aligned with the resolution MEPC.207(62) of the International Maritime Organization. The project has the purpose of providing centralized information about biofouling species on the Brazilian coast, associated to a risk assessment of bioinvasion. The information system consists in an open access database to store data of Brazilian biofouling species, such as taxonomic information, distribution with their geolocation and status in relation to invasion. A reference collection of the biofoulers included in the database has been organized to support the information system. Complementary, field investigations have been performed to monitor biofouling in natural and artificial substrates at harbor areas or coastal areas where exotic species have been already detected. Laboratory experiments to test their invasive abilities by chemical defense, competition and predation are also programmed. Furthermore, the risk assessment of bioinvasion will be conducted, combining the database information to the shipping routes around the world and along Brazilian coast. We believe that the results of the present project will contribute to a better understanding of biofouling dynamics and consequently of bioinvasions. In addition, the results should support actions to reduce the risks, to develop control and prevention technologies and to improve solutions for invasive species control in coastal areas.

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INVESTIGATION OF BIOFOULING ORGANISMS IN THE NORTH YELLOW SEA OF CHINA

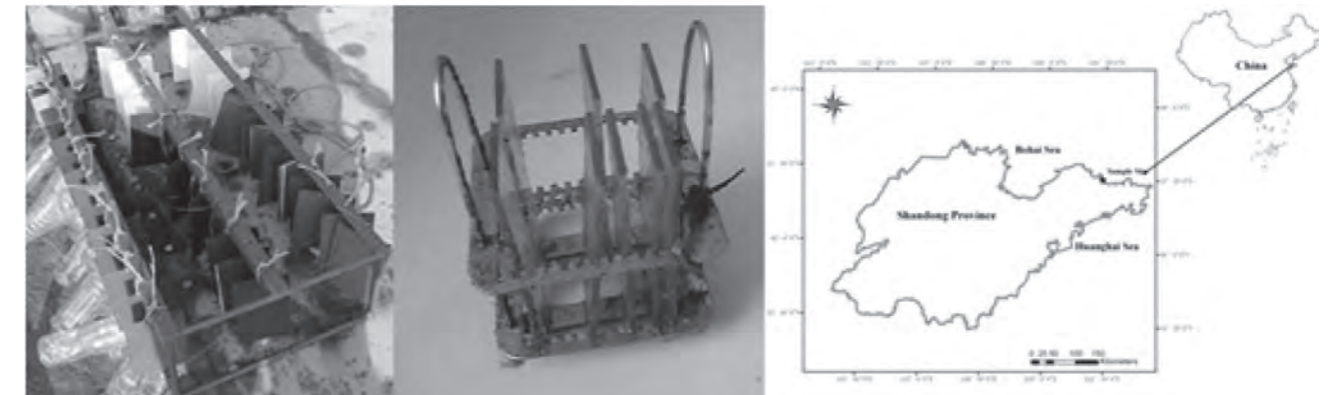
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Marine biofouling refers to the undesirable adhesion and growth of colonizing organisms on the surfaces of underwater artificial facilities. Biofouling organisms include marine microbes, algae (diatoms, red alga, brown alga, etc.) and other macrobiofouling organisms (barnacle, mussel, oyster, bryozoon, etc.). Due to the differences of organisms adhesion caused by spatial and temporal disparities, it is important to carry out field investigation for biofouling studies in different sea areas. In this study, biofouling organisms were achieved in Yantai, Shandong province at 37°30'48.45"N, 121°26'41.37"E. Sampling facilities and sampling spot was shown in the following figure.

Biofouling bacteria were isolated through spread plate techniques and identified through physiology and biochemistry tests and 16S rRNA analysis. 53 bacteria were isolated and the following experiments revealed they mainly fell in 3 genera, 8 species and exhibited rod form. Main fouling diatoms were diluted and observed using microscope, which were identified as *Nitzschia* sp. and *Cylindrocapsa* sp. diatoms. The main macrobiofouling organisms in the North Yellow Sea were barnacle *Balanus amphitrite*, mussel *Mytilus edulis*, bryozoon *Bugula neritina*.

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DEVELOPMENT OF A NEW CAGE SYSTEM FOR OFFSHORE FISHFARMING WITH ECOLOGICALLY FRIENDLY ANTIFOULING STRATEGIES

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As a result of increasing needs and shrinking resources, aquaculture was gaining importance in the recent years. Due to high fish density in the farms and the resulting enhanced biofilm growth the use of copper as antifouling (AF) strategy is a commonly occurring technique.

Particularly regarding the increasing number of fish which will be produced in farms in the future environmental friendly solutions are needed. Current trends focus on larger farms operated offshore. To make these farms working safe and economical, reliability has to be improved and maintenance costs need to be reduced. Also, alternatives with higher mechanical strength compared to current textile net materials as well as common metal wires might be necessary for these developments.

In the present work a new net system from high tensile stainless steel wires as net material with environmentally friendly AF-properties suitable for off-shore fish farm cages was developed.

First, different kinds of stainless steels were evaluated in terms of manufacturing and corrosion behaviour. A selection of different net systems (material and antifouling strategy) were exposed at eight sites worldwide for a period of 6 months in order to investigate the individual fouling behaviour compared to existing net systems in the practical use. Therefore, the samples were positioned in the area of fish farms or shellfish farms. The fouling was documented and evaluated in defined sequences using photography and light microscopy. Furthermore, the cleaning capability of the different net systems was tested using a standardized cleaning process. After the immersion tests, the samples were evaluated concerning its corrosion behaviour and the antifouling.

In addition to these immersion tests, laboratory tests were conducted, such as microbiological investigations and corrosion tests in order to investigate the different net systems and AF-strategies.

The performed tests revealed a much higher mechanical strength of the new high tensile stainless steel net system compared to current nylon nets.

Even if the biofouling of the stainless steel net is slightly higher compared to current copper based solutions, a better cleaning capability could be observed.

The higher strength of the stainless steel enables a much smaller wire diameter of the net, which increases the level of water flow rate. This water flow is a very important parameter for the fish growth and their health.

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ANALYSIS OF PYRITHIONE RESIDUE IN FARMED ATLANTIC SALMON AND IN SEDIMENT BELOW FARM NETS

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Farm raised salmon are far more common in fish markets and restaurants than wild caught salmon. Many fish markets and restaurants only offer the farmed fish, wild caught being much more expensive. Because most of the nets on the farms are treated with antifouling additives, there is concern for residue that might accumulate in the fish.

Copper pyrithione is used in the net treatments mainly to prevent the growth of hydroids that will clog the nets. Nets clogged with fouling will reduce the oxygen in the water and prevent removal of fish wastes, resulting in fish mortality. Farm owners and fish consumers want to be sure there is no residue in the edible flesh. Methods of analysis were developed and the growing fish were analyzed over the course of about a year. The results of this study along with sediment analysis are presented.

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TASMANIAN SALMON FARMS EXAMINE NET BIOFOULING TO REDUCE IMPACTS

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Greater knowledge of fouling organisms and their settlement can help lead to greater effectiveness of fouling removal and net cleaning practices. If cleaning is done regularly at certain times of the year, fouling organisms may be easier to remove or kept from settling on nets. A two-year study at salmon farms in Tasmania that observed experimental frames housing different net types found that short-term settlement of fouling organisms differed between sites and some net type and that the amount of copper released during *in situ* cleaning of nets with copper-based coatings was within a comfortable range.

A collaborative project between Huon Aquaculture Company Pty Ltd and Tassal Operations Pty Ltd made possible by the Federal government Caring for Our Country grant.



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RECRUITMENT AND SUCCESSION PATTERN OF BIOFOULING COMMUNITY IN THE COASTAL WATERS OF KALPAKKAM, SOUTH EAST COAST OF INDIA

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Biofouling studies in the coastal waters of Kalpakkam, Southeast coast of India, Bay of Bengal, were carried out during 2006-12 to evaluate the pattern of fouling, the dominant species, seasonal succession and the role of environmental driving forces acting upon them. Three series (weekly, monthly and cumulative) of teak wood panels (12X9X0.3 cm) were exposed to coastal waters. Wide variations in macrofoulants settlement were observed in the weekly as well as in seasonal panels. The biofouling community succession pattern follows the following order, barnacle – hydroid - sea anemone – ascidian and finally green mussel (*Perna viridis* Linn. 1758). A visible shift in the peak settlement period of green mussel was noticed as compared to 15 years ago. Green mussel was found to be the climax & most dominant fouling species. Remarkably, during the entire period of 2010, green mussel appearance was negligible or almost absent and could not be attributed to any known factors. Settlement of oysters in significant numbers (~7-20% of total fouling population) was encountered during the present study as compared to earlier data of almost nil. Barnacle settlement was observed throughout the year and was at the highest during October-March. During July – September, relatively high species diversity index (Shannon diversity index-0.32 – 0.85) was observed, which coincided with relatively high temperature, salinity and chlorophyll-a. Total number of fouling organisms observed was ~125, of which 107 were identified. Weekly results, available for the first time for this locality, form the baseline data for future reference and impact assessment studies. Biofouling load (g. per 100 cm²) of weekly panels varied between 1 and 11, which increased with increase in exposure time [28 day (d) -77, 56d - 97, 112d- 185 and 150d – 648]. The paper also discusses in detail the change in fouling pattern during the last 25 years at this location.

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BIOFOULING COMMUNITY DEVELOPMENT ON METALLIC SURFACES

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Metallic surfaces are extensively used at various installations in the marine environment. Hence, knowledge on qualitative and quantitative aspects of biofouling with respect to metal surfaces is of great value to design an efficient fouling control strategy. Keeping this in mind, nine types of metal [SS-316, SS-304, MS, Titanium, Admiralty Brass, Aluminum Brass, Copper, Monel and Cupro-nickel] panels (12 x 9 x 0.1 cm) were exposed to coastal water of Kalpakkam (south east coast of India) from Madras Atomic Power Station (MAPS) jetty at a depth of 2 m below the sea surface. The study was primarily focused to assess the fouling pattern on different metal surfaces including seasonality pattern of settlement. Results indicated that copper based panels were foul-free except monel. Although, fouling settlement was encountered on monel, the adherence was weak. Non-copper based metals showed 100% area coverage with high population density. However, in case of MS, due to exfoliation of corrosion deposits, unevenness in fouling colonization at later stages of development took place, though the early settlement was unaffected by initial corrosion. As expected, Titanium showed high rate of fouling growth along with high fouling diversity compared to other non-copper based metals. Absence of specific foulants such as, crustaceans and algae on Titanium surface reported by others was not observed during our study. The information on Titanium would be handy for Prototype Fast Breeder Reactor (PFBR) cooling water system wherein, the same has been selected as condenser and process water heat exchanger material. Biofouling load was almost nil on all copper based alloys except monel. For non-copper based alloys including monel the fouling load ranged from 18 to 40 g. 100 cm⁻². The major fouling organisms such as, barnacle, green mussel and ascidian constituted ~ 70-80% of the total fouling. The sequence of fouling succession observed during the present study was as follows; barnacle – hydroid - sea anemone – ascidian and finally green mussel (*Perna viridis* Linn. 1758). Species diversity indices (diversity, richness and evenness) are also discussed in detail.

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CONTROLLING SEAWATER CHLORINATION SYSTEMS WITH ADVANCED TRO SENSOR

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Electrochlorination is well suited to control biofouling in shipboard cooling systems. It is relatively inexpensive to operate, requires only electricity and seawater and has a proven track record. However, discharge from chlorination systems is getting more and more scrutiny from Marpol, IMO, environmental agencies and port authorities around the world and may be regulated in the future.

Given these future challenges an effective, durable, stable and low maintenance seawater chlorine sensor is needed to control the electrochlorination process. Until now this ideal sensor has been unavailable. Seawater presents many measurement issues for existing technology. This new sensor overcomes many of these limitations. It resists fouling, is self-cleaning, flow independent, and measures Total Residual Oxidant (TRO) concentrations below 0.10 ppm and up to 15 ppm. This makes the sensor ideal for compliance with IMO and EPA regulations for dechlorination. This improved control and rapid feedback for closed loop chlorine generators results in better corrosion control and more effective biofouling control.

Data shows good performance over a wide range of temperatures, TRO concentrations, even at low salinity and temperatures. The sensor performs as well as DPD reagent fed optical systems without the need for waste lines and reagent replacement. Since it is flow independent, installation directly into piping is possible, enabling lower installation costs, rapid feedback and control. This novel approach uses no membranes or electrolytes and results in long calibration intervals and very low maintenance requirements.

There are several benefits to controlling the electrochlorination process. First, the biofouling process can be more effective as optimal dosing levels will be maintained. Secondly, dechlorination systems can potentially be eliminated as chlorine levels can be set below regulated levels. Lastly, corrosion within seawater systems can be minimized by preventing overchlorination.

Integrating this new sensor into real world electrochlorination designs will be discussed. There are many methods that can be employed to control the process ranging from a simple single sensor and discharge design to a multiple dosage and discharge point design. How to best control the discharge TRO levels, maximize the antifouling process and minimize corrosion simultaneously will be reviewed so owners, engineers and regulators can make optimal decisions.

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INVESTIGATION OF ALGAE SETTLEMENT ON POLY(N-ISOPROPYLACRYLAMIDE) WITH DIFFERENT WETTABILITY CHARACTERISTICS

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Microalgal fouling and slimes are a huge problem in the water industry. Understanding microalgal adhesion and detachment behavior is an important consideration in the biofouling of agriculture planktonic bioreactors and harvestors used in algal biofuel production systems. It has been demonstrated that the switchable behavior of PNIPAAm can be used to release bacterial fouling from selected surfaces. The substrate used was a commercially available PE-based material, grafted with poly(N-isopropylacrylamide) through an atom transfer radical polymerization (ATRP) protocol. Poly(N-isopropylacrylamide) or PNIPAAm is a type of chain polymer that exhibits switchable wettability characteristics under the influence of surrounding temperature. In this study, we examined the behavior of *Chlorella vulgaris*, a common species of freshwater single-cell green algae cultured in BG11 medium under ambient condition. The settlement behavior on hydrophilic and hydrophobic surfaces was investigated. We demonstrate the behavior of *C. vulgaris* biofilms on PNIPAAm as the surfaces were subjected to temperatures ranging from 20°C to 35°C and discuss how this behavior may be useful in controlling biofouling.

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ADDED DRAG OF FOULING IN TERMS OF CHANGE IN FRICTION COEFFICIENT

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Frictional resistance contributes up to 80-90 % of total resistance for commercial sailing vessels. For an accurate prediction of the frictional resistance of a ship, detailed knowledge on the frictional resistance coefficient of the wetted surface area of the ship is required. This frictional resistance coefficient depends largely on the roughness and texture of the wetted surface area.

The true roughness of a sailing ship with accumulated fouling onto a weathered coating system is hard to define. Effects of physical roughness parameters on friction coefficient were established long ago in towing tank experiments and are well described in literature. Friction drag effects of different types of biological roughness have not yet been quantified in a systematic way, mainly because of the lack of a suitable and reliable experimental method to determine such effects. Towing test facilities are not suitable, especially not for making replicate measurements. A small scale laboratory test set up, such as the Friction Disk Machine (FDM), has significant advantages in this respect.

In the FDM comparative drag measurements are done on rotating disks with different surface properties or fouling conditions. Prediction of full scale frictional resistance coefficients from rotating disk experiments can be done with the similarity law approach described by Granville (1978, 1982). However, the use of an outer radius similarity law in this method leads to overestimation of friction velocity and less accurate friction resistance coefficients. A modified Granville approach is proposed based on similarity of mean flow characteristics across the radius of the disk and the length of an equivalent flat plate. The roughness function determined with the new method is in better agreement with the Nikuradse friction line and predicted full scale friction coefficients can be estimated at realistic ship speeds.

Different types of hull coatings with and without fouling have been measured on friction drag properties. Short term raft exposure was used to obtain coated disks with representative fouling patterns that may be found on ship hulls. Clear differences were found between self-polishing coatings and fouling release coatings both in accumulation of fouling and foul release properties. The modified method is subsequently used to translate the drag data into estimated effects on ship scale friction coefficients. Such data may form the basis of a systematic approach for establishing drag effects of biological roughness at ship scale.

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THE USE OF COPPER-BASED ANTIFOULING ON ALUMINIUM HULLS

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Copper, most commonly in the form of Cuprous Oxide (Cu₂O), is used in the majority all antifouling globally, but some paint companies do not allow their Cu₂O –based antifouling to be used on aluminium hulls. This is because aluminium is more anodic in the electrochemical series than copper, and if the two are directly connected in sea water the aluminium will corrode away. This galvanic reaction only occurs if copper metal is in direct contact with aluminium, and since modern Cu₂O –based antifouling contain virtually no metallic copper there appears to be no valid reason for the ultra-cautious approach regarding the use of Cu₂O –based antifouling on aluminium hulls. This is particularly important in areas of high fouling intensity, such as occurs in tropical regions, where only the Cu₂O –based high performance antifouling can provide the level of fouling control required.

A number of different Cu₂O –based high performance antifouling were applied on suitably prepared Marine-grade aluminium panels, with and without an epoxy priming system, along with an un-coated control panel. The panels were immersed in sea water and inspected at various intervals for any corrosion caused by the antifouling. Electrochemical measurements were carried out to determine the extent of corrosion. Also a laboratory experiment was undertaken at the university where aluminium panels coated in the same way as above were submerged in salt water as a controlled experiment, using Electron Microscopy to conduct corrosion analysis and determined whether current Cu₂O –based high performance antifouling caused galvanic corrosion of Marine-grade aluminium.

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EFFECT OF STRAY CURRENT ON MAGNESIUM ANODE PROTECTION SYSTEM

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Nowadays, electrical equipments increase with the rapid development of modern society. Most of the electrical equipments introduce stray current corrosion to buried pipelines nearby. Cathodic protection is one of the most important technologies in preventing pipelines from corrosion. There are two kinds of systems in cathodic protection: impressed-current protection system and sacrificial anode protection system. In order to study the influence of stray current on magnesium anode protection system, a series of experiments were carried out. The results show that stray currents affect output currents of sacrificial anode and have little influence on its discharge performance. The anti-interference ability of magnesium anode protection system is weak. When the outer power source is on the pipeline side, the output currents of sacrificial anode increase with the stray current increasing. Once the stray current is fixed, there is a polarization electric field generated by stray current in the soil. As a result, slaving voltage between the pipeline and magnesium anode increase by the polarization electric field. The anode output currents increase with the time of operation. A calcium-magnesium sedimentary formation develops on the surface of discharged sacrificial anode. It decreases the discharge performance of magnesium anode. Stray currents accelerate the development of sedimentary formation. On the contrary, slaving voltages decrease when the outer power source is on the anode side. At the same time, the anode output currents decrease.

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INVESTIGATION OF IMPRESSED CURRENT CATHODIC PROTECTION WITH RESPECT TO CALCAREOUS DEPOSITS (CATHODIC CHALKS) AND ITS EFFECT ON SHIP PROPELLER ROUGHNESS.

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Cathodic chalks which form on ship propellers increase roughness and reduce efficiency which significantly increases fuel consumption. This study investigates the effect of impressed current cathodic protection operations, propeller materials and environmental conditions on the types, structure and texture of cathodic chalks. The development of chalk on ship propellers will be monitored with respect to: potential, current density, time, total charge transfer, hydrodynamics and ambient seawater conditions. The chemical composition and structure, thickness, mass, rate of deposition and electric resistance of chalks will be measured. Based on the above experimental research, numerical models will be developed to optimize the operation of impressed current cathodic protection systems.

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IN-SITU STUDY OF DIATOM BIOFILMS DEVELOPMENT ON SURFACE MICROTOPOGRAPHIES IN FLOWING SEAWATER

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Biofouling on submerged surfaces begins as primary films comprising a large amount of benthic microalgae. Among these organisms, diatoms are widespread and have a clear dominance in aquatic biofilms. Considering the important role of diatoms in the fouling processes, it is necessary to inhibit diatom growth on the fresh surface. Current studies have showed surface microtopographies are effective against diatoms. The testing to evaluate the probability of diatom fouling on surface microtopographies is usually performed in static culture with water-suspended diatoms. However, the surrounding environment around ship hulls is more complex than stationary culture. A major factor is the movement of seawater which has a predictable influence on the growth of diatom biofilms. The development of diatom biofilms growing on surface microtopographies under flowing seawater remains uncertain. Therefore, we designed and fabricated a testing system, which was composed of three parts: seawater pipelines with diatoms flowing through, a testing channel for fixing microtopographies, a microscope whose objective was over the microtopographies. The real-time images of diatoms growing on microtopographies were recorded by microscope every minute within 2 hours. The results showed that the number of diatoms attaching to the topographies increased with time, presenting a sigmoid growth curve, while the number of diatoms suspending in flowing seawater did not visibly increase within testing time. The data indicated that the surface characteristics of microtopographies were transformed gradually by diatoms which secreted exopolymers. Meanwhile, our in-situ measurements revealed that flowing seawater maybe impelled diatoms to produce more exopolymers in a shorter time.

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ROUGHNESS-DRIVEN BENTHIC DIATOM ATTACHMENT AND ITS APPLICATION TO SHIP HULL MICROFOULING

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Benthic diatoms are a major component of biofilms that form on surfaces submerged in marine environments. Roughness of the underlying substratum affects the settlement of both diatoms and subsequent macrofouling colonizers. This recently published study reports the effects of roughness on diatom communities established in a Florida estuary on acrylic panels with a range of surface roughnesses. Smoother substrata exhibited higher cell density, species richness, and diversity. Twenty-three of 58 species were found either exclusively or more abundantly on the smooth surfaces compared to one or both roughened treatments. The results suggest a greater ability of benthic diatoms to recruit and colonize smooth surfaces, likely explained by a higher degree of contact between the cells and the surface. Details on the relationship between surface roughness and diatom community composition will be discussed, along with new applications to microfouling data from currently used antifouling and fouling release coatings with different roughness characteristics.

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THE IMPORTANCE OF BACTERIAL FILM COMPOSITION FOR GERMINATION OF ZOOSPORES OF THE GREEN ALGA ULVA

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The green macroalga *Ulva* is a worldwide known and distributed fouling organism on ship hulls. The initial rate of germination is a critical process in macroalgae as it contributes to the success of colonization. The germination process is essential for the survival of settled zoospores and has consequences in relation to competition for space on surfaces with other fouling organisms. In this study the role of bacteria for germination and initial growth of zoospores from the green alga *Ulva* was investigated. The presence of a bacterial biofilms was seen to enhance germination. Further the influence of different bacteria biofilm composition was investigated using natural bacterial assemblages. The natural assemblages contained different proportions of *Alphaproteobacteria*, *Gammaproteobacteria* and *Bacteroidetes* and were analyzed/characterized with the Fluorescent in Situ Hybridisation (FISH). More zoospore germination occurred on biofilms with a high proportion of *Gammaproteobacteria*. The possible consequences of different bacterial densities and community composition for *Ulva* spore germination are discussed.

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IN SITU MEASUREMENTS OF DIATOM ADHESION TO FOULING RELEASE SHIP HULL COATINGS

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Diatoms are tenacious and have been observed to remain on fouling release coatings at speeds in excess of 30 knots. This study was designed to investigate the adhesion of diatoms to three fouling release coatings (Intersleek[®] 700, Intersleek[®] 900, and Hempasil X3) and one reference coating (Dow Corning 3140). These coatings were exposed at a static immersion test site and subjected to water jet testing to determine biofilm adhesion and the subsequent pressures needed to remove specific diatom species. Differences in the initial (pre-water jet testing) community composition were observed among coatings, as well as, after applied pressures. All diatoms were removed from HX3 after 0.28 MPa; however, the pressure required to completely remove biofilm and diatoms on DC 3140, IS 700, and IS 900 varied. Biofilm removal pressure ranged from 0.28 to 1.38 MPa on DC 3140, 0.55 to 1.38 MPa on IS 700, and 0.28 to 1.38 MPa on IS 900. Significant differences were observed among coatings for removal pressure, as well as initial diatom abundance, however differences were dependent on the sampling date. The diatom genera, which required the highest pressure for removal from the fouling release coatings, were *Achnanthes*, *Amphora*, *Cocconeis*, *Navicula*, and *Synedra*. The results show differences in the adhesion strength of diatoms to different fouling release coatings and highlight those species, which have the potential to contribute to biofilms remaining on ship hulls once a vessel is underway.

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STUDY ON PREPARATION AND PROPERTIES OF NEW BIOORGANIC-METAL WITH LOW SURFACE ENERGY FOR SHIP ANTIFOULING

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With the depletion of oil resources and the continuous improvement of environmental protection requirements, the development of green ships has become the direction for future marine development. The science and technology of tribology plays a remarkable role in green ship. Ship antifouling and drag reduction is a typical research issue in marine tribology. Ship antifouling is always a key factor to postpone the increase of ship voyage velocity. The surface anti-fouling property of the material is closely related with the surface energy. When the surface energy is low or ultra-low, the fouling occurrence will be difficult or fouling releasing is very easy. This study focuses on how to use the peptide - steel reaction to yield a new bioorganic-metal with low surface energy. Through designing proper peptide and optimizing processing approaches, a new bioorganic-metal with low surface energy will be obtained by the peptide - steel reaction. The anti-fouling property of the developed material will be studied in further. The corresponding mechanisms will be investigated and presented in the manuscript. The knowledge obtained in this study will provide theoretical references for the design and practice application of surfaces with low surface energy and contribute to the development of green ship.

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ZINC OXIDE NANO-ROD COATINGS FOR THE PREVENTION OF MARINE MICRO- AND MACRO-FOULING

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Zinc oxide (ZnO) nano-rods and nano-particles inhibit growth of fresh water bacterial and fungal strains through the process of photocatalysis and assisted by Zn ions formed by slow dissolution of nano-particles. Here, in laboratory experiments, the antifouling activity of ZnO nano-rod (width = 130nm, length = 5.6µm) coatings developed on glass slides were tested in sea water against the marine bacterium *Acinetobacter* sp. AZ4C, larvae of the bryozoan *Bugula neritina* and the brine shrimp *Artemia salina*, in light (light intensity= 50 Klx) and dark (0 Klx) conditions. After 5 h in light, nano-rod coatings prevented biofilm formation, growth of bacteria and significantly reduced total DNA concentration. There was no inhibition of bacterial growth and biofilm formation in dark. After 5h in light, the larvae of *B. neritina* over nano-rod coating had 90% death and 10% settlement. In dark, 96% of larvae were alive and attached to the coating. In light, the coatings resulted death of 62% of *A. salina* larvae. In dark, 14% of larvae died in the presence of ZnO nano-coatings. In static conditions with light, ZnO nano-rod coatings effectively prevent marine micro- and macro-fouling.

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EVALUATION OF ADHESION FORCES FOR CYPRID TEMPORARY ADHESIVE PROTEINS USING AFM

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Atomic force microscopy (AFM) was used to study the effect of surface wettability on cyprid footprints (FPs), which are temporary adhesive proteins secreted when the larvae explored surfaces. The morphology of FPs was characterized in seawater condition and showed significant larger sizes on the hydrophobic surfaces. However, the overall volume of proteins secreted on the surfaces showed no difference, in the range of 4.7-6.5 μm^3 . The FP proteins were immobilized on an AFM colloidal probe and used as a force probe to study the interaction of the proteins with the various wettability surfaces based on force spectroscopy method. The FP proteins had a stronger interaction with the hydrophobic surface. The adhesive force on the hydrophobic surface is $(21 \pm 2 \text{ nN})$, which is much larger than the value measured on hydrophilic surface $(7.2 \pm 1 \text{ nN})$. Also, more energy is required to detach the FP proteins from the hydrophobic surface.

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MOLECULARLY ENGINEERED MULTIFUNCTIONAL SURFACES FOR COMBATING MARINE BIOFOULING

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Materials that are free from fouling, biofouling, and biocorrosion are vital for the voyage efficiency of marine vessels and the service life of submerged structures. Current antifouling technology based on controlled-depletion coatings and paints is under scrutiny due to its detrimental effect towards the environment. Non-leached functional polymer brushes and coatings with tailored antifouling and antimicrobial properties represent a durable and environmentally-benign alternative. The environmental friendliness of the coatings can be further enhanced by the application of tannic acid from tea extract and mussel-inspired adhesive polydopamine as the biomimetic anchors for surface antifouling and antimicrobial post-functionalization. Bifunctional synthetic anchors, e.g. brominated tannic acid or poly(*N*-dopamine maleimide)-*alt*-(*p*-vinylbenzyl chloride)), can be coupled to the metal surface *via* coordination interaction of the hydroxyphenyl moieties, yielding functionalizable platforms with radical-halide initiators for subsequent graft polymerization of antifouling and antimicrobial polymer brushes. In a more direct approach, post-functionalization of the tannic acid- or polydopamine-anchored surface can be achieved by incorporation of thiol- or amine-labeled antifouling and antimicrobial polymers *via* Michael addition or Schiff base reaction. Surfaces functionalized with hydrophilic, cationic, and zwitterionic polymer coatings or brushes exhibit positive efficacies in the inhibition of protein adsorption, bacterial adhesion, biofilm formation, microalgal attachment, and barnacle cyprid settlement.

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DEVELOPMENT OF AUGMENTATIVE BIOCONTROL TOOLS FOR THE MANAGEMENT OF BIOFOULING

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Augmentative biocontrol, through the enhancement of native natural enemies, is a frequent practice in terrestrial and freshwater systems, however there is a lack of research investigating the feasibility of marine biocontrol. Here we present an overview of ongoing research to develop biocontrol tools for the management of marine pests, both in artificial and natural habitats of New Zealand. Initially, theoretical framework was developed for the selection of biocontrol agents based on a range of traits that an ideal agent should satisfy before application. Seven invertebrate species were screened as potential biocontrol agents for biofouling on floating artificial structures. Predators, grazers and space pre-emptors were applied both to fouled and defouled surfaces, to evaluate response and prevention management strategies, respectively. We also present the results of a case study investigating non-target effects associated with use of the sea urchin, *Evechinus chloroticus*, as an augmentative biocontrol agent to eradicate the invasive Asian kelp *Undaria pinnatifida* in an area of high conservation value, namely Fiordland. Collectively, our research indicates that augmentative biocontrol using natural enemies could be an effective and environmentally sound method to mitigate effects of biofouling and the spread of non-indigenous species in marine habitats.

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EXTRACELLULAR POLYMERIC SUBSTANCES FROM A MARINE BIOFILM FORMING STRAIN, PSEUDOALTEROMONAS ULVAE TC14: CHARACTERIZATION OF EXOPOLYSACCHARIDES AND ANTIBIOFILM ACTIVITY

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In marine environment, bacterial communities called biofilms cover inert or living surfaces. Bacteria in biofilms are embedded in a matrix of extracellular polymeric substances (EPS). In this work, a marine bacterial strain identified as *Pseudoalteromonas ulvae* and initially isolated in the early stages of fouling, was selected for its ability to produce abundant carbohydrate-rich antibiofilm-active EPS. This study allowed the characterization of these EPS, the aim being the identification of original exopolysaccharides with antifouling properties.

EPS were harvested from culture medium as soluble EPS, or biofilm itself from which they were extracted with a methodology allowing to obtain loosely bound- and tightly bound- EPS. Their contents in proteins, carbohydrates, nucleic acids and lipids were quantified. A chloroform/methanol/water partition allowed their separation into water- and low-water-soluble polymers which were further purified and separated by anion-exchange chromatography in order to isolate polysaccharidic fractions. Nature, purity and molecular weight distribution of each fraction were estimated through GC-MS, NMR and HPSEC analysis. Finally, these fractions were assayed for their antibiofilm activity against five marine strains using the BioFilm Ring Test®.

Results showed that *Pseudoalteromonas ulvae* TC14 cultivated in biofilm was able to produce large quantities of exopolysaccharides: (i) a low-water soluble glucan with a molecular weight distribution between 1000 and 2000 kDa, neutral and substituted by lactates, and (ii) a water-soluble glucan with a molecular weight from 2000 to 4000 kDa, anionic and O-acetylated. The latter glucan was the major polysaccharide of soluble- and tightly bound -EPS and seemed to be the sole component of the loosely-bound EPS fraction. Glucans enriched -EPS fractions showed an inhibitory activity on biofilm formation by several other marine strains isolated from the Mediterranean Sea.

Extended studies have to be pursued in order to determine, after their purification, the structure of these two exopolysaccharides and to assess their possible involvement as inhibitors of biofilm formation.

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ANTIFOULING POTENTIALS OF MARINE-DERIVED FUNGI AND THEIR SECONDARY METABOLITES

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Marine-derived microbial secondary metabolites are promising potential sources of nontoxic antifouling agents. The search for environment-friendly and low-toxic antifouling components guided us to investigate the antifouling potentials of fungal isolates from deep-sea sediments and coral samples of the South China Sea. The antifouling activity was primarily evaluated by antibacterial activity against larval settlement inducing bacteria, and antilarval activity against larval settlement of bryozoan *Bugula neritina* and *Balanus Amphitrite*, and then tested in field trial. The crude ethylacetate extracts of ten fungal isolates showed significant antibacterial and antilarval activity. And among them, four extracts displayed significant antifouling activity in a lasting four months' field trial. By further bioassay-guided isolation, over 20 antifouling compounds with no-toxicity were obtained from the four antifouling fungal strains, and meleagrins, an alkaloid that can be produced by *Penicillium* sp. with high production, showed significant antifouling activity in both lab and field trial. The potentials of these antifouling compounds as natural no-toxic antifouling agents are under further evaluation.

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BIOFOULING OF MODEL TURBINES FOR TIDAL CURRENT POWER GENERATION AND THE EFFECT OF ANTI-FOULING PAINT

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The sea off Ikitsuki I., Nagasaki Prefecture, Japan, has been the site of tests of tidal current power generation using turbines actuated by water flow. Such turbines are likely to be fouled by various benthic organisms. For about 8 months we conducted a biofouling study of model turbines, using an array of simple three-blade propellers mounted in a steel frame set at a depth of 7 m on the sea bottom off Ikitsuki I. to check the effects of propeller rotation and anti-fouling paint on the accumulation of fouling organisms. Significant biofouling, up to 30-40 kg/m² in total and notably dominated by clumps of the barnacle *Megabalanus rosa*, occurred on both the frame and unpainted propellers, whether the latter were rotating or not. However, on propeller blades coated with anti-fouling paint, only a biofilm, and no macro-fouling, was observed. Such paint may also prove useful in preventing massive fouling of turbines used for tidal current power generation.

Key words: tidal current power generation, model turbine blade, biofouling, antifouling paint, barnacles

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MARINE ANTI-FOULING FROM THIN AIR

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A promising alternative to the maritime industry's current use of biohazardous antifouling substrates may lie in the form of a thin coating of air. Air layers apparent on submerged surfaces have been shown to combat attachment by the broad range of fouling species, resisting their equally diverse mechanisms of adhesion. It is proposed that the key mechanism is the physical barrier that the liquid/vapor interface creates on submerged surfaces; a phenomenon known as the plastron.

The effect of controlled modification of surface properties leads to a range of plastron morphologies - by gaining an understanding of the origins of air availability, replenishment and retention, the control of antifouling may be achievable in the long term. Correlations between settlement of a range of biota of varying sizes, sensory capabilities and settlement behaviours, and the nature of plastrons are discussed.

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ON-DEMAND DYNAMIC SURFACE DERFORMATION OF SILICONE POLYMERS FOR CONTROLLING MARINE BIOFOULING

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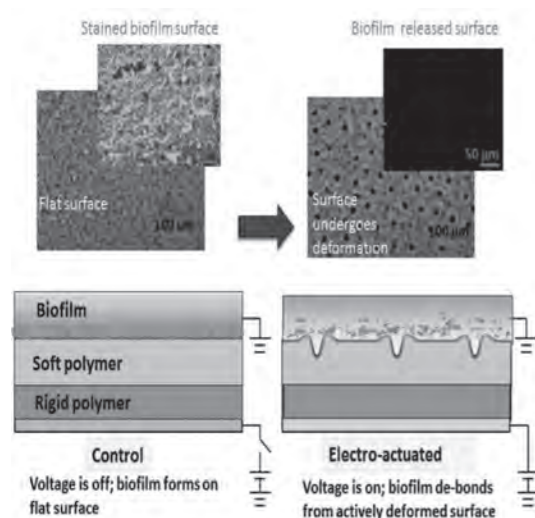
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Current commercial fouling release coatings on marine equipment are mostly based on non-polar hydrophobic silicone polymers that have low adhesion strength for broad range of fouling species. These surface coatings however require mechanical way to remove adhered biofilms, and in that process often undergo undesired abrasions. Recently we reported a new bio inspired fouling release approach for controlling biofouling using silicone surfaces that can undergo dynamic change of its surface area and topology. Our findings were based on the initial hypothesis that biofilms formed on elastomer surface can de-bond upon applying substrate strain. We have developed electro- and pneumatic-actuation methods using silicone polymer that can be actively deformed and be used for on-demand biofilm release. Experiments were conducted using model marine bacterial biofilm and barnacles in laboratory settings that confirmed more than 90 percent biofilm release when the applied substrate strain reaches a critical value; field studies in marine waters (at Beaufort, NC) showed similar results. Our studies indicate that biofilm thickness and substrate modulus affect the critical strain needed to detach biofilms.

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DEVELOPMENT AND EVALUATION OF FDR-SPC (FRICTIONAL DRAG-REDUCTION SELF-POLISHING COPOLYMER) ANTI-FOULING PAINTS

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The self-polishing copolymers (SPCs) have the mechanism of a hydrolysis or ion exchange reaction of an acrylic polymer with seawater. So it has been variously applied to antifouling paints as the binder. Recently, there have appeared several kinds of low-frictional AF coatings based on diverse physical mechanism of skin friction reduction. In this study, a novel frictional drag reduction (FDR) SPC coating has been employing poly(ethylene) glycol methacrylate (PEGMA) as a monomer which has the drag reducing functional groups such as PEG. The PEG is well known as one of drag reducing agent to exhibit Toms effect, the attenuation of turbulent flows by long chain polymer molecules in the near wall region. We synthesized FDR SPC resins depending on molecular weights and mole fraction of PEGMA. The structures of the synthesized polymers were confirmed by using ¹H-NMR and FT-IR. Then we checked the erosion rate of SPC resins by rotating disk method and the drag-reduction by PIV (particle image velocimetry). In addition, we manufactured the several FDR AF paints using the synthesized FDR SPC resins and examined the basic coating properties, such as sagging resistance, solid volume ration, finesse, viscosity, density, non-volatile contents etc, and the antifouling performance through the immersion test.

Acknowledgments:

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ANTIFOULING COMPOUNDS FROM THE SUB-ARCTIC ASCIDIAN SYNOICUM PULMONARIA

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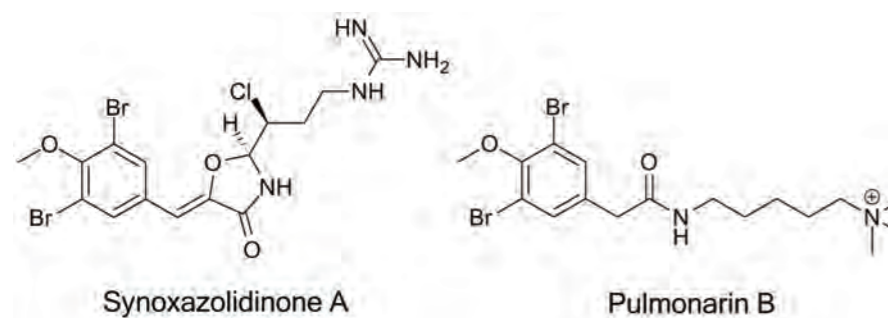
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Marine invertebrates and their associated bacterial symbionts represent interesting organisms with great potential for the discovery of bioactive compounds and novel chemical scaffolds. The sessile benthic lifestyle promotes the production of defensive secondary metabolites to provide an evolutionary advantage and prevent ongrowth. One group of marine compounds being described in the literature as displaying particular potential as antifoulants are bromotyrosine derived sponge metabolites. Several promising antifouling secondary metabolites such as barretin, oroidin and the bastadins have been studied. Both barretin and oroidin and their synthetic derivatives have been incorporated in paint formulations and been shown to prevent ongrowth in field studies.

The current study describes the antifouling properties of members belonging to the recently discovered Synoxazolidinone¹ and Pulmonarin² families, both isolated from the sub-Arctic sessile ascidian *Synoicum pulmonaria* collected off the Norwegian coast. Simplified synthetic analogs are also included in the study. Several compounds display IC₅₀ values in the micro-nanomolar range against relevant marine species involved in both the micro- and macrofouling process. Studies on *Balanus* cyprids indicate a high deterring effect and a low toxicity for selected compounds.



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BIOMIMETIC AIR RETAINING SURFACES FOR REDUCTION OF DRAG, CORROSION AND FOULING

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The biological model, the floating fern *Salvinia molesta*, is able to permanently keep an air layer at the upper leaf surface. The air retention is caused by a most complex hierarchical superhydrophobic structuring of the surface. The long term stability of the enclosed air layer is resulting from a unique chemical inhomogeneity. Hydrophilic patches on the tips of the complex hairs pin the air-water-interface in case of negative pressure differences preventing the loss of air by bubble formation (Salvinia Effect).

For technical applications we develop biomimetic air retaining surfaces exhibiting the Salvinia Effect. First air retaining prototypes already revealed a drag reduction of about 30% due to the lower viscosity of the air layer. Some prototypes even retain an air layer for up to three years until now.

Permanent air layers possibly prevent the attachment of fouling organisms and should therefore minimize fouling. Tests on the fouling behaviour are currently done.

Even if the air layer would collapse locally or fouling organisms attach regardless of the air layer it is an option to combine the coating with conventional biocides. In case of an intact air layer the biocide would have no contact with the water and would be an environmentally most friendly antifouling coating.

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EXPERIMENTAL INVESTIGATION FOR REDUCING RATE OF FRICTIONAL RESISTANCE OF MARINE ANTIFOULING COATINGS

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It has been well known that a fouled hull increases a ship's frictional resistance and reduces speed and increases fuel consumption. Shipowners and operators always use antifouling coatings to prevent fouling and frictional resistance increase. The purpose of this paper is to discuss reducing rate of frictional resistance of difference kinds of antifouling coatings. The paper describes a frictional resistance test facility which is based on shearing-stress measurement. The test facility operation principle, structural composition, operating procedures and result calculation are expounded. Three kinds of antifouling coatings have been selected, and reducing rate of frictional resistance has been test. It is found that reducing rate of frictional resistance of antifouling coating is different, reducing rate of frictional resistance of self-polishing antifouling coating and fouling release coating is better than that of ablative antifouling coating.

Acknowledgments:

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EVALUATION OF ANTIFOULING ACTIVITY BY MICROSCOPY

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The settlement of living organisms on immersed surfaces takes place following four successive steps. These are i) formation of a conditioning film, ii) attachment of bacteria to the surface, iii) settlement of unicellular species, and iv) settlement of multicellular eukaryotes. This community is characterized by intricate interactions.

It is generally agreed that the prevention of marine fouling can be achieved by coatings from which a release of biocides prevents the growth of organisms (bacteria, algae, mollusks). This strategy was applied by conceiving self-polishing paints. In the early 70s, organostannous erodable paints revolutionized fouling prevention by their efficiency. They were composed of tributyltin (TBT) grafted to a polyacrylic backbone via an ester linkage. TBT was found to be a harmful molecule to marine ecosystems, and so its removal from paint formulae is planned.

In order to develop less toxic paints, it is necessary to further investigate the properties of antifouling coatings. The use of confocal laser scanning and scanning electron microscopies was investigated to facilitate the observation of adhered microfouling on antifouling coatings.

To understand the effects of coatings on biofilm formation, we have used different conditions of immersion:

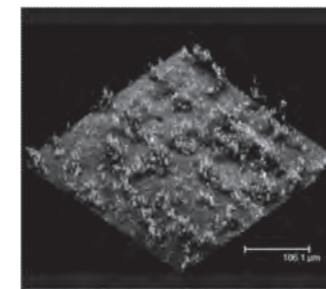


Figure: Observation of multi-species biofilms onto antifouling paint

- In natural seawater to evaluate the kinetics of colonization of natural microfouling onto coatings. Results have confirmed that a link exists between the microfouling observed and the antifouling activity of the coatings: the microfouling adhesion kinetic was sensibly decreased on a coating with good antifouling properties.
- In vitro, by evaluation of bacterial initial adhesion and biofilm formation in static conditions.
- In vitro, to evaluate the attachment of a diatoms onto coatings
- In a bioreactor, to verify the cellular arrangement between marine bacteria and marine diatoms over time by studying the dynamics and architecture of multi-species biofilms.

The study revealed the utility of CLSM for the evaluation of antifouling paints and reports on the efficacy of CLSM to study the initial microfouling layer. This method yields important data relating to biofilm morphology, particularly film thickness and biomass measurements. This non-invasive technique enabled us to obtain qualitative and quantitative data about the biofilm formation.

Keywords : biofilms, antimicrobial surfaces, antifouling, confocal scanning microscopy

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BIOFOULING GROWTH ON ASTM A-131 CARBON STEEL IMMersed AT GUANABARA BAY, RIO DE JANEIRO, BRAZIL: DIFFERENCES BETWEEN UNCOATED COUPONS AND COATED WITH A COMMERCIAL ANTICORROSIVE COATING

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Metallic materials employed in the marine environment are exposed to aggressive and complex corrosive conditions, which are often accentuated by biofouling growth. Organic coatings are very efficient and widely used against corrosion and fouling, but biofouling growth can cause the rupture of the protective layer particularly by the action of barnacles and cause serious failures. The goal of the present experiment was to register biofouling colonization on carbon steel (ASTM A-131, 150mm x 200mm x 2mm) uncoated coupons and coupons protected by an epoxy coating cured with polyamine, in order to verify the differences in the colonization process and to identify possible damages in the protective layer with visual inspections and monitoring the corrosion potential (E_{corr}) behaviour. The experiment was conducted at Guanabara Bay, Rio de Janeiro, an eutrophic tropical area with heavy fouling load. Four coupons of each treatment (coated and uncoated) were suspended in floating structure along 3 months. Photographs of the coupons were taken once a week concurrently with corrosion potential measurements in relation to Ag/AgCl electrode. In this period, biofouling community totally covered the coupons. It comprised the same dominant biofoulers vs. time in both treatments: *Obelia dichotoma* (hydrozoan) and *Amphibalanus amphitrite* (barnacles) in the first six weeks and *Serpula* sp. (tube worm) and *Bugula neritina* (bryozoan) from the 8th week until the end. The percent cover of *O. dichotoma*, *B. neritina* and *Serpula* sp. showed no differences between treatments, however, *A. amphitrite* percent cover were significantly higher ($p > 0,002$; $t = 3,876$; $df = 11$) on coated coupons than on uncoated ones. E_{corr} values were more noble for coated (min: $-698\text{mV}_{\text{Ag/AgCl}}$; max: $-604\text{mV}_{\text{Ag/AgCl}}$) than uncoated coupons (min: $-835\text{mV}_{\text{Ag/AgCl}}$; max: $-701\text{mV}_{\text{Ag/AgCl}}$) and the variation did not indicate the rupture of the protective layer, as was also observed in the visual inspections. However, several barnacle bases firmly attached could be detected only on coated coupons, confirming that the most stable substrate provided by the coating facilitated the adhesion of barnacles. The natural detachment of the bases (not observed) may represent initial points of protective layer rupture along time.

Acknowledgments:

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THREE-DIMENSIONAL BEHAVIOURAL ANALYSIS OF BARNACLE CYPRIDS DURING SURFACE EXPLORATION.

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The motile larvae of sessile marine invertebrates often engage in a period of surface exploration prior to selecting a suitable location for permanent attachment. Barnacle cypris larvae are perhaps the most highly specialised for this role. Using their paired antennules, on which are found apparatus for rapidly reversible adhesion, barnacle cyprids 'walk' across surfaces in a bi-pedal fashion, detecting the physical and chemical characteristics of the surface with a diverse array of sensory structures. The relation of exploratory behaviour to the nature of the surface and, by extension, the likelihood of larvae to settle on a given surface have been subjects of previous research. However, it remains unclear whether or not 'general rules' can be drawn regarding the behavioural response of settling larvae to a given surface type, or if these behaviours once defined can be used to predict the likelihood of settlement. Previous attempts to describe cyprid exploratory behaviour on diverse surfaces using conventional two-dimensional video tracking have fallen short of expectations, due in part to the lack of a vertical dimension in the analysis. Using experimental substrata with well-defined surface properties and a novel system for three-dimensional video tracking, the movements of cyprids on surfaces can now be recorded at high resolution for subsequent analysis. This poster details the adaptation of Simi reality motion software for investigating microscopic zooplanktonic organisms, the design of the apparatus for behavioural tracking during surface exploration and the development of methods for extracting pertinent information from the data output. It is anticipated that quantitative measures of the interactions between fouling organisms and surfaces will provide an additional tool to inform the development of novel fouling-resistant coatings.

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ACCURATE AND PRECISE METHODS TO QUANTIFY BIOFOULING ACCUMULATION

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In response to industry and government requests for verifiable means of assessing antifouling strategies, the Pacific Northwest National Laboratory of the United States Department of Energy is developing a suite of significantly more quantifiable methods to measure and characterize the accumulation of fouling material. These methods provide greater accuracy and precision when examining fouling processes and quantitatively comparing material performance. Reports of antifouling material performance can be difficult to compare when the experiments are conducted by different laboratories or at different times. One root cause is the combined effect of both engineered and uncontrollable variation between exposures. A second problem however, is the lack of uniform and broadly applicable quantitative methods. Several of the methods in use by industry and the military, including the published ASTM methods, are highly subjective, relying on observations and the indeterminable skill of the observer. Although attempts have been made to control both exposures and measurements by using monoculture studies with highly controlled environments, these single organism studies are not representative of natural fouling environments and may underestimate fouling potential. And while studies using natural settings for exposures may be more comprehensive or inclusive of different classes of organisms and pathways to failure, the descriptive methods of analysis used with complex fouling communities lead to significant ambiguity when comparing reports.

We present a suite of methods that we believe provide more quantitative measures of fouling accumulation, particularly when studying natural biofouling accumulations. The use of highly quantifiable methods would reduce the uncertainty that currently exists when comparing studies by different groups. These methods include differential staining for improved visualization of the conditioning film and biofilm combined with an image processing MATLAB utility to provide consistent and automated measurements of coverage density. Second, procedures to measure total carbon (TC) and total organic carbon (TOC) accumulating on surfaces with negligible damage to underlying coatings. Third, wet and dry mass methods that better capture the relative contribution of both calcareous organisms those with high-water mass. And fourth, rapid molecular microbiological methods to fingerprint biofilm community structure and determine species/cell counts.

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LAB-BASED ALL YEAR ROUND ANTI-FOULING BIOASSAY TO SCREEN FOR PRE- AND POST-SETTLEMENT BIOCIDES ACTIVITY AGAINST BARNACLES.

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Barnacles are important fouling organisms worldwide, largely increasing the hydrodynamic drag of ships. By penetration, barnacles may also damage the coatings usually applied on underwater surfaces, also increasing the risk for corrosion. Barnacles have been extensively used as a model in antifouling research over the past decades and valuable bioassays have been developed. Barnacle cyprids are today commonly used to screen for marine anti-fouling substances in static, lab-based systems such as Petri dishes. Reliable flow-through test assays for the screening of antifouling paints and its incorporated biocides are, however, rare.

The barnacle species *Balanus (Amphibalanus) improvisus* can be found worldwide and is by far the most common barnacle species in the brackish Baltic Sea. An all year round culture of this species is maintained at the Sven Lovén Centre for Marine Sciences – Tjärnö at the University of Gothenburg, Sweden and cypris larvae are used in a novel bioassay in order to test pre- as well as post-settlement biocide activity against this common biofouler. The assay is based on open flow cells allowing a continuous flow of seawater that prevents accumulation of biocides in the bulk water. This is a necessary feature for testing coatings where the biocide action is confined to the paint surface. This includes a new strategy of antifouling technology where biocides are strongly bound to the paint matrix and the antifouling activity is exercised only when the fouling organism makes contact with the paint, e.g. at settlement or post-settlement penetration. Each flow cell can hold one treated and one control panel of 11 x 11 cm allowing appropriate statistical analysis, and the design of the flow cells, especially the nylon net material, ensures that the test panels are the only surfaces available for barnacle cyprids to settle. This assay is applied within the European FP7 Collaborative project "LEAF ¹", aiming to develop sustainable antifouling solutions based on a newly discovered "Low Emission AntiFouling" paint concept.

Preliminary tests with biocide-free panels show that settlement rate is high in the flow cells and that settled barnacles can be monitored after metamorphosis to explore the time-dependent effect of biocides. The novel flow-cell assay is now used to test for antifouling activity against barnacles, achieved by trace amounts of macrocyclic lactones where the biocide effect is triggered when post-settlement barnacles penetrate the coating rather than from biocide released from the coating into the bulk water.

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007- 2013) under grant agreement n° 314697.

¹ <http://www.leaf-antifouling.eu/>

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RAPID LABORATORY SCREENING OF DRAG DUE TO SLIME FOULING ON MARINE COATINGS

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Fouling of a vessel's hull by marine micro-organisms, commonly referred to as 'slime', can lead to a considerable hydrodynamic drag penalty. Slime fouling can remain attached at speeds greater than 30 knots even on foul release coatings. Existing test methods to measure drag using towing tanks or large disc rotor rigs are cumbersome and expensive. A benchtop disc rotor method has been developed which uses a sensitive rotational rheometer to measure the torque range on 25 mm diameter acetal polymer discs rotating at tangential velocities up to 3.75 m s⁻¹ (7.3 knots). Acrylic coatings containing experimental natural antifouling compounds were applied to acetal discs which were exposed in the sea for short periods to accumulate slime fouling. The rheometer technique was used to assess the resulting increase in torque needed to rotate the discs over a fixed range of angular velocities. The disc momentum coefficient (C_m) is proposed as a suitable parameter for comparing increases in drag due to slime fouling. C_m values were increased by up to 20% after only 5 days sea exposure. The relevance of these rapidly obtained C_m values to full-scale ship performance will be discussed.

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LOW EMISSION ANTIFOULING (LEAF) PROJECT: ANTIFOULING COMPOUNDS AND EVALUATION OF TOXICITY ON CORAL SYMBIONTS.

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Most of the maritime trading routes go via tropical waters. Moreover, the contamination of tropical marine environment (water column and sediment) by leachate from antifouling paints has led concerns regarding the effects on corals and their symbionts. Healthy coral reefs are among the most biologically diverse and economically valuable ecosystems on earth, providing valuable and vital ecosystem services (food, protection of coastlines from storms and erosion, providing habitat, spawning and nursery grounds for economically important fish species, providing jobs and income to local economies from fishing, recreation, and tourism, hotspots of marine biodiversity). Thus, in order to develop new eco-friendly anti-fouling solution, it is of high importance to evaluate their impact on key coral reef organisms.

Reef-building corals consist of a symbiosis involving an animal and a microalgae. Studies have demonstrated that coral-bleaching is in most of the case linked to the death or loss of the symbionts to detrimental environmental conditions. Thus, within this project we have evaluated the potential toxicity of seven biocides: two booster biocides (Diuron and Irgarol), two synthetic biocides (Thiram and Zinc pyrithione) and three biocides of natural origin (Capsaicin, Myristic acid and Totarol) at environmental concentrations, toward the survival of four species of *Symbiodinium* sp.: *Symbiodinium microadriaticum* CCMP 2467, *Symbiodinium kawagutii* CCMP 2468, *Symbiodinium* sp CCMP 2556 and *Symbiodinium* sp AC 561. Based on the results obtained recommendation about eco-friendly AF formulation will be presented and discussed.

Acknowledgments:

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007- 2013) under grant agreement n° 314697.



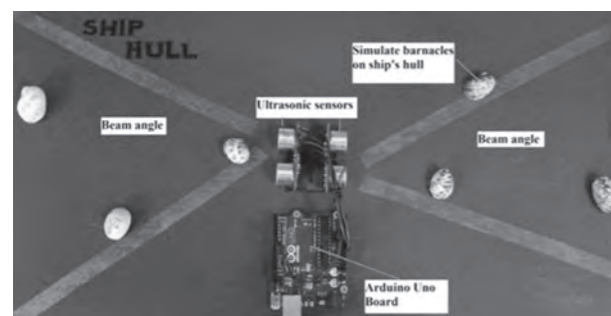
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REAL TIME MECHATRONIC SYSTEM FOR MONITORING BARNACLES NEAR WATERLINE USING ULTRASONIC SENSOR

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This paper presents the monitoring of barnacles on ship's hull near waterline using an ultrasonic sensor. It is important to maintain a clean hull surface to avoid additional hydrodynamic drag that causes higher fuel consumption. As fouling is the main cause for increasing the roughness of the hull, a few antifouling coating types are used to prevent these fouling. However, antifouling coatings deplete over time and it is difficult to predict and control. Thus it is vital to develop a hull monitoring system at the waterline to attain a constant updates on the condition of the hull. The information obtained can facilitate early hull cleaning that eventually reduces the fuel consumption and subsequent nitrogen dioxide, carbon dioxide and sulphur dioxide and emissions of soot. The experiment test conducted on the proposed real-time monitoring system using ultrasonic sensors shown that is able to detect the barnacles' existence on the hull.

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INVESTIGATION OF DERMAL UPTAKE FROM A PAINT FORMULATION WITH FOCUS ON SELEKTOPE *IN VIVO*.

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Human health risk assessment is based on exposure via dermal uptake and inhalation. The default EU risk assessment, if no direct data are available, assumes that 100% of the dermal deposits will reach the systemic circulation. This overly conservative approach can be challenged by using an *in vitro* experimental design with cadaver skin. However, there are technical difficulties with the *in vitro* set-up and also, no general regulatory agreement on how to interpret the results.

Selektepe® is the antifouling trademark of the generic compound medetomidine. As having an origin as a pharmaceutical, it has been ethically possible to verify the dermal uptake of Selektepe from an antifouling paint formulation in healthy volunteers. The investigation was performed according to Good Clinical Practice (GCP) using a standard phase 1 clinical study protocol.

An area of skin (400 cm²) was painted with 10 g of solvent-based antifouling paint containing 1% Selektepe, approximately ten times the commercial formulation. By knowing the applied amount of Selektepe on a defined skin area during six hours and thereafter measuring the plasma levels, it was possible to estimate the dermal uptake. Among the 8 subjects, 4 men and 4 women, 6 had detectable plasma levels above the detection limit. Among those five, the highest value was 0.048 ng/ml plasma which is half of the earlier established No Effective Concentration (NOEC), derived from medical investigations. Based on this, it was possible to estimate a dermal uptake of 0.06%.

Even though the dermal uptake of a compound is highly dependent on its molecular structure, physico-chemical properties and formulation, the present data suggest that a realistic dermal uptake estimate for Selektepe is less than 0.06% from a commercial paint formulation. For future studies, it would be of importance to compare the *in vitro* methodology with the present *in vivo* data in order to more realistically estimate dermal uptake of other antifouling substances.

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RISK ASSESSMENT – HOW SAFE IS “SAFE”?

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Regulatory Compliance Ltd, Edinburgh*

Risk Assessment procedures for antifouling substances are constantly under development, and while general rules and principles are defined, National interpretation of these principles is always inevitable. The goal of protecting the receiving environment from the adverse effects of the substance is often conflict with the efficacy of the coating, increasing the risk of introducing invasive species, and a cost/benefit analysis becomes a priority. In this instance, it is worth understanding how and where the risk assessment tool has introduced protection levels in order to refine the process. Several different parameters may be amended to allow conservatism both in terms of the estimate of emissions and the capacity of the receiving environment. A practical example of the relative importance of these estimates will be presented, demonstrating how the risk assessment may be amended to return more realistic results, while maintain a conservative overall conclusion.

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METABOLOMICS OF CORRODING SYSTEMS AND APPLICATIONS TO CORROSION MONITORING

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The chemical environment at a metal surface is of critical importance to the rates of corrosion, through its influence both on the metal oxidation process and on the associated reduction process(es). Oxide layers and varied mineral deposits (corrosion products) constitute a part of this environment and has been the subject of extensive research. The chemicals and biochemicals in the aqueous phase, the "metabolome", may well be of equal importance. In particular, it can reasonably be argued that the chemical environment created by microbial activity in the near-surface region, such as at the base of a biofilm, is the essence of microbially-influenced corrosion, MIC. However, studies of these direct chemical effects on MIC are scarce. We are using mass spectrometry for broad characterization of the metabolomes in corroding systems in the presence of microbial growth. This serves not only to define the chemical environment, but also to diagnose and classify the microbial activity in the system. Early results indicate that the metabolome, in the absence of microbial cells, is of critical importance to the extent of both general corrosion and pitting of carbon steel under aerobic conditions. Thus, pitting and severe general corrosion have been found to occur in localized regions of "metabolic space", while in other regions, aerobic corrosion is slow. While their interpretation is not obvious, these results are consistent with a selection of dominating compounds in the metabolome having an influence on the rate of oxygen reduction. The stability, or properties, of surface oxide layers may also be influenced, for example through the presence of iron-ion coordinating compounds. A discrimination of corrosion properties in metabolic space imply that corrosion monitoring is possible by tracing the "path" of the metabolome. Within this perspective, corrosion mitigation would be achieved by influencing the metabolic path, by externally forcing, before highly corrosive compositions. Similarly, the efficiency of various mitigation strategies can in principle be evaluated through their effects on the evolution of the metabolome.

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THE EFFECT OF GROOMING ON BIOFOULING COMMUNITIES: LESSONS LEARNED FROM NEARLY A DECADE OF GROOMING

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This review will summarize nearly a decade of research on the effect of grooming on biofouling communities. Grooming is the gentle, proactive, frequent wiping of a surface that has been proposed as an effective method in maintaining surfaces free from fouling. This will reduce drag, fuel costs, greenhouse gas emissions and the spread of non-indigenous species. Grooming effectiveness is determined by the method, coating type, fouling pressure and operational schedule. The future of grooming will be discussed as the technology moves from testing on small panels to a large scale test platform.

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MACROFOULING COMMUNITY STRUCTURE AND THE EFFECTS OF DAMAGE TO SILICONE FOULING RELEASE SURFACES

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Silicone fouling release systems are now being applied as biocide free coatings to commercial ships. They function by reducing the adhesion strength of organisms to the surface. Silicone coating systems are easily damaged; these areas may foul. This study investigated the effect of mechanical damage on coating performance. A total of 28 polyvinyl chloride (PVC) panels cut to 10 cm by 20 cm were used giving 4 replicates of 7 treatments including controls. Test panels were coated with a three-part silicone fouling release system (epoxy, tie-coat, and top-coat respectively). The test panels were artificially damaged to two widths (0.3 cm and 1.3 cm) and to different depths exposing the tie-coat and epoxy layers of the coating system. The damage area was 18.75 percent of the total surface area. The panels were statically immersed, allowed to foul freely and visually assessed monthly. It was observed that organisms preferentially recruited to epoxy and tie-coat surfaces. All damaged areas fouled regardless of width or depth. The results demonstrate the need to maintain fouling release coatings in an undamaged condition.

Acknowledgments:

This study was made possible by the funding and support of the Office of Naval Research (N0001410919).

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DEVELOPMENT OF A FIELD INSTRUMENT TO QUANTIFY VISCOUS DRAG OF MICROFOULING COMMUNITIES ON A SHIP HULL

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Many questions still remain unanswered with respect to the viscous drag of microfouling communities on a ship hull. These communities are difficult to replicate in the lab as the distribution of shear stresses and duty cycle of an in service ship are challenging to reproduce. Thus, there exists a need to measure the viscous drag of the microfouling communities in the field. This research continues to develop a tool that has been proposed to measure the viscous drag of microfouling communities on surfaces (Worley 1990, Flack et al 2012). Ambient seawater was drawn at moderately low to mid Reynolds' number along a fixed conduit. Pressure drop in the streamwise direction was measured using wall taps. This was then used to calculate wall shear stress which was integrated to compute the drag force. Repeatability tests were completed using surfaces of known drag to determine the accuracy and precision bias.

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ANALYSIS OF KEY PARAMETERS CONTAINED IN EXISTING DATA SETS FOR SHIP PERFORMANCE MONITORING

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In parallel with pressure from rising fuel prices, energy and hence fuel efficiency has become an important topic in shipping due to increasing environmental awareness and the enforcement of the first maritime energy efficiency regulations. Ship performance monitoring supports the improvement of many energy efficient operational strategies, such as: optimising hull and propeller cleaning; providing performance feedback to increase personnel motivation; to identify benefits from applying performance improvement technologies and procedures. To date ship performance monitoring is carried out by very few shipping companies, and those that do have typically invested in internally or externally developed monitoring systems requiring input data from various sources. The objective of this paper is to investigate if data currently collected by shipping companies (ship reports, often known as noon reports) is adequate for representing ship performance. An elaboration of the data is carried out including definition of data fields, standardisation of sets for analysis and data filtering. Calculation of additional propulsion plant and ship parameters is performed by applying hydrodynamic principals. Using a Suezmax tanker as a case study, a statistical analysis is undertaken to identify how adequate the data is for determining ship performance throughout operation and a comparison is made between the use of different key parameters, including fuel consumption, resistance and power.

Key words: Energy efficient shipping, Performance monitoring, Operational strategies

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UNDERSTANDING THE IMPACT OF COATING AND HULL ROUGHNESS ON FRICTIONAL RESISTANCE

Philip Stenson, Barry Kidd

AKZO-NOBEL International Paint Ltd, Felling, UK

The topography of fouling control coatings can be described in terms of micro ($L_c < 10$ mm) and macro ($L_c > 10$ mm) roughness elements which contribute to the frictional resistance coefficient (C_f). It is important that roughness measurements clearly state and acknowledge the specific scale of features under analysis. In order to obtain a full understanding of the impact of surface topology additional careful attention must be paid to experimental design to ensure that representative macro and micro features are present in the surfaces and properly measured. This presents a challenge for laboratory testing which often represents an idealised scenario in which many of the macro features associated with the real world field application of coatings are not present. Although numerous previous studies have measured the hydrodynamic drag associated with fouling control coatings it is pertinent that the overwhelming majority of work has been carried out on such laboratory-applied test pieces. Here we present work that aims to bridge this important gap in the understanding of the hydrodynamic impact of fouling control coating roughness through a focus on measurements whereby in-field macro roughness elements are simulated and present alongside inherent micro roughness elements associated with the coating formulation. Additionally we present and discuss work to measure the micro features associated with in-field application of fouling control coatings. Typically, field roughness measurements focus on macro ($L_c = 50$ mm) features detected using the industry standard Hull Roughness Analyser. This methodology continues to provide meaningful data that forms an important part of the collective understanding of the impact of hull roughness on ship efficiency. However, our work reveals that an expansion of the current approach towards a more in-depth acknowledgement of all scales of roughness (both micro and macro features) is required in order to gain the most meaningful insight into the impact of both coating roughness and hull roughness on frictional drag. Although individual trends in surface topology and drag can be discerned from a focus on either micro or macro roughness elements, an holistic approach that fully considers all scales of roughness elements is required in order to make the most robust predictions of ship efficiency.

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THE EFFECT OF NAVAL FUELS AND NITRATE ON MARINE CORROSION OF CARBON STEEL BY MARINOBACTER SP

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Dissolved inorganic nitrogen (DIN) is considered to be an indicator of pollution in marine environments. Recently, increased levels of DIN in coastal seawater have been proposed as one of the parameters which ought to be considered when evaluating long-term corrosion behavior of carbon steel.

This communication presents laboratory investigations of the effect nitrate, in levels which represent pollution in marine habitats, exerts on marine corrosion of 1018 carbon steel in the presence of *Marinobacter* spp. The isolate (B1) was recovered and purified from Key West sweater (KWSW)/navy fuel enrichments. Sequence of 16S rRNA demonstrated 90% homology with that of *Marinobacter hydrocarbonoclasticus*. The latter has been reported to be able to degrade straight and branched alkenes.

Deterioration of steel coupons was monitored in a range of incubations comprising *Marinobacter* isolate B1 using filter sterilized KWSW as a medium with and without sodium nitrate and with different navy fuels/biofuel blends. Weight loss measurements, light profilometry, electron microscopy and electrochemical techniques revealed that *Marinobacter* isolate B1 formed biofilms on surfaces of carbon steel and that steel corrosion varied with fuel type and with nitrate addition. Molecular biology methods were applied to detect and quantify the expression of selected functional genes involved in assimilatory and dissimilatory nitrate reduction and in aerobic hydrocarbon degradation pathways in an attempt to correlate bacterial metabolism with corrosion. Biodeterioration of naval infrastructure as a result of fuel biodegradation combined with marine pollution is discussed.

Acknowledgments:

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ADDENDUM - OPENING ADDRESS

OPENING ADDRESS BY MR ANDREW TAN, CHIEF EXECUTIVE MARITIME AND PORT AUTHORITY OF SINGAPORE (MPA), AT THE 17TH INTERNATIONAL CONGRESS ON MARINE CORROSION AND FOULING (ICMCF) HELD AT THE NATIONAL UNIVERSITY OF SINGAPORE ON MONDAY, 7 JULY 2014, 0900HRS

Dr Andrew Scardino, Chairman COIPM and COIPM Committee Members

Professor Peter Ng, Director of Tropical Marine Science Institute (TMSI), National University of Singapore (NUS)

Ladies and Gentlemen

A very good morning and warm welcome to all our overseas friends to Singapore.

Congratulations to the International Congress on Marine Corrosion and Fouling (ICMCF) on its 50th Anniversary. We are honoured that ICMCF has chosen Singapore to hold its 17th Congress. You could not have chosen a better place to discuss the conference topics, given the fact that Singapore plays a unique role as a coastal, port and flag state all rolled into one. The maritime sector is also a vibrant part of Singapore's economy, contributing some 6-7% of our GDP and providing jobs to 170,000 people. We are the 5th largest ship registry in the world and the world's largest bunkering port. For Singapore, ensuring high standards as a global hub port and quality flag are important components of our efforts to develop Singapore into a leading international maritime centre.

Beyond this, Singapore hopes to contribute to the development of industry solutions by supporting research and development (R&D) in the marine and offshore sectors. In this regard, today's conference focusing on marine fouling and corrosion - two perennial challenges facing the maritime community - is timely. It is encouraging to see industry players, the research community and experts from all over the world come together to address these issues.

As we all know, marine biofouling takes places rapidly depending on salinity, temperature, nutrient levels, flow rates and the intensity of solar radiation. It affects all marine structures. High level of fouling on ship's hull, for example, could significantly increase drag, reduce a vessel's performance, and increase fuel cost. Likewise, the corrosion of marine structures can result in premature failures, reduce service life, increase maintenance costs and pose safety hazards. I don't have the global figures for how much it costs to deal with marine fouling and corrosion worldwide - there are various estimates - but suffice it to say that it is a huge recurring amount.

Marine Biofouling and Corrosion - Challenges and opportunities: Following the economic downturn of 2008, the global maritime industry is still not out of the woods yet, although there are signs of pick up in some segments. Many shipping lines continue to face overcapacity and are under pressure to adopt cost-cutting measures. As fuel takes up more than half of a vessel's operational cost, shipping companies have turned to other solutions to improve fuel efficiency, such as antifouling coatings to prevent fouling and reduce drag. With growing environmental concerns and the introduction of new international regulations such as the upcoming Ballast Water Management Convention, the need for the maritime industry to search for effective environmentally-friendly solutions is real. There is therefore a large market for solutions that are cost-effective, replicable and scalable.

As a global transshipment hub and a leading petrochemical centre, Singapore is well-positioned for this opportunity. Already, major paint manufacturers such as International Paints and Akzo Nobel have established their R&D bases in Singapore. We also have a large and growing cluster of research institutions under the Agency for Science, Technology and Research, or A*STAR, and our universities ready to work with interested collaborators to bring inter-disciplinary approaches to the field of marine biofouling and corrosion.

ADDENDUM - OPENING ADDRESS

On the marine and offshore front, asset owners and operators too are looking for effective ways to extend the life and integrity of offshore structures and installations without compromising safety. There are many aging offshore assets, in this region and globally, that critically need innovative solutions for corrosion inspection and monitoring. Singapore is a leading offshore and repair centre, and will continue to build on our strength in developing an entire value-chain covering R&D, test-bedding, manufacturing, repair and maintenance in this sector. I believe the cross-sharing of knowledge and expertise across both the marine and offshore sector can shed new insights on solutions that are cost-effective yet durable. In addition, with the growing inter-disciplinary approach taken towards research, I am confident that new breakthroughs in either chemical-based solutions or more novel new surfaces could arise. But I stress again that all these solutions can only be adopted if they are economical and cost-effective. Industry support and participation in what needs to be a joint solutioning process is therefore critical.

Singapore Promotes R&D in Marine Bio-fouling and Corrosion

The Maritime and Port Authority of Singapore (MPA) is a keen supporter of both industry and academic R&D projects to develop environmental-friendly antifouling substances and methods of reducing corrosion. To-date, projects by the Tropical Marine Science Institute (TMSI) of NUS, the Institute of Chemical & Engineering Sciences (ICES) of A*STAR, and the Nanyang Technological University (NTU) have resulted in a number of patents. Last Friday, BW Ventures, in collaboration with MPA and the Singapore Maritime Institute (SMI), successfully performed the first environmental-friendly hull cleaning test trial at the Port of Singapore. This method of using high-technology, remotely operated underwater vehicles (ROVs), is capable of performing fast, efficient and cost effective hull cleanings to remove biofouling.

The SMI, set up to develop strategies and programmes related to the academic, policy and R&D aspects of the maritime industry, has identified marine fouling and corrosion as one of the focus areas in its R&D Roadmap 2025. New initiatives to support and strengthen research into sustainable biofouling management are currently underway.

MPA has also set aside a S\$100 million Maritime Singapore Green Initiative to fund green shipping programmes in Singapore. S\$25 million has been committed under its Maritime Innovation and Technology (MINT) Fund for the Green Technology Programme to encourage local maritime companies to develop and adopt technologies which are environmentally friendly. These include new technologies and approaches to prevent fouling and corrosion.

Beyond investing in innovation and technology, as a longstanding Council Member, MPA takes a strong interest in, and participates actively in regulatory developments at the International Maritime Organization (IMO) to manage antifouling. The International Convention on the Control of Harmful Anti-Fouling Systems on Ship, or AFS Convention, was implemented in the Port of Singapore in 2010.

Ladies and gentlemen, you have a busy and exciting programme over the next four days. Judging from the substantive conference programme, the organisers of this 17th Session of the Congress have obviously worked hard to bring together industry experts and top scientists from around the world to discuss the latest trends and developments of fouling and corrosion, and address the key challenges and opportunities. I am confident that this platform will catalyse in-depth discussions and potential collaborations that will extend well into the future. I wish everyone a fruitful Congress.

Thank you.

ADDENDUM - REVISED PROGRAMME

THURSDAY, 10 th July 2014		
8.30am	PLENARY 3: ANTIFOULING RESEARCH & DEVELOPMENT Dr Steve McElvany, US Office for Naval Research Coatings Program, United States	
9.20am	SHORT BREAK	
	TRACK A SHIP HYDRODYNAMICS AND ENERGY EFFICIENCY Session Chair: Dr Andrew Scardino	TRACK B MARINE CORROSION - MATERIALS AND COATINGS Session Chair: Dr Dominique Thierry
9.30am	KEYNOTE: THE EFFECT OF ANTIFOULING PAINTS ON LONG TERM HYDRODYNAMIC PERFORMANCE OF SHIPS RELATED TO ENERGY EFFICIENCY Dr Noriyuki Sasaki, Monohakobi Technology Institute, Japan	KEYNOTE: METALS AND THEIR CORROSION BEHAVIOUR IN SEAWATER - AN ENGINEERS OVERVIEW Mrs Carol Powell, Copper Development Association and Nickel Institute, United Kingdom
10.15am	ORAL 1: FOULING AND VESSEL PERFORMANCE ON AN ALUMINIUM HULLED PATROL BOAT OPERATING IN TROPICAL WATERS Andrew Scardino, Defence Science & Technology Organisation, Australia	ORAL 1: STUDY OF PHYSICO-CHEMICAL AND MICROBIOLOGICAL TESTING PARAMETERS IN RELATION TO MARINE CORROSION Scott Wade, Swinburne University, Australia
10.30am	ORAL 2: FOULING-RELEASE PROPELLER COATINGS : EFFICACY AND DURABILITY ON A US NAVY LSD-CLASS VESSEL Elizabeth Haslbeck, Naval Surface Warfare Center, Carderock Division, United States	ORAL 2: CORROSION PERFORMANCE OF 25%CR SUPERDUPLEX STAINLESS STEEL FOR DIFFERENT SEAWATER APPLICATIONS Nicolas Larché, Institut de la Corrosion, France
10.45am	ORAL 3: LONG TERM DRAG PERFORMANCE OF HULL COATINGS FOR OCEAN GOING VESSELS Asger Lindholdt, Technical University of Denmark, Denmark	ORAL 3: LOCALIZED CORROSION OF 316L STAINLESS STEEL IN SINGAPORE SEAWATER Daniel Blackwood, National University of Singapore, Singapore
11.00am	COFFEE BREAK	
	TRACK A - AUDITORIUM INDUSTRY SESSION Session Chair: Mr John Lewis	TRACK B - LT 52 SHIP HYDRODYNAMICS AND ENERGY EFFICIENCY (Continue)
11.30am	KEYNOTE: THE TANKER INDUSTRY PERSPECTIVE – MODERN ANTIFOULING SYSTEMS: EXPERIENCE AND IMPACTS Mr Tim Wilkins, INTERTANKO, Singapore	ORAL 4: HYDRODYNAMIC PERFORMANCE EVALUATION OF FDR-SPC (FRICTIONAL DRAG REDUCTION SELF-POLISHING COPOLYMER) Inwon Lee, Pusan National University, Korea
11.45am		ORAL 5: HULL AND PROPELLER PERFORMANCE MEASUREMENT FOR VESSEL IN SERVICE Andreas Krapp, Jotun A/S, Norway
12.00pm		ORAL 6: PREDICTION OF THE EFFECT OF HULL FOULING ON SHIP RESISTANCE USING CFD Yigit Kemal Demirel, University of Strathclyde, United Kingdom
12.15pm	ORAL 1: THE BURDEN OF BIOFOULING : WHAT DOES IT WEIGH? John Lewis, ES Link Services, Australia	ORAL 7: AN EXPERIMENTAL INVESTIGATION INTO DIFFERENT SKIN FRICTION ANALYSIS METHODS FOR COATINGS WITH DIFFERENT ROUGHNESS RANGE Irma Yeginbayeva, Newcastle University, United Kingdom
12.30pm	ORAL 2: PREVENTING THE ESTABLISHMENT OF INVASIVE PESTS IN A MARINE CONSERVATION AREA THROUGH EFFECTIVE MARINE BIOSECURITY Simon McKirdy, Chevron, Australia	ORAL 8: BOUNDARY LAYER AND ROUGHNESS CHARACTERISTICS OF A COMMERCIALY AVAILABLE NANOSTRUCTURED ANTIFOULING COATING Irma Yeginbayeva, Newcastle University, United Kingdom
12.45pm	ORAL 3: SONIC MITIGATION OF FOULING SERENA WILKENS, NIWA, NEW ZEALAND	ORAL 9: A NUMERICAL TOOL DEVELOPMENT ON THE EFFECT OF COATING AND BIO-FOULING ON THE MARINE PROPELLERS KwangcheolSeo, Newcastle University, United Kingdom
1.00pm	LUNCH (NOT PROVIDED)	

ADDENDUM - REVISED PROGRAMME

THURSDAY, 10 th July 2014		
	TRACK A - AUDITORIUM SHIP HULL MANAGEMENT Session Chair: Professor Geoffrey Swain	TRACK B - LT 52 INDUSTRY SESSION (Continue)
2.00pm	KEYNOTE: MANAGING UNDERWATER HULL PERFORMANCE Dr Raouf Kattan; Safinah Limited; Newcastle University, United Kingdom	ORAL 4: EFFECT OF PARTICLE SIZE OF COPPER PYRITHIONE ON LEACH RATES FROM ZINC ACRYLATE ANTIFOULING COATINGS Paul Kappock, Lonza, United States ORAL 5: MICROBIOLOGICALLY INFLUENCED CORROSION RISKS IN THE INTERIOR OF OFFSHORE WIND MONOPILES Felipe Leon, ENDURES BV, Netherlands ORAL 6: EVALUATION OF ANTIFOULING PAINTS AND DEVELOPMENT OF BIVALVE MOVEMENT SENSOR FOR BIOFOULING CONTROL IN COOLING WATER SYSTEM Kamala Kanta Satpathy, Department of Atomic Energy, India
		FOULING IN AQUACULTURE Session Chair: Dr Belinda Yaxley
2.45pm	INVITED: MANAGING IN-WATER HULL INSPECTIONS, CLEANING AND OTHER TREATMENTS TO REDUCE BIOSECURITY RISK AND BIOLOGICAL ROUGHNESS: THE EXPERIENCE AT SINGAPORE Robert Hilliard, Intermarine Consulting Pte Ltd, Australia	4B - KEYNOTE: CHALLENGES AND OPPORTUNITIES FOR UNDERSTANDING AND MANAGING BIOFOULING IN MARINE AQUACULTURE Dr Oliver Floerl, SINTEF Fisheries and Aquaculture, Norway
3.15pm	ORAL 1: DATA MASHING, BIG DATA AND MULTIVARIATE MODELLING TO PREDICT COATING PERFORMANCE Jeremy Thomason, Ecoteknica SCP, Mexico	
3.30pm	ORAL 2: THE EFFECTS OF GROOMING ON COPPER ABLATIVE COATINGS: A SIX YEAR STUDY Melissa Tribou, Florida Institute of Technology, United States	ORAL 1: BLUE MUSSEL (MYTILUS GALLOPROVINCIALIS) OVER SETTLEMENT ON NEW ZEALAND'S GREEN-LIPPED MUSSEL (PERNA CANALICULUS) FARMS Javier Atalah, Cawthron Institute, New Zealand
3.45pm	ORAL 3: DRYDOCK COATING INSPECTION METHODOLOGY AND SHIP HULL MANAGEMENT Abhishek Koka, Florida Institute of Technology, UNITED STATES -To be presented by Geoffrey Swain	ORAL 2: THE ROLES AND DYNAMICS OF CALCIUM ION AND GLW-AMIDE PEPTIDES IN SETTLEMENT AND METAMORPHOSIS OF ACTINULA LARVAE OF MARINE HYDROID TUBULARIA MESEMBRYANTHEMUM Keiji Yamashita, Sessile Research Corporation, Japan
4.00pm		ORAL 3: ARE SALMON FARMS PROPAGULE RESERVOIRS FOR MARINE BIOFOULING ORGANISMS? Nina Blecher, SINTEF Fisheries and Aquaculture, Norway
4.20pm	BEST YOUNG RESEARCHER PRIZE PRESENTATION, CLOSING REMARKS (AUDITORIUM)	
4:30-6:00pm	NETWORKING TEA	

ADDENDUM - ORAL PRESENTATION

SONIC MITIGATION OF FOULING

Serena L. Wilkens, National Institute of Water and Atmospheric Research, Private Bag 14901, Kilbirnie, Wellington, 6241, New Zealand (presenter)

Jenni A. Stanley, Leigh Marine Laboratory, University of Auckland, PO Box 349, Warkworth, 0941, New Zealand

Andrew G. Jeffs, Leigh Marine Laboratory, University of Auckland, PO Box 349, Warkworth, 0941, New Zealand

Justin I. McDonald, Western Australian Fisheries and Marine Research Laboratories, PO Box 20, North Beach, Western Australia 6920

Recent ecological research indicates that underwater sound plays an important ecological role in the settlement behaviour of many marine organisms. Laboratory and field experiments have shown that some types of underwater sound trigger directional movement of larvae and more rapid settlement in a wide range of species, including some biofouling organisms. Large, steel-hulled vessels generate a range of underwater sound during movement and port operations. In this research, we investigate whether sound generated by vessels exacerbates the settlement and growth of biofouling on hull surfaces. In particular, we explored whether the underwater sound emitted by vessels in port enhances fouling of their submerged surfaces. Three experiments were designed to investigate the effects of generator sound:

1. In the laboratory, mussel larvae were exposed to pre-recorded generator noise emitted by large steel hulled ships whilst in port. Results indicated a significant increase in settlement and metamorphosis of larvae when subjected to vessel noise.

2. In the field, clean settlement plates were deployed in a harbour (free of vessel traffic) and subjected to pre-recorded vessel noise. Levels of biofouling and species diversity were significantly higher on the plates which had been exposed to the pre-recorded vessel noise compared with silent controls. Furthermore, the growth rate of newly-settled biofouling was enhanced by the presence of vessel noise.

3. In the laboratory, ascidian larvae were exposed to pre-recorded generator noise from domestic fishing vessels. Larvae exposed to the loudest noise (i.e. recordings taken closest to the generator) settled and metamorphosed significantly faster than larvae which were exposed to a lower intensity (quieter) noise (i.e. recordings taken on the opposite side of the vessel or the stern). These results were also further substantiated by an assessment of the level of biofouling and species diversity on the vessel hulls.

These novel results indicate that underwater vessel noise plays an important role in stimulating biofouling. Our research suggests that taking practical steps to reduce generator and engine noise could have positive outcomes for the management of biofouling on vessels.

ADDENDUM - POSTER PRESENTATION

VESSEL SEACHEST BIOFOULING: MINIMISATION AND CONTROL THROUGH IMPROVED DESIGN?

Richard Piola¹, Martin Leary², Scott Mayson², Jeff Shimeta³ and Steven Toppi⁴

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The accumulation of biofouling on marine vessels and structures results in reduced operational efficacy and increased running costs, in addition to posing significant environmental risks through the transport of unwanted marine pest species. For vessels, one particular design feature that has long posed a problem for biofouling control is sea chests - recesses built into a vessel's hull below the waterline that house the intake pipes for sea-water used for ballast, engine cooling and firefighting. This is primarily because sea chests are difficult to access and inspect, and their diverse shape and size result in variable water flow regimes that are poorly suited to minimising biofouling settlement, and for the efficient performance of antifouling coatings. The work presented here describes a process that utilises the flexibility and low-batch production capabilities of additive manufacture, or 3D printing, to produce low-cost custom-made inserts aimed at reducing biofouling in vessel sea chests. This is achieved by improving the flow profile within the sea chest, thereby reducing low-velocity regions (or 'dead spots') that can accumulate biofouling organisms. In addition, a reduction in the variation of shear stresses is observed across the sea-chest surface, which enables more uniform ablation and performance of antifouling coatings. Importantly, this manufacturing process provides a means of retro-fitting (and retro-designing) existing vessel sea chests, ensuring improved performance and reduced biofouling accumulation at a low-cost to the operator.

ADDENDUM - POSTER PRESENTATION

QUORUM SENSING AND ANTIFOULING INHIBITORY POTENTIAL OF BRAZILIAN MARINE SPONGES

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Marine sponges are rich sources of biologically active compounds which can be used in biotechnological applications. Quorum sensing (QS) is a bacterial population density dependent genetic mechanism regulating adhesion, growth, and biofilm formation. Thus, compounds that inhibit QS provide a way to control biofilm and biofouling. In this study, we screened extracts of 14 marine sponges from upwelling and non upwelling areas for their ability to inhibit bacterial QS, biofilm formation, bacterial growth and larval settlement of *Bugulaneritina*. About 85% of MeOH (methanol:water) and 7% of DCM (dichloromethane) extract showed QS inhibitory properties for *Chromobacterium violaceum* CV017. Quantitative determination of QS based on production of violacein by *C.violaceum* CV017 and elastase by *Pseudomonasaeruginosa* PA01 demonstrated that the same species of sponges collected from upwelling and non upwelling area had different activity. Both extracts of *A. brasiliensis* (DCM and MeOH) as MeOH of *Pachychalina* sp. and *Darwinella* sp. inhibited biofilm formation of *P.aeruginosa* PA01. Extracts of 6 species tested at tissue levels inhibited the growth of marine bacteria. MeOH extracts of *Dysidea robusta*, *Dysidea aetheria* and *A. brasiliensis* was toxic to *B. neritina* larvae. This study showed that environmental conditions are important for antifouling activity of marine sponges that need to be considered in the future studies.

Acknowledgments:

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ADDENDUM - POSTER PRESENTATION

VISUAL CUE FOR LARVAL SETTLEMENT IN BARNACLES

Kiyotaka Matsumura^{1,2} and Pei-Yuan Qian¹¹The Hong Kong University of Science & Technology, Hong Kong²Tokyo College of Biotechnology, Tokyo, Japan

Gregarious settlement, an essential behavior for many barnacle species that can only reproduce by mating with a nearby barnacle, has long been thought to rely on larval ability to recognize chemical signals from conspecifics during settlement. Until now, two types of settlement-inducing proteins, substratum-bound and waterborne types, have been isolated and cloned.

On the other hand, the cyprid, the settlement stage larva in barnacles, has one pair of compound eyes that appear only at the late nauplius VI and cyprid stages, but the function(s) of these eyes remains unknown. Here we show that cyprids of the intertidal barnacle *Balanus (=Amphibalanus) amphitrite* can locate adult barnacles even in the absence of chemical cues, and prefer to settle around them probably via larval sense of vision. We also show that the cyprids can discriminate color and preferred to settle on the red surface. Moreover, we found that shells of adult *B. amphitrite* emit red auto-fluorescence and the adult extracts with the fluorescence as visual signal attracted cyprid larvae to settle around it.

To examine molecular mechanisms, two barnacle opsin genes, named *Ba-op1* and *Ba-op2*, expressed in the larval stage of *B. amphitrite* were cloned, sequenced and characterized in expression profiles. The phylogenetic analysis suggested that *Ba-op1* is a long wavelength sensitive opsin. Developmental expression profiling of *Ba-op1* by quantitative real time PCR and *in situ* hybridization indicated that this opsin gene is expressed most highly in the cyprid stage and is expressed in the cyprid compound eyes and in the nauplius eye. It may be a major component of compound eye opsins and therefore play a role in the settlement of barnacle larvae. The cyprids may discriminate red fluorescence signal in adult shells by using the long wavelength sensitive opsin, *Ba-op1*, expressed in their compound eyes.

We propose that the perception of specific visual signals can be involved in behavior of zooplanktons including marine invertebrate larvae, and that barnacle auto-fluorescence may be a specific signal involved in gregarious larval settlement.

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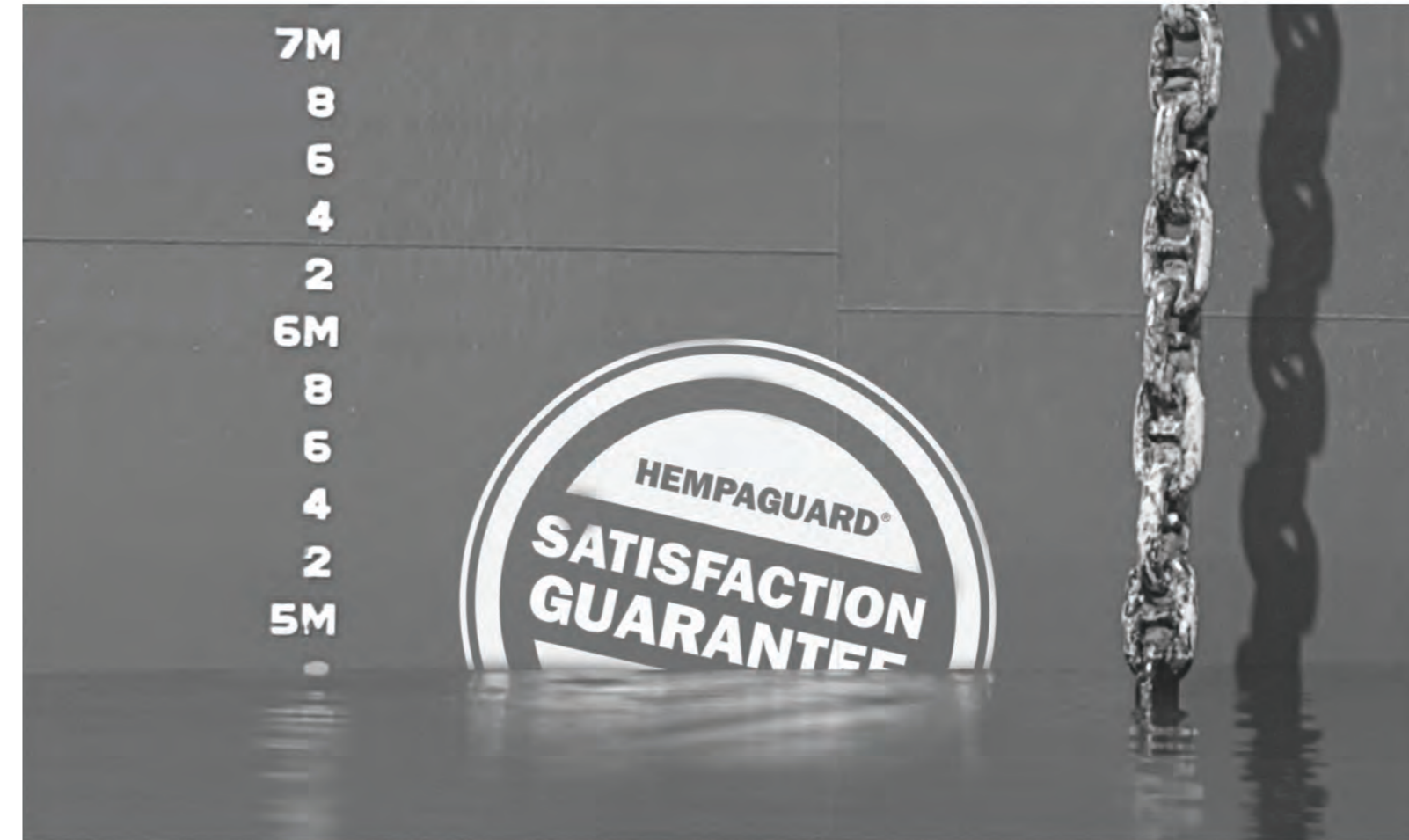
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