GloFouling PARTNERSHIPS

1st GEF-UNDP-IMO GloFouling R&D Forum and Exhibition on Biofouling Management

4th ANZPAC Workshop on Biofouling Management for Sustainable Shipping

Proceedings

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Melbourne, Australia

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The GEF-UNDP-IMO GloFouling Partnerships is a five-year global project aimed at protecting biodiversity by tackling the transfer of harmful aquatic species through biofouling in some of the developing regions of the world. The project encourages the sharing and adoption of technologies and innovative solutions that can improve biofouling management across all maritime industries and the energy efficiency of ships.
http://www.glofouling.imo.org/

Executing Agency:
IMO - the International Maritime Organization – is the United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine pollution by ships.
www.imo.org

Implementing Agency:
UNDP – the United Nations Development Programme – partners with people at all levels of society to help build nations that can withstand crisis, and drive and sustain the kind of growth that improves the quality of life for everyone. On the ground in nearly 170 countries and territories, we offer global perspective and local insight to help empower lives and build resilient nations.
www.undp.org

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The Global Environment Facility (GEF) was established on the eve of the 1992 Rio Earth Summit to help tackle our planet's most pressing environmental problems. Since then, the GEF has provided over USD 17 billion in grants and mobilized an additional USD 88 billion in financing for more than 4000 projects in 170 countries. Today, the GEF is an international partnership of 183 countries, international institutions, civil society organizations and the private sector that addresses global environmental issues.
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Acknowledgements

This publication contains a selection of papers and presentations from the 1st Research & Development Forum on Biofouling Management, and the 4th ANZPAC Workshop on Biofouling Management for Sustainable Shipping, held in Melbourne, Australia, from 1 to 4 October 2019.

While it is impossible to name everyone, it is important to give credit to all the people and organizations that collaborated in the event and contributed to its success. In first place, our very special thanks go to Ms. Lyn O'Connell, Deputy Secretary, Department of Agriculture, Water and the Environment, Australian Commonwealth, for her kind attention and willingness to deliver the inaugurating address of the Forum. We are also indebted to Mr. Theofanis Karayannis, Head of Marine Biosecurity at IMO's Marine Environment Division, for his presence and inspiring opening remarks at the Forum.

Our appreciation is due to Mr. Peter Stoutestdjik and the Marine Biosafety staff at the Australian Department of Agriculture, Water and the Environment, for the support and advice prior to and during the event. Special thanks are also owed to the partners who made this joint event possible, in particular Mr. John Lewis, who was instrumental in handling preparations from Australia, and IMarEST, a Strategic Partner of the GloFouling Partnerships, which actively facilitated collaboration and communications. Our warm thanks to Ms. Alison Saunders for her invaluable support with local logistics for the event.

Our sincere thanks to the ANZPAC Steering Group that helped coordinate the event, shape the programme and, in some cases, acted as chairpersons in some of the sessions: Mr James Chapman, Mr Eugene Georgiades, Ms. Angela Gillham, Ms. Sonia Gorgula, Ms. Clare Grandison, Mr. Nick Hutchins, Ms. Marion Massam, Mr. Justin McDonald, Mr. Jason Monty, Mr. Richard Piola, Ms. Alison Saunders, Mr. Michael Sierp, Mr. Richard Stafford-Bell and Mr. Peter Wilkinson. We cannot forget the remaining chairpersons that so diligently facilitated and moderated the discussions during the Forum sessions, namely Mr. Richard Stafford-Bell, Mr. Michael Sierp, Ms. Violeta Luque, and Mr. Paul Holthus.

In particular, we would like to thank the members of the Scientific Committee that helped us in selecting topics and papers for the Forum; and of course, thank you to all of the speakers for their papers, presentations and interventions in the discussions as well as for their knowledgeable contributions for publication in these proceedings. The Forum success was mainly attributed to the active engagement of all the delegates and participants and we would like to extend our sincere appreciation to them and to all the sponsors, supporters and exhibitors for their participation and contribution: EcoSubsea, The University of Melbourne, Maritime Industry Australia Ltd, CleanSubSea, Franmarine Underwater Services, Hempel, Inchcape, American Chemet Corporation, Rightship, EPSCO, ESLink Services and the Department of Agriculture of the Australian Government.

Finally, many thanks are also due to our IMO colleagues who supported the 2019 GloFouling R&D Forum, in particular Mr. Jose Matheickal, Mr. John Alonso and Ms. Violeta Luque.

Lilia Khodjet El Khil
Project Technical Manager
GEF-UNDP-IMO GloFouling Partnerships

Foreword

The objective of GloFouling Partnerships when undertaking the 1st Research & Development Forum on Biofouling Management was to raise awareness of progress made on biofouling management thus far and to spur greater interest in the further development of emerging technologies. We believe we have successfully accomplished this goal: The Forum gathered more than 170 participants representing technology developers, the maritime industry, academia, several national governments and international and regional agencies from around the world. 74 speakers presented topics over 16 plenary sessions that covered all aspects of biofouling management, including IMO's impending review of the Biofouling Guidelines, the challenges for regulators, and perspectives from the private sector during an Industry Panel chaired by the World Ocean Council. These sessions also highlighted emerging technologies, risk assessment frameworks, the linkages between different maritime industries, and the need for collaboration and capacity building to enhance biofouling management in developing nations. The wide participation of eminent experts allowed for a productive discussion and was also a great opportunity to showcase new research on promising technologies.

This first edition of the R&D Forum has also made a positive contribution towards maintaining the global momentum to find optimal solutions and discuss the main aspects of biofouling management in shipping just before the review of the IMO Biofouling Guidelines commences in early 2020. The socio-economic and ecological costs of marine aquatic invasions around the world are already very significant, and while introductions by ship's ballast water and sediments have been addressed at the global level, the need for action is apparent for invasions via biofouling, to reduce both biosecurity risk and greenhouse gas emissions. The presentations and papers enclosed in this publication reflect the international interest in addressing biofouling which is of critical importance for the future of our marine environment.

The challenges ahead are undoubtedly still many in the case of biofouling, not least due to the cross-sectoral nature of the problem and the variety of interests at stake. In this sense, the Forum also serves as an opportunity for industry, biosecurity policy-makers and managers, and academic stakeholders to hear and learn from each other, harmonize efforts and promote innovative biofouling management practices and options that can cater to the various needs of the different maritime industries involved. We hope that this first edition of the Forum opens the way to increased collaboration between all sectors and interests involved and that the next Forum will be just as successful.

Before I end, I take this opportunity to congratulate the GloFouling Partnerships in its first year. This initiative between GEF, UNDP and IMO has already become a major catalyst to bring together the global community in a joint effort to develop new practices and technologies and bring the transformation of all maritime industries to contribute to their environmental sustainability and reducing their impact on marine ecosystems. I encourage all of you to continue such dialogue and information exchange, which is significantly contributing to our common efforts to protect the marine environment.

Jose Matheickal
Chief
Department of Partnerships and Projects
International Maritime Organization

Opening Speeches

MS. LYN O'CONNELL
Deputy Secretary
Department of Agriculture, Water and the Environment
Australian Commonwealth

Lyn O'Connell started as Deputy Secretary in the department in October 2015 and is responsible for biosecurity, compliance, service delivery and oversees the Australian Chief veterinary and plant protection offices. Lyn was previously a Deputy Secretary at the Department of Infrastructure and Regional Development, a position she held for nearly seven years. Prior to that, Lyn held a number of senior executive positions in other government portfolios and the private sector. She has a Bachelor of Science degree (ANU); is a Graduate of the Australian Institute of Company Directors and a Fellow of the Australian Institute of Management. Lyn was awarded a Public Service Medal in 2014.

I value the opportunity to provide an opening address at this inaugural research and development forum for the GloFouling Project and the fourth ANZPAC biofouling workshop, for which we are proud to be a corporate sponsor. I'd like to thank the organisers and sponsors for pulling together a great program that I'm sure will promote discussion and collaboration.

We're really pleased that the first research and development forum for GloFouling is being held in Australia and I'd like to welcome all, especially those of you that have travelled a long way to be here. We highly value the benefits of the ANZPAC workshop and combining this with the first GloFouling research and development forum really does provide a wonderful opportunity for learning, sharing and solving mutual problems in the management of biofouling.

Biofouling on ships is well recognised as a major pathway for the introduction of marine pests and diseases. Unlike ballast water though, there is no international convention to set the rules. Without this, we must work together to achieve effective risk reduction in a consistent manner.

To put the biofouling issue in context for Australia, we have 59,700 kilometres of mainland and island coastline. We take biosecurity seriously. Marine biosecurity, in particular managing the pathways of biofouling and ballast water, are especially important in order to protect our unique marine environment, our marine industries and infrastructure.

We are an island nation, we rely heavily on our marine environment and industries for our food, our trade and our livelihoods. We must protect these through the prevention of introduction of marine pests and diseases.

In my department we work hard to manage biosecurity risks. As many of you would know, we are developing a biofouling policy consistent with the International Maritime Organization's biofouling guidelines. This policy was informed by many of you who provided input to our 2015 Review of National Marine Pest Biosecurity. The review recommended a focus on prevention, noting the difficulties associated with management and eradication of pests and diseases in the marine environment.

The review also recommended Australia implements biofouling requirements. Our preferred approach promotes proactive biofouling management practices. Following consultation on our regulatory impact statement earlier this year, we are in the process of refining our preferred policy based on feedback from stakeholders. We will be seeking government decision in the coming months. You will hear more detail about Australia's proposed biofouling requirements during this workshop from officers from my department's marine biosecurity team.

The IMO biofouling guidelines set the international standard for biofouling management. Having this standard is key to the development of internationally consistent biofouling requirements. In Australia, we have translated the IMO biofouling guidelines into a suite of sector specific guidelines.

We are working hard with fellow regulators from other governments to achieve consistency in biofouling requirements, and you will hear from many of those regulators this afternoon. This workshop is an excellent opportunity to further our collaboration and have important discussions. Through this we hope to harmonise biofouling requirements and provide the shipping industry with clarity about how to meet biofouling requirements in all parts of the world.

The upcoming review of the IMO biofouling guidelines is also critical to the successful implementation of biofouling requirements. We need to make sure biofouling management practices do not just focus on a clean hull for energy efficiency, but that they have an equal focus on managing biosecurity risks. This means turning our focus to the difficult problems, such as management of niche* areas and determining minimum standards for effective biofouling management plans.

Together with our colleagues from New Zealand, we have been proactively working with many of our international colleagues through connections made at the IMO in the lead up to the review of the IMO Biofouling Guidelines. We are putting together submissions now and coordinating this work so that the review is conducted efficiently and delivers outcomes that enable greater uptake of the guidelines internationally.

We have also been pleased to take an active role in the IMO's GloFouling project. Our participation at the inception workshop and in-country workshops in Fiji, Tonga, Mauritius, Madagascar and the Philippines has enabled Australia to share our knowledge and understanding of biofouling and how to approach developing biofouling regulation. We have developed good connections with the project team and in-country leaders working on biofouling, and in doing so expanded our global network of biofouling regulators.

The GloFouling project provides a platform to promote the development of biofouling requirements more broadly, and provides much needed resources and expertise to facilitate this.

As a strategic partner in the project, we are committed to continue to work with the project team and lead partner countries to provide support and subject matter expertise, and importantly work to ensure that everyone working on biofouling is talking to each other. Those communications are essential if we hope to consistently implement the IMO Biofouling guidelines, and ensure industry does not face a patchwork of regulation across the globe.

Our work on biofouling has benefited greatly from the contributions and collaborations we have with our international colleagues, in particular those from New Zealand, California and Hawaii. Those interactions and your generosity in sharing what you have developed and learned is invaluable to us.

You may be aware that in February this year the Prime Ministers of Australia and New Zealand released a joint media statement affirming our commitment to consistency and collaboration in marine biosecurity. We have a long history of working collaboratively with our colleagues in New Zealand. In biofouling, we have worked on joint research projects, shared data and information and had many discussions on the assessment of biofouling risk and practical implementation of biofouling regulations. These discussions continue and now also include working together to build capacity in our region for managing marine biosecurity risks.

Indeed, we are working with many of you and others around the world. Some of our current projects are good examples of this collaboration. Projects such as vessel risk profiling, developing new methods for undertaking hull inspections including automated image analysis, and the development of an in-water cleaning standard are just a few examples of areas where we are working together.

I'd like to wish you all a very productive workshop.

I know each of you will have come here with a problem in mind that you are looking for others to help you solve, information to share, or in search of information to help you with your own work.

This is the time to make new connections, facilitate introductions, and develop new networks. I encourage you to approach the workshop with an open mind knowing that we are all here to further our own understanding.

I hope the discussions, collaborations and new friendships made this week prove useful in bringing us closer to the goal of effective, proactive and internationally consistent biofouling management.

Thank you and have a great workshop.

THEOFANIS KARAYANNIS
Head, Marine Biosafety
International Maritime Organization

Deputy Secretary O'Connell, ladies and gentlemen,

It is a great pleasure and privilege to address you here in Melbourne. On behalf of the Secretary-General of the International Maritime Organization, Mr Kitack Lim, I convey IMO's best wishes for a successful event and commend IMarEST and the Australian Department of Agriculture for their assistance with hosting and organising this prestigious Forum and Workshop.

I would like to express my special thanks to you, Secretary, for taking the time from your busy schedule to join us here today. I would also like to thank Mr John Lewis and IMarEST for accommodating the first Forum and for their enthusiasm to share our programme with the ANZPAC workshop.

As most of you are aware this is the first R&D Forum and Exhibition on Biofouling Management organized by the GloFouling Partnerships. The aim is to bring together scientific experts and academia with the maritime industry and leaders in technology development for biofouling management. As such, we hope the Forum will be instrumental in promoting information exchange and fostering dialogue between key stakeholders, which are vital facilitators for the harmonized implementation of IMO's Biofouling Guidelines.

Secretary, ladies and gentlemen,

Ships and other mobile structures in the ocean and our coastlines play an important role in our economies and our standard of living. However, as we all know only too well, these structures may also pose serious ecological, economic and human health threats due to the non-indigenous species that may be transferred from one marine ecosystem to another. The harmful impacts of established invasive species are often irreversible.

But the continued loss of biodiversity is not a simple environmental and economic issue. It risks undermining the achievement of most of the UN Sustainable Development Goals. Biodiversity is central to development, through food, water and energy security. The loss of biodiversity can be a security issue in so far as loss of natural resources, especially in developing countries, can lead to conflict. It is an ethical issue because loss of biodiversity hurts the poorest people, further exacerbating an already inequitable world. And it is also a moral issue, because we have a responsibility to conserve the living planet – including for our own future generations.

The challenge is to transform our practices, many of which are unsustainable today, into ones that continue to facilitate the economic progress we need while conserving biodiversity.

Secretary, ladies and gentlemen,

Australia, with one of the longest coastlines in the world, bordering many different seas and climates, has not been spared from the impacts of invasive species. A series of high-profile marine pest detections in Australia in the 1980s and 1990s, including the northern Pacific seastar (*Asterias amurensis*), the Japanese seaweed (*Undaria pinnatifida*) and the black-striped mussel (*Mytilopsis sallei*), urged the creation of a national task force at the turn of the century to address the issue.

Since then, Australia has always played a catalysing role in biofouling management research and initiatives, and was the first country to report to IMO, in 2006, the harmful effects of unwanted species in ships' biofouling. It is therefore only logical that this R&D Forum takes place here in Melbourne at a time when the Biofouling Guidelines are going to be reviewed, starting from early 2020, at IMO's Sub-Committee for Pollution Prevention and Response.

IMO has done its part in supporting this process with committed work to facilitate the effective and globally uniform implementation of the Biofouling Guidelines. During the Forum we will have the opportunity to hear about the latest developments derived from the launch of GloFouling, the new initiative from IMO with the Global Environment Facility and the United Nations Development Programme created to sustain the global momentum in tackling the issue of the transfer of non-indigenous species. The Project was launched this year and is already working towards expanding government capacities; instigating legal, policy and institutional reforms at national level; developing mechanisms for sustainability; and driving regional coordination and cooperation. Today we, at IMO, can be proud to state that, in the context of the Project, 12 developing countries representing seven regions around the world have taken the step forward to address biofouling through the development and implementation of a national policy.

We are also appreciative of the wide range of support and the expectations that have been placed on this programme of work, including from different parts of the industry, to address one of the most serious threats to the world's oceans. We hope that the R&D Forum will be the flagship global event of this Project and I am particularly encouraged to see it following the example of similar forums organised by our previous project, GloBallast.

This brings me to the principal message I wish to convey to this Forum.

The significance of all this work must be understood in the wider context of growing concern about ocean health and marine biodiversity, in which context the issue of good governance of the world's seas and oceans is being pursued actively at the United Nations level.

From IMO's wider perspective, international shipping will continue to play a pivotal role in supporting world trade and helping to build and expand the maritime economic potential of developing countries – that is, a "blue economy" based on the huge development opportunities offered by the seas and oceans thus enabling less developed countries to realise their potential for growth and prosperity.

Secretary, ladies and gentlemen,

I wish to conclude by saying that the multi-faceted and complex nature of biofouling management has not deterred us from consistently working together to seek the most efficient as well as comprehensive solutions, through what is a truly global partnership, integrating biological requirements of diverse marine ecosystems, innovative engineering solutions, economic parameters of a modern shipping industry, and civil society's demands for stringent regulation to protect the marine environment.

A Forum such as this provides an excellent platform to push the boundaries of human ingenuity in a collaborative spirit. I know that all of you are committed to making your own, distinct contribution through knowledgeable debate and open information exchange in the coming days. I can assure you that IMO, on its part, remains fully committed to the task in hand and to doing its bit for a sound, global system of shared responsibilities for good ocean governance.

Thank you.

Programme

Day 1 - Morning	Tuesday, 1 Oct 2019
0900 - 0910	*Welcome* John Lewis, IMarEST / John Alonso, GloFouling Partnerships, IMO
0910 - 0920	*Opening address* Theofanis Karayannis, Head – Marine Biosafety, International Maritime Organization
0920 - 0930	*Opening address* Lyn O'Connell, Deputy Secretary, Australian Government Department of Agriculture, ACT
Session 1 – Biofouling Risks & Impacts	Chair: John Lewis
0930 - 0955	*Ship biofouling: a novel habitat driving ecosystem change in the Anthropocene* Ian Davidson, Cawthron Institute, NZ
0955 - 1020	*Impacts of biofouling in aquaculture* Nina Blöcher, SINTEF, Norway
1020 - 1045	*Unintended consequences: Disease and pathogen spread in a global economy* Sarah Culloty, University College Cork, Ireland
1045 - 1115	**Refreshment Break**
Session 2 - Invasive and Non-Indigenous Marine Species	Chair: Richard Stafford-Bell
1115 - 1135	*Are all marine pests equal?* Jeff Ross, University of Tasmania, TAS
1135 - 1155	*What's at stake? Studies on the impacts of non-indigenous species on New Zealand's marine ecosystems* Graeme Inglis, NIWA, NZ
1155 - 1215	*The Australian Priority Marine Pest List (APMPL) – its purposes, genesis, composition and shortcomings* Richard Willan, MAGNT, NT
1215 - 1235	*National priority list of exotic environmental pests and diseases* Jess Evans, ABARES, ACT
1235 - 1250	Panel Discussion: Biofouling NIS impacts
1250 - 1330	**Lunch** *(sponsored by School of Mechanical Engineering, University of Melbourne)*

Day 1 - Afternoon	Tuesday, 1 Oct 2019
Session 3 – Biofouling Regulations and Requirements	Chair: Sonia Gorgula
1330 - 1345	*Australia's biofouling management requirements; minimising risk and regulatory burden* Peter Wilkinson, Department of Agriculture, ACT
1345 - 1400	*Evidence-based decision making to underpin New Zealand's CRMS for vessel biofouling* Eugene Georgiades, Ministry for Primary Industries, NZ
1400 - 1415	*What's going on down under: verification and enforcement of New Zealand's biofouling requirements* Tracey Bates, Ministry for Primary Industries, NZ
1415 - 1430	*Lessons learned through implementing and enforcing California's biofouling management regulations* Chris Scianni, California State Lands Commission, USA
1430 - 1445	*Biofouling management of commercial vessels in the United States: from VGP to VIDA* Juliette Chausson, US Environmental Protection Agency, USA

1445 - 1500	*The state of biofouling management in Canada* Wendy Simmons, Transport Canada, Canada	
1500 - 1520	Panel Discussion: Regulations and Requirements	
1520 – 1540	**Refreshment Break**	
Session 4 – Offshore		Chair: Justin McDonald
1540 - 1600	*Regulation of biofouling risks in the offshore petroleum industry* Tim Carter, NOPSEMA, WA	
1600 - 1620	*Biofouling management: a shifting paradigm and the value of refocussing on critical safeguards in managing biofouling risk – an industry perspective* Johann van der Merwe, Chevron, WA	
1620 - 1640	*Cup coral prevention and control actions adopted by the O&G industry* Jane Mauro, Petróleo Brasileiro, Brazil	
1640 - 1700	*Offshore vessel marine biosecurity – agreeing on best practice* Angela Gillham, Maritime Industry Australia Ltd, VIC	
1700 - 1730	Panel Discussion: Offshore Biofouling	

Posters & Drinks *(sponsored by American Chemet Corp)*	**Tuesday, 1 Oct 2019**
1730 - 1930	Clarendon Rooms, MCEC, South Wharf

Posters	**1-4 Oct 2019**
P001	*Ecological engineering of marine infrastructure for biosecurity* Nina Schaefer, Sydney Institute of Marine Science, NSW
P002	*Biological risk assessment approach for establishing in-water cleaning criteria of ship's hull fouling* Min-Chiu Jang, Korea Institute of Ocean Science and Technology, Korea
P003	*Combating biofouling through research. DST Marine infrastructure.* Jim Dimas, Defence Science & Technology Group, VIC
P004	*3D printed antifouling material and micro-UV LED for protection of marine optics* Richard Piola, Defence Science & Technology Group, VIC
P005	*In-water cleaning in NSW waters* Melissa Walker, NSW Department of Primary Industries, NSW
P006	*Wastewater from high-pressure water blasting is a toxic contaminant source on coastal non-target organisms?* Jee Hyun Jung, Korea Institute of Ocean Science and Technology, Korea

Day 2 - Morning		**Wednesday, 2 Oct 2019**
0845 - 0850	Day 2 Welcome & Housekeeping	
Session 5 – Biofouling & Vessel Efficiency		Chair: Nick Hutchins
0850 - 0910	*Predicting and monitoring the impact of fouling control coatings on vessel efficiency and emissions* Haoliang Chen, AkzoNobel, Singapore	
0910 - 0930	*Effect of biofouling on ship performance and energy efficiency* Yigit Kemal Demirel, University of Strathclyde, UK	
0930 - 0950	*Towards bio-fouling management and drag reduction* Rey Chin, University of Adelaide, SA	
0950 - 1010	*Managing the underwater hull – challenges and opportunities* Ralitsa Mihaylova, Safinah Group, UK	
1010 - 1030	*In-situ measurements of the ship hull drag penalty due to biofouling* Jason Monty, The University of Melbourne, VIC	
1030 - 1045	*International collaborative research in ship drag penalty due to hull roughness* Bagus Nugroho, The University of Melbourne, VIC	
1045 – 1105	**Refreshment Break**	

Session 6 - Biofouling Management and Prevention Systems (1)	Chair: James Chapman
1105 - 1125	*Taking the rough with the smooth: controlling surface topography as an antifouling strategy – recent progress and new insights?* Tim Sullivan, University College Cork, Ireland
1125 - 1145	*Novel antifouling materials for 3D printing and additive manufacture* Richard Piola, Defence Science & Technology Group, VIC
1145 - 1205	*'Smart' antifouling biocides based on peptides* Patrick Cahill, Cawthron Institute, NZ
1205 - 1225	*Antifouling solutions from seaweed biomimetics* Bernardo da Gama, Universidade Federal Fluminense, Brazil
1225 - 1245	*A bug's life: liquid metals for biofilm removal – antimicrobial leading to antifouling solutions* James Chapman, RMIT University, VIC
1245 - 1250	*Conference carbon accounting & carbon neutrality* Sarah Braude, Rightship, VIC
1250 - 1330	**Lunch** *(sponsored by School of Mechanical Engineering, University of Melbourne)*

Day 2 - Afternoon	**Wednesday, 2 Oct 2019**
Session 7 – Navy (1)	Chair: Clare Grandison
1330 - 1400	*Warships and biofouling: a comparison with commercial ships* John Polglaze, RAN / PGM Environment, WA
1400 - 1420	*Using CFD and experiments to estimate impacts of biofouling on ship resistance* Eric Holm, Naval Surface Warfare Center, USA
1420 - 1440	*Biofouling challenges for Australia's national shipbuilding enterprise* Andrew Scardino, Defence Science & Technology Group, VIC
1440 - 1500	*NZDF biofouling management of Navy ships* Sarah Strong, New Zealand Defence Force, NZ
1500 - 1520	*Reduction of biofouling on naval vessels in The Netherlands* Job Klinjstra, Endures BV, The Netherlands
1520 – 1540	**Refreshment Break**
Session 8 – Navy (2)	Chair: Clare Grandison
1540 - 1600	*Navigating the choppy seas of maritime regulation* Alex Hayes-Graham, Department of Defence, ACT
1600 - 1620	*Royal Canadian Navy's application of the Canadian Marine Invasives Screening Tool* Adam Valenta, Department of National Defence, Canada
1620 – 1640	Panel Discussion: Navy
Session 9 – Biofouling Risk Assessment.	Chair: Michael Sierp
1640 - 1700	*Next generation pro-active biosecurity management to mitigate the transfer of harmful aquatic species through biofouling* Dave Abdo, Department of Primary Industries and Regional Development, WA
1700 - 1720	*Digital biofouling risk assessment using big data* Ralitsa Mihaylova, Safinah Group & Richie Ramsden, AkzoNobel, UK
1720 - 1730	Panel Discussion: Risk Assessment

ECOsubsea Workshop Dinner	**Wednesday, 2 Oct 2019**
1900 - 2300	River's Edge, 18-38 Siddeley Street, Melbourne

Day 3 - Morning	**Thursday, 3 Oct 2019**
0855 - 0900	Day 3 Welcome & Housekeeping
Session 9 – Regional and National Perspectives from Developing Countries	Chair: Violeta Luque
0900 - 0920	*Overview of the GEF-UNDP-IMO GloFouling Partnerships Project* John Alonso, GloFouling Partnerships, International Maritime Organization

0920 - 0940	*Threat of the Invasive Alien Species (IAS) introduced through biofouling in Sri Lankan waters* Jagath Gunasekera, Marine Protection Authority, Sri Lanka
0940 – 1000	*Assessment of national publications on Biofouling/Bioinvasion in Brazil* Ricardo Coutinho, Instituto Estudos Almirante Paulo Moreira, Brazil
1000 - 1020	*State of knowledge of non-indigenous marine species along Peruvian waters* Patricia Carbajal, Instituto del Mar del Peru, Peru
1020 - 1050	*Working towards a strategic regional strategy for addressing invasive aquatic species* Anthony Talouli, Secretariat of the Pacific Environment Programme, Fiji
1050 - 1110	**Refreshment Break**
Session 10a – Domestic, Small and Recreational Vessels and Craft	Chair: Angela Gillham
1110 - 1130	*ROVing around marinas: utility of mini ROVs in biofouling management* Emily Jones, Ramboll Environ, NZ
1130 - 1150	*Neat and innovative biofouling treatment options that actually work* Mike Sierp, Aquatic Biosecurity, SA
1150 - 1210	*Fouling on recreational boats as a major spreading vector of non-indigenous species in the Mediterranean Sea* Agnese Marchini, Universita di Pavia, Italy
Session 10b – Regional NIS Assessment	Chair: Angela Gillham
1210 - 1230	*A baseline study of the occurrence of non-indigenous species in Danish harbours* Frank Stuer-Lauridsen, LiteHauz, Denmark
1230 - 1250	*Practical lessons towards management of Non-Indigenous Species in Mauritius waters* Prakash Mussai, Mauritius Oceanography Institute, Mauritius
1250 - 1330	**Lunch** *(sponsored by Melbourne Energy Institute, University of Melbourne)*

Day 3 - Afternoon	**Thursday, 3 Oct 2019**
Session 11 – In-Water Cleaning	Chair: Eugene Georgiades
1330 - 1350	*An independent performance evaluation of a vessel in-water biofouling cleaning and capture system* Mario Tamburri, University of Maryland, USA
1350 - 1410	*When theory meets reality: evaluation of protocols for assessing reactive in-water cleaning & capture systems* Dan McClary, Ramboll Environ, NZ
1410 - 1430	*Cleaning up the clutter: How is in-water cleaning currently regulated in California?* Chris Scianni, California State Lands Commission, USA
1430 - 1450	*Mind the Gap* Trecia Smith, Ministry for Primary Industries, NZ
1450 - 1510	*Steps towards an Australian standard for the in-water cleaning of biofouling* Sonia Gorgula, Department of Agriculture, ACT
1510 - 1530	*Development for assessment and management of the risk arising from the wastes considering in-water hull cleaning activity* Jung-Hoon Kang, Korea Institute of Ocean Science and Technology, Korea
1530 – 1550	**Refreshment Break**
Session 12 – Hull Grooming	Chair: Richard Piola
1550 - 1610	*In-water grooming to maintain ship hulls: from research to reality* Geoff Swain, Florida Institute of Technology, USA
1610 - 1630	*Development of a test apparatus and method of evaluating the impact of hull cleaning tools on coating wear and biocide release* Eric Holm, Naval Surface Warfare Center, USA
1630 - 1650	*Chemical compositions and toxicity potentials of antifouling biocides released during ships' hull cleaning by hydroblasting* Moonkoo Kim, Korea Institute of Ocean Science and Technology, Korea
1650 - 1710	*Exploring vessel in-water cleaning as a source of ocean microplastics* Mario Tamburri, University of Maryland, USA

1710 - 1730	Panel Discussion: In-water Cleaning and Hull Grooming

Industry Panel & Happy Hour *(sponsored by Tas Global)*		**Thursday 3 Oct 2019**
1730 – 1900	Clarendon Rooms, MCEC, South Wharf	Chair: Paul Holthus

Day 4 - Morning	**Friday, 4 Oct 2019**
0850 - 0900	Day 4 Welcome & Housekeeping
Session 13 – Pathogens and Diseases	Chair: Eugene Georgiades
0900 - 0925	*Vessel biofouling as a route for transmission of pathogens* Marty Deveney, SARDI Aquatic Sciences, SA
0925 - 0950	*Understanding environmental detection of aquatic pathogens to inform vessel management policy in Australia* Tim Carew, Department of Agriculture, ACT
0950 - 1015	*Biofouling and aquatic pathogens: the case study of the* Ostreid Herpesvirus 1 Marine Fuhrmann, The University of Sydney, NSW
1015 - 1045	Panel Discussion: Pests and Diseases
1045 - 1105	**Refreshment Break**
Session 14 – Non-Shipping Sectors – Aquaculture, Offshore Energy	Chair: John Alonso
1105 - 1125	*Biofouling management in New Zealand salmon farms: challenges and directions* Lauren Fletcher, Cawthron Institute, NZ
1125 - 1145	*NZ's Shellfish Aquaculture Research Platform - integrated biofouling management* Patrick Cahill, Cawthron Institute, NZ
1145 - 1205	*Managing corrosion and biofouling of the offshore monopile supports for wind turbines* Geoff Swain, Florida Institute of Technology, USA
1205 - 1225	*Monitoring biofouling, and testing antifouling coatings, in the offshore renewable energy industry* Andrew Want, Heriot-Watt University, UK
1225 - 1245	Panel Discussion: Biofouling in aquaculture: impacts and management
1245 - 1325	**Lunch** *(sponsored by Melbourne Energy Institute, University of Melbourne)*

Day 4 - Afternoon	**Friday, 15 Sept 2017**
Session 15 – Future Strategies for Risk Assessment & Management	Chair: Peter Wilkinson
1325 - 1345	*The use of eDNA for detecting the presence and spread of invasive species* Craig Sherman, Deakin University, VIC
1345 - 1405	*Introduction to BioPass, a simple, pragmatic solution designed to manage biofouling for the international shipping industry* Rowan Fenn, rise-x.io Technologies, WA
1405 - 1425	*Biosecurity communications - driving behaviour change to minimise risk* Melissa Walker, NSW Department of Primary Industries, NSW
1425 - 1445	*Building stronger scientific understanding on the dynamics and pathways of marine invasive species introductions via biofouling - a case for international scientific cooperation on ocean observations, data management, capacity development and technology transfer* Ward Appeltans, IOC-UNESCO, Belgium
1445 – 1505	**Refreshment Break**
Session 16 – The Way Forward	Chair: John Lewis
1505 - 1530	Panel Discussion: The Way Forward
1530 - 1550	Workshop/ Forum Close Theofanis Karayannis, IMO / John Lewis, IMarEST

Conference Proceedings

Next generation pro-active biosecurity management to mitigate the transfer of harmful aquatic species through biofouling

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Abstract

Biofouling is widely recognised as one of the most significant pathways for the introduction of invasive marine species (IMS) that can cause severe social, environmental and economic impacts. Addressing IMS is not only a matter of ensuring the health and integrity of marine ecosystems but ultimately about safeguarding ecosystem services that sustain the livelihoods of coastal communities across the globe. We describe a global vessel risk assessment portal "Vessel-Check" to aid the maritime industry and governments in identifying actions that can as low as reasonably practicable mitigate the risk of vessels transferring IMS across the world's oceans. Focusing primarily on a vessel's management practices, the portal rapidly and consistently assesses a vessels biofouling management practices to ensure they are sufficient to mitigate the introduction of IMS. The early detection of vessel mediated biofouling risks through Vessel-Check allows for more effective risk management options by both developing countries that have limited capacity to effectively manage IMS risks, as well as developed counties where it can be used to enhance existing practices. Further, increased consistency between biofouling regulators provides certainty and Increased understanding of biofouling risk factors within the maritime industry. Vessel-Check provides the global solution to IMS risk mitigation via shipping; will make direct contributions to the targets set out in the United Nations Sustainable Development Goals (SDG)(e.g. SDG 13, 14 & 15), and will contribute to Convention on Biological Diversity and its Aichi Biodiversity Targets (e.g. Strategic Goal B, and Aichi Target 9).

Introduction

Exotic marine species invade marine habitats via numerous pathways. Using detailed inventories of marine invasions from different sources, Molnar et al. [1] and Davidson et al. [2] identified international shipping as the main human-assisted pathway for the introduction of invasive marine species (IMS). It is also a trade pathway that has been growing steadily over the last decade and will continue to do so into the future [3, 4].

Ballast water and vessel hull biofouling are key potential modes of introduction (MoI) contributing to the risk of spreading IMS along the shipping pathway. Through the adoption of the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 (BWM Convention), the Member States of the International Maritime Organization (IMO) made a clear commitment to minimising the transfer of invasive aquatic species through ships' ballast. However, biofouling is widely recognised as one of the most significant MoI for IMS that can cause severe social, environmental and economic impacts [5, 6, 7, 8].

The accumulation of aquatic organisms like microorganisms, plants and animals on immersed surfaces and structures exposed to the aquatic environment is known as biofouling [5]. When attach to the hard surfaces of vessels, sessile organisms (e.g. mussels, starfish, clams, fanworms) can be transported and subsequently establish at new locations [9]. This can lead to environmental impacts such as changes in biodiversity of marine habitats, erosion and alteration of physical habitat structures and of marine food webs [10].

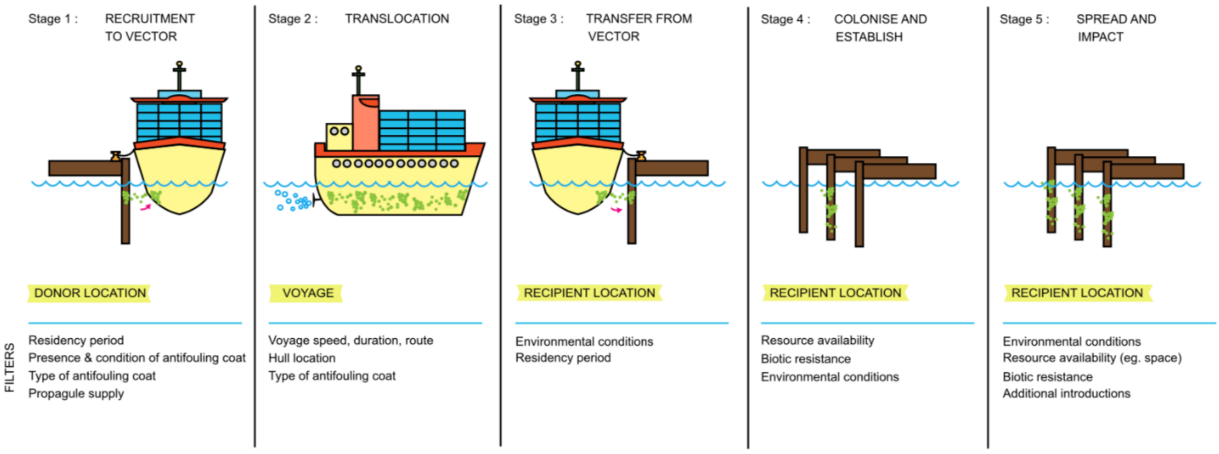

Figure 1: Stages of introduction of non-indigenous species by vessel biofouling [9].

Internationally, New Zealand and California have developed regulations to minimise the risk of transferring invasive marine species through the vessel biofouling MoI. New Zealand's '*Craft Risk Management Standard: Biofouling on Vessels Arriving to New Zealand*' came into force on 15 November 2018 and was issued under the New Zealand Biosecurity Act 1993. In a world-first, this standard defines a "clean hull' and prescribes thresholds for long-stay and short-stay vessels. California's State Lands Commission has enforced biofouling management regulations to minimise the transfer of nonindigenous species from vessels arriving at California ports since 2017. Australia is moving to implement regulation with the recent release of the Australian Commonwealth Governments Biofouling Management regulatory impact statement for consultation in 2019, however, Australian jurisdictions have already implemented requirements for the management of vessel biofouling (e.g. Western Australia and Norther Territory)

The regulations being set globally are generally aligned between jurisdictions, and consistent with voluntary guidelines published by IMO's Marine Environment Protection Committee (MEPC) for best-practise management of biofouling [5]. The MEPC's guidelines for the control and management of ships' biofouling stipulate that vessel owners should have a biofouling management plan for each vessel and keep a biofouling record book for documenting all inspections and biofouling management activities related to that vessel [5].

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

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

The Vessel-Check portal is designed for vessel owners/operators providing information to biosecurity management agencies, the portal does not rely on any specific questions – it effectively seeks what vessel biofouling management is being undertaken for a vessel and assesses whether the outlined management is sufficient to mitigate the transfer of invasive marine species (IMS) to as low as reasonably practicable (ALARP). The indicative risk provided by the Vessel-Check portal indicates the likely efficacy to mitigate the transfer based on the management practices being employed on a vessel.

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

Portal Methodology

The portal provides an indicative risk assessment for a vessel, based on its indicated management practices to mitigate the transfer of an IMS. It follows the best practice set out by the IMO's guidelines for the management of ships biofouling [5]. In brief, the portal achieves this by allowing a vessel (Owner, operator and/or vessel agent of a vessel) to register on the portal (free to register and use). Associated users for a vessel (vessel company representative, vessel agent or vessel master/officer) supplies the requisite vessel biofouling management information and any associated documentation (i.e. copy of vessel's biofouling management plan etc). The required information, is outlined in the IMO biofouling management guidelines and covers:

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

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

The Vessel-Check Portal (based on supplied information in vessel's profile) calculates an indicative risk associated with the vessel based on 10 metrics covering the vessels management practices, the implementation of its management practices and also its operational profile (**Error! Reference source not found.**). The overall indicative risk assessment for a vessel is the average of the individual metrics for a vessel.

Figure 2: Vessel-Check metrics used to assess the management practices employed by a vessel to mitigate the transfer of invasive aquatic species to as low as reasonably practicable

Nominations into jurisdictional waters are captured through the designation of the 'next port of call' in the AIS data for the vessel (e.g. vessel enters destination into AIS system). The portal identifies to regulatory user that a vessel is expected into their monitored port and provides the indicative risk of the vessel to regulatory user (and vessel operator). To maintain the most up-to-date indicative risk profile for a vessel, the vessel operator need only update the record book information associated with the vessels profile to demonstrate the continued implementation of the vessels biofouling management practices.

Discussion

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

The Vessel-Check portal improves a vessels proactive management of biofouling risks by allowing a vessel the ability to self-assessment and undertake proactive management of biofouling risk when transiting between international jurisdictions and/or domestically between jurisdictions within a country (e.g. Australia). This means a small vessel owner/operator who may not have the same resourcing to appease various jurisdictional requirements can achieve a similar level of biosecurity conformity in its operations as larger operators who have more resources can (**Error! Reference s ource not found.**). From a regulatory perspective, the Vessel-Check portal provides an improvement in efficiency in service delivery to industry and an ability to prioritise resources according to risk. Smaller nations with developing biosecurity management can now achieve awareness and oversight of biofouling risk management issues for international and domestic vessel arrivals comparable to that of larger or more developed jurisdictions, creating a truly global solution to the impacts of transferring invasive aquatic species (**Error! Reference source not found.**). Early detection of biofouling risk m anagement issues for international and domestic vessel arrivals will allow for more effective risk management options by biosecurity agencies ensuring a jurisdictions biosecurity while minimising impacts to industry.

Synergistically, implementing management of a vessels' biofouling through the Vessel-Check portal can also lead to benefits in a vessels' performance, as hull fouling leads to significant increases in vessel resistance through the water [11]. It is well known that vessel fouling has a large impact on the vessel's performance, consumption and thus operational cost [12]. Additionally, influences the emissions of air pollutants and greenhouse gases generated by the vessel. Therefore, biofouling management through the Vessel-Check portal can be an effective tool in enhancing energy efficiency and reducing air emissions for ships (**Error! Reference source not found.**). This has significant benefits f or both vessel owner/operators in ensuring compliance with GHG emission requirements, as well as jurisdictions by contributing to global sustainable development goals.

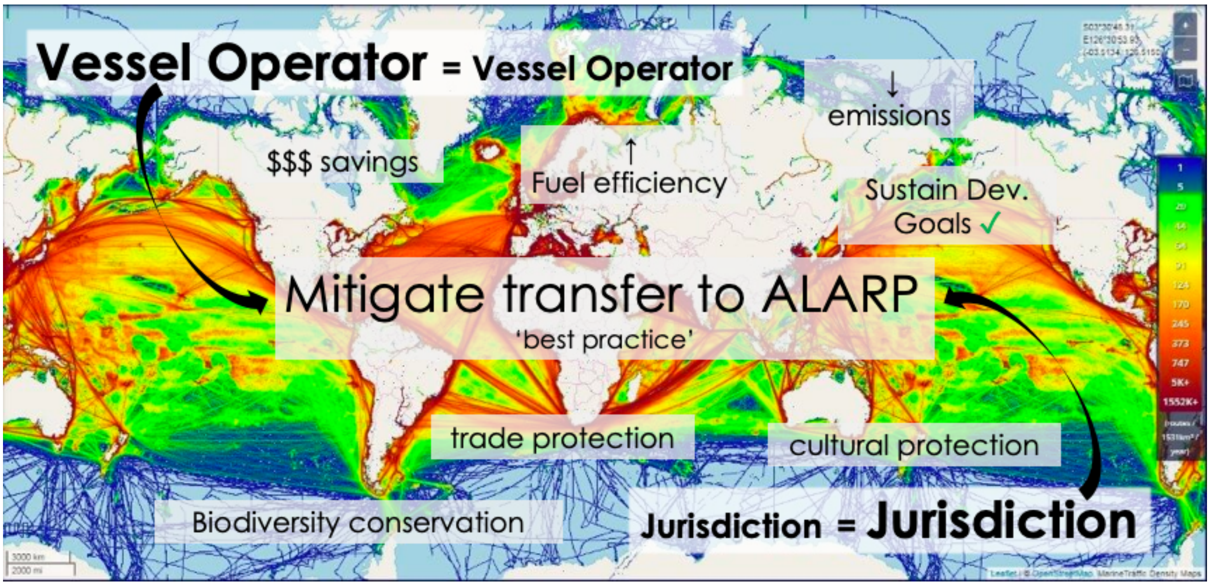

Figure 3: Benefits of implementing next-generation vessel biofouling management practices through the use of the Vessel-Check portal.

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Antifouling solutions from seaweed biomimetics

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Abstract

Since ancient times, human entrepreneurship has faced the seas, but biofouling has always imposed severe constraints to all maritime activities. The usual way to deal with the undesired growth of marine benthic organisms on man-made structures has been to employ the "biocide approach", such as the recently banned tributyltin (TBT), effective but harmful to marine life. Substitute biocides comprise a Pandora's box of different synthetic compounds, mostly with unknown environmental fate and toxicity. A paradigm shift is therefore urgent in order to deal with biofouling efficiently, but in an environmentally friendly way. The emerging field of biomimetics comprises the imitation of the models, systems and elements of nature to solve complex human problems. A biomimetic approach to deal with biofouling is based on the fact that seaweeds, as benthic, sessile organisms living in the euphotic zone, where fouling pressure is maximal, had billions of years to evolve antifouling defence, and different seaweeds are now known to dedicate energy and resources in the production, storage and release of natural antifouling (AF) compounds. In Brazil (Southwestern Atlantic), red and brown seaweed extracts and compounds exhibited strong and frequent AF activity. However, natural defence mechanisms are often multifaceted, and emerging evidence has accumulated concerning other macroalgal mechanisms to keep algal thalli devoid of undesired growth, such as oxidative bursts, epithallus sloughing, bacterial quorum sensing modulation and microtopography. Bioinspired antifouling approaches to some of these mechanisms already exist – such as AF microencapsulation, ablative, and low-adhesion paints – or are under investigation, such as engineered, bioinspired AF microtopographies and quorum sensing modulation. It seems likely that, in order to develop new solutions to this old problem, we need to learn from nature and develop bioinspired AF solutions that combine several mechanisms. A combined biotechnological approach, joining bioinspired chemical and physical AF defence is expected to start soon. Understanding not only the cellular and molecular dynamics of seaweed AF defence, but also the global patterns and mechanisms underlying the production of algal AF is a fundamental step toward this goal.

Introduction

Marine biofouling, the natural colonization and growth of micro and macro-organisms on any submerged surface, such as living or non-living natural (e.g., rocks) and man-made structures is an ubiquitous phenomenon in the marine environment. Communities inhabiting hard substrata make a significant contribution to the productivity and stability of coastal ecosystems. However, uncontrolled biofouling coverage on man-made structures is heavily detrimental for efficient operation and functioning of submerged man-made structures, such as ship hulls, offshore oil and gas platforms, oceanographic sensors, aquaculture farms, and even clean energy generation in the sea (Want & Porter, 2018).

Ship hull fouling increases significantly drag (**Figure 1**), and hence fuel costs and greenhouse gas emissions, in particular during long, transoceanic trips. Ship hull biofouling has also been recognized as a major vector for the introduction of non-native organisms, which frequently become harmful bioinvasions in the new environments (Gollasch, 2002).

***Figure 1**. A boat rudder with a heavy cover of marine biofouling (photo: B.A.P. da Gama)*

Past and present solutions to prevent or reduce biofouling involve a "biocide approach", i.e., using toxic compounds ('biocides') with adverse effects on marine life, such as TBT (tributyltin) in antifouling (AF) paints. TBT was banned in AF coatings in 2008 by the International Maritime Organization – IMO), following a wide set of evidence of adverse effects on non-target marine organisms, such as imposex in gastropod molluscs.

New biocide formulations have shifted towards using high volumes of copper and a plethora of other 'booster biocides', including herbicides such as Irgarol and Zineb. However, evidence is accumulating that these compounds show significant build-up - and negative effects - in marinas and harbours (Chapman et al 2014), which will probably lead to future restrictions or even a ban, as happened with TBT in AF paints.

A paradigm shift is currently under way, with attempts to develop new, non-biocidal AF technologies, such as fouling-release (FR) coatings. These attempts have somewhat succeeded with the development of polydimethylsiloxane elastomers (PDMSe). However, current commercial FR coatings suffer from a number of drawbacks and thus represent only a small proportion of the total marine coatings market (Callow & Callow, 2011).

There is an urgent need for the development of novel, non-toxic (or low toxicity) alternatives to keep man-made structures devoid of biofouling. Biomimetics is an interdisciplinary field that involves the imitation of the models, systems, and elements of nature for the purpose of solving complex human problems. The application of biomimetics to the biofouling problem is relatively new (Salta et al. 2010), and demands a certain degree of knowledge and understanding of the mechanisms that marine organisms have evolved to cope with epibiosis – fouling growth on living marine organisms – or AF defence mechanisms prior to the development of new bioinspired AF technologies.

A biomimetic approach to deal with marine fouling is based on the fact that seaweeds, as benthic, sessile organisms living in the euphotic zone, where fouling pressure is maximal, had billions of years to evolve mechanisms to deal with epibiosis, and different macroalgae are known to compromise energy and resources in the production, storage and release of natural AF compounds (Saha et al. 2018) or marine natural products (MNPs). Marine macroalgae as a whole are known to produce as many as 3600 secondary metabolites (from a total of ca. 15000 MNPs, according to Bhadury and Wright, 2004), most of which play ecological roles yet unknown. AF chemical defense in seaweeds and is probably an evolutionary response to the ecological disadvantages of epibiosis, particularly in photosynthetic organisms.

This study reports results from a wide scale project investigating the AF chemical defence mechanisms of marine macroalgae. This involved the sampling, extraction and testing of crude extracts and sometimes pure or semi-pure fractions or compounds from several seaweed species and populations. Results up to 2008 were already published (da Gama et al. 2008) and we will thus focus on a synopsis of new data up to 2019.

Materials and Methods

Sampling of marine algae and extract preparation

Seaweeds were collected by hand while SCUBA or free diving in the shallow subtidal zone in several localities along the Brazilian coast (Southwestern Atlantic), between 3 and 27°S. Seaweeds were immediately transferred to the laboratory in isothermic boxes, where they were gently washed in seawater, sorted, and cleaned from associated biota. Macroalgae were then identified and either freeze-dried or dried at room temperature to constant weight (dry weight). Selection of seaweed species was mainly on the basis of available biomass, which should be sufficient to allow laboratory and field testing with proper replication, and compound purification, where appropriate. Dried algae were grinded into a fine powder and then extracted exhaustibly (at least thrice) in a mix of 1:1 methanol:dichloromethane.

Antifouling bioassays

Filterpaper discs of 9 cm diameter were soaked in each extract and allowed to air dry for at least 24 hours prior to experiments. Extract preparation was always focused on obtaining natural concentrations, i.e., the same weight of dried seaweed was extracted and soaked into an equal filterpaper weight used in the experiments (usually ca. 4 g for 10 replicated discs per species). Controls were always prepared by soaking a similar set of 10 discs in the same organic solvents employed in seaweed extraction. Laboratory bioassays were performed using the 'mussel test' (da Gama et al. 2002, 2003), in which juvenile mussels (*Perna perna*) are exposed to natural concentrations of extracts or compounds in sterile Petri dishes containing extract-treated or control filterpaper discs in the bottom. After 12 hours the number of byssal threads produced is carefully counted and compared with controls in statistical analysis (factorial ANOVA).

Results and Discussion

In the first set of results (up to 2008; da Gama et al. 2008), 51 seaweed populations belonging to 42 species were sampled, extracted and tested in a laboratory and in some cases, in the field. The majority of the red seaweeds (55%) exhibited significant, strong (>80%) antifouling activity, while 14% of brown algae exhibited strong, significant AF activity, and only 27% of the green macroalgae exhibited significant, but moderate (<80%) AF activity. Among the 5 pure compounds tested, only 2, the halogenated sesquiterpene elatol (da Gama et al. 2003), from the red seaweed *Laurencia* *dendroidea*, and a dolabellane diterpene from the brown alga *Dictyota pfaffii* (Barbosa et al. 2007) exhibited significant AF activity, in both cases confirmed by further field testing.

From 2008 to 2019, a total of 60 seaweed species from 6 sampling sites along the Brazilian coast were sampled. Of this total, 21 (51%) belonged to the Ochrophyta (brown seaweeds = Phaeophyta) and 20 (49%) to the Rhodophyta (red seaweeds). 86% of the Ochrophyta and 70% of the Rhodophyta exhibited significant AF activity, in comparison to their respective controls. Green seaweeds (19 species) were sampled but not tested at this stage.

Despite our initial observations of a higher AF activity among red algae (<2008), the second set of data (up to 2019) revealed a more equitative distribution of AF activity among red and brown seaweeds, with even more activity among brown algae. This may be a result of (1) a more balanced sampling among these two algal divisions or (2) the specific identity of the seaweeds sampled. It is noteworthy, however, that other authors (e.g., Saha et al. 2018) also reported more activity among red macroalgae. This trend is likely a result of the unique chemistry in red algal compounds, resulting in halogenated MNPs, most of which exhibit interesting bioactivities, including AF activity, e.g., halogenated furanones in *Delisea pulchra* (de Nys et al. 2006), and sesquiterpenes such as elatol in several *Laurencia* species (e.g., Sudatti et al. 2008). On the other hand, research on AF compounds from brown algae seems to have been focused in phlorotannins (polyphenolic compounds), and other promising chemical types have been neglected until recently, such as glycolipids (Plouguerné et al. 2014).

Among reported seaweed AF defence mechanisms, chemical defence seems to play a prominent and more widespread role (da Gama et al. 2014). However, natural defense mechanisms are often multifaceted, and emerging evidence has accumulated concerning other macroalgal mechanisms to keep thalli devoid of undesired growth, such as oxidative bursts, epithallus sloughing (crustose coralline red algae), bacterial quorum sensing modulation and microtopography (**Figure 2**). Bioinspired antifouling approaches to some of these mechanisms already exist – such as microencapsulation (Price et al. 1992), oxidative bursts (Olsen et al. 2010), ablative, and low-adhesion paints – or are under investigation, such as bioinspired AF microtopographies (Chapman et al. 2014) and quorum sensing modulation by microorganisms (Dobretsov et al. 2013).

A promising biomimetic AF mechanism seems to be microencapsulation, emerging from new materials and bioinspired by the enclosure, in specialized cells or organelles, of AF compounds. This was recently observed in a number of red algae (Rhodophyta) of the subclass Rhodymeniophycidae, such as the *corps en cerise* in *Laurencia* (Sudatti et al., 2008), a prolific and varied genus belonging to the order Ceramiales, the 'gland cells' in *Delisea pulchra* (de Nys et al. 2006), *Asparagopsis armata* (Paul et al. 2006), and *Bonnemaisonia hamifera* (Nylund et al. 2013), all three species from the order Bonnemaisoniales, and the recently discovered 'mevalonosomes' in *Plocamium brasiliense*, a Plocamiales (Paradas et al. 2015). It is noteworthy that natural AF compounds from marine origin (the octocoral *Renilla*) and their analogs have already been microencapsulated in AF paints, with a resulting performance enhancement (Price et al. 1992).

Although our understanding of seaweed AF mechanisms has increased greatly in the last decades, research has probably been excessively focused on chemical defence, despite striking evidence that seaweeds possess large amounts of other compounds that can possibly elicit some sort of physical defence mechanism, such as sulphated polysaccharides. Seaweeds produce a variety of polysaccharides, such as alginate, *k*-carrageenan, agarose-6-sulfate, fucoidans, and ulvans. The common green seaweed *Ulva* has ca. 22.3% of sulphated polysaccharides, while the brown alga *Fucus* may have as much as 40.6% of sulphated polysaccharide yield (Reis, 2016). It seems likely that these polysaccharides, if released at the thallus surface, could significantly reduce the coefficient of friction (μ) thus hindering fouling adhesion. If confirmed, this hypothesis could, combined or not with chemical defence, lead to rapid availability of bioinspired AF solutions, as seaweed polysaccharides are globally available at a commercial scale, as well as obtained and modified by synthesis.

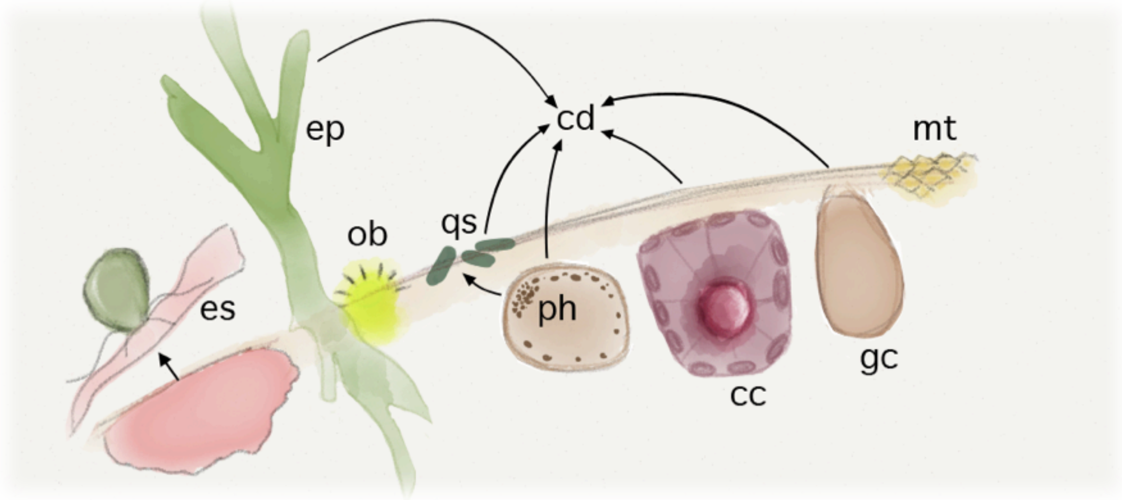

***Figure 2**. Several seaweed mechanisms to deal with epibiosis. **es**: epithallus sloughing; **ep**: epibiont defence; **ob**: oxidative burst; **qs**: quorum sensing; **ph**: brown seaweed physodes; **cc**, **gc**: 'corps en cerise' and 'gland cells' from red seaweeds; **mt**: microtopography, and **cd**: chemical defence (da Gama et al. 2014).*

New biomimetic AF solutions are expected to combine more than a single mechanism (*e.g.,* physical and chemical mechanisms), providing a multilevel defence system against fouling (*sensu* Wahl & Mark, 1999). Such a system can comprise non-toxic, biodegradable chemicals bioinspired in seaweed AF natural products in coatings that also exhibit interactive surface properties (*e.g.*, ablative, self-polishing, non-adhesive / fouling-release, low coefficient of friction, and/or microtopography features).

It seems likely that, in order to develop new solutions to this old problem, we need to learn from nature and develop bioinspired antifouling solutions that combine several mechanisms. Understanding global patterns and mechanisms underlying the production of algal MNPs with AF activity is therefore a fundamental step toward this goal.

Acknowledgement

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Occurrence of non-indigenous species in Danish harbours

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1. Introduction

A recent report by Andersen et al. (2014) for the Danish authorities outlined a new monitoring programme for non-indigenous species (MONIS) suited to the obligations of the EU Marine Strategy Framework Directive. This monitoring programme demonstrates a high level of utilisation of existing monitoring activities and is aimed at ports, other hotspots and baseline stations. Through a series of follow up studies we can now report the first nation-wide study of the occurrence of non-indigenous species in Danish harbours, called MONIS 4. The aims of the study were to:

- Monitor, assess and report occurrence of non-indigenous species in 16 selected Danish harbours mainly by eDNA.
- Apply full conventional method (Joint Harmonized Procedure, JHP) and using biomolecular methods for monitoring levels of environmental DNA (eDNA).
- Provide proof-of-concept regarding the Danish strategy of combining conventional and biomolecular methods.

The current paper is a summary of the presentation given by Frank Stuer-Lauridsen at the 4th ANZPAC meeting in Melbourne 2019, which included the 1st GEF-UNDP-IMO GloFouling R&D Forum and Exhibition on Biofouling Management. Data presented and more detailed analyses are submitted to peer reviewed journals.

2. Methods

The sampling was carried out using both conventional monitoring and using biomolecular methods for detecting environmental DNA (eDNA) in water samples (e.g. Agersnap et al., 2017; Sigsgaard et al., 2016; Knudsen et al., 2019). There were two main objectives: (i) to monitor NIS using conventional monitoring schemes in 16 main commercial harbours and to (ii) assess the applicability of monitoring eDNA levels from non-indigenous species (NIS) using biomolecular methods on filtered water samples, using species-specific qPCR setups for detection of 20 target species. The method utilises DNA collected from the environment and species-specific test systems for 20 selected NIS species from the Danish Target Species List.

In two prioritised ports (Aarhus Harbour and Esbjerg Harbour, numbers 1 and 2 respectively in Figure 1), the eDNA results from analysed water samples were cross referenced with a comprehensive conventional sampling of plankton, soft- and hard-bottom communities and mobile epifauna (fish, crustaceans) in accordance with a dedicated sampling protocol (Andersen et al. 2017) exceeding the requirements of the Joint Harmonised Procedure (JHP) of OSPAR/HELCOM. The two ports were chosen because they are both relatively busy but have different characteristics: Esbjerg Harbour is a fisheries and offshore service port exposed to the North Sea and located close to the Wadden Sea; the port in Aarhus is a container hub located in the Kattegat/Baltic Sea area close to ecologically sensitive

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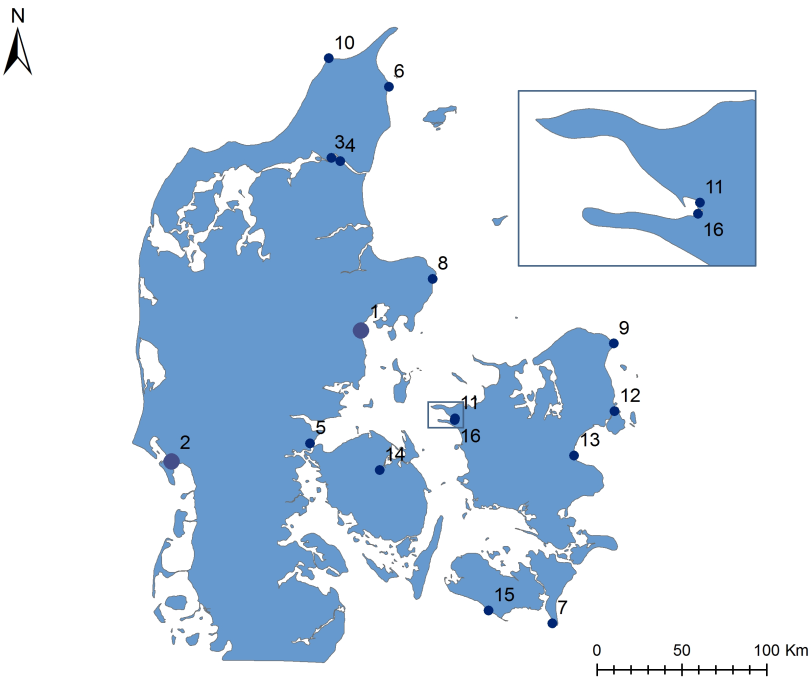
areas (Natura 2000 areas). In 14 harbours (numbered 3-16 in Fig. 1) conventional sampling was carried out with a reduced programme as outlined in Table 1.



1. Aarhus Harbour
2. Esbjerg Harbour
3. Aalborg Portland Harbour
4. Aalborg Harbour
5. Fredericia Harbour
6. Frederikshavn Harbour
7. Gedser Harbour
8. Grenå Harbour
9. Helsingør Harbour
10. Hirtshals Harbour
11. Kalundborg Harbour
12. Københavns Harbour
13. Køge Harbour
14. Odense Harbour
15. Rødby Ferry Port
16. Statoil Harbour (Kalundborg)

Figure 1. Location of the 16 ports sampled for non-indigenous species. Aarhus (1) and Esbjerg (2), in bold font, have particularly heavy ship traffic and are prioritized in this study.

The conventional sampling protocol applied in the JHP is based on the CRIMP methods devel-oped in Australia and aligned with the survey methods used in the HELCOM Maritime ALIENS 2 project. The eDNA programme covered 20 species, using a species-specific operational test system, applying quantitative polymerase chain reaction (qPCR) detection to water samples, like previous species-specific detection attempted in the Baltic Sea (Knudsen et al., 2019). The conventional sampling programme included grab samples for water and sediments, plankton nets, traps, fouling plates, scrape poles, fish nets, and visual observations by snorkelling.

Table 1. Conventional expanded sampling programme in two ports and reduced in 14 ports.

Conventional sampling (two ports)	Reduced sampling (14 ports)
• Physical parameters (temperature, salinity, oxygen) and Secchi depth • Grab samples for water and sediment (benthic infauna, epifauna) • Plankton nets (phyto- and zooplankton) • Traps (mobile epifauna). • Scrape poles and fouling plates (fouling organisms)	• Snorkelling transects at night (fish, jellyfish, epifauna) • Fish nets (Gill-net and Fyke-net)
• Fish nets (Gill-net and Fyke-net) • Triplicates in each section of port	• All sampling was carried out in early summer (May-July) and autumn (Sept.-October) 2017

3. Results for conventional sampling

The conventional monitoring detected 26 NIS and based on these results, we make the following conclusions regarding NIS in Danish harbours: 1) more NIS are found in the western parts of Denmark (North Sea region) than in the eastern parts (Baltic Sea), and 2) two new NIS in Danish marine areas were recorded, i.e. the two bristle worms *Eteone heteropoda* (fam. Phyllodocidae) and *Streblospio benedicti* (fam. Spionidae) in the western parts near the Wadden Sea.

4. Results for the eDNA method

Thirteen NIS were recorded using eDNA-based methods. The eDNA methods could be applied in all ports (although suspended solids impaired detection limits in Esbjerg), and while species-specific qPCR detection of eDNA is limited to reporting only presence or absence of the target species, the eDNA results support the NIS reported by conventional sampling. Among the 20 eDNA-targeted NIS the rare species are not detected, most likely because these NIS are, fortunately, still infrequent in Danish seas. Four species restricted to fresh- and brackish waters were not detected, perhaps because water samples mainly comprised more brackish-saline waters. Five very common NIS are consistently found with both conventional monitoring and with the biomolecular method. The results from the seasonal sampling showed a higher level of agreement between the two methods in fall than in spring.

SPRING results:

- 188 good matches: 186 not found/no eDNA detection + 2 found/eDNA detection
- 37 poor matches: 32 found/no eDNA detection + 5 not found/eDNA detection

FALL results:

- 197 good matches: 183 not found/no eDNA detection + 14 found/eDNA detection
- 23 poor matches: 16 found/no eDNA detection + 7 not found/eDNA detection

5. Findings regarding biofouling species

This study was not directed towards biofouling species *per se,* but a subset of data showed the identification by conventional methods of NIS generally considered as fouling species. Ten NIS were identified on the settling plates and from sub-sea substrates in the two ports prioritized for expanded sampling protocol, Aarhus and Esbjerg.

Table 2. NIS related to fouling found in two ports Aarhus and Esbjerg.

Group (common name)	Species
Anthozoa (sea anemones)	*Diadumene lineata**
Ascidiacea (sea squirts)	*Molgula manhattensis*
	Styela clava
Cirripedia (barnacles)	*Amphibalanus improvisus*
	*Austrominius modestus**
Bivalvia (mussels, clams)	*Crassostrea gigas*
Crustacea (crabs, shrimps)	*Caprella mutica*
	Hemigrapsus sanguineus
Rhodophyta (red algae)	*Heterosiphonia japonica*
	*Neosiphonia harveyi**

** NIS, but not considered invasive*

The study also showed that a rapid assessment survey method gave insufficient results compared to settling plates deployed and the scraping of subsea structures.

This represents the first study of monitoring NIS in 16 Danish harbours using both conventional and biomolecular monitoring cf. Table 3. Twenty-six NIS were recorded using conventional sampling and 13 NIS were recorded using eDNA-based methods. Excluding overlapping records, we have recorded a total of 34 NIS in the 16 Danish harbours studied.

Table 3. Summary of the results of the MONIS 4 project.

Settling plates (PVC) and rope of fixed type and length	Scraping of subsea structures	Rapid assessment survey (RAS)
Nine units in Aarhus Port and nine units in Esbjerg Port Deployed from early to late summer (May to September) Semi quantitative identification	Eighteen locations in Aarhus Port and in Esbjerg Port Qualitative species identific-ation under microscope	Submerged substrates: • floating buoys, • fender constructions, • ropes etc. Examined at two sites within the three survey areas in both ports
Nine and six NIS found	**Three and six NIS found**	**No NIS found**

The occurrence of NIS in Danish harbours is systematically documented here using both conventional and biomolecular monitoring. The MONIS 4 project also provided a proof of concept with regard to eDNA-based monitoring of non-indigenous marine species in Danish marine waters. Hence, we suggest the following next steps for future monitoring:

1. The eDNA-based monitoring of non-indigenous species cf. the EU Marine Strategy Framework Directive in Danish marine water should be executed and operationalized as planned.
2. Relevant international conventions such as HELCOM and OSPAR should be informed about the progress made and also invited to collaborate on development of relevant species-specific operational test systems for monitoring of eDNA.
3. A critical evaluation of the internationally coordinated and agreed joint monitoring protocols should be carried out in collaboration with neighbouring countries in order to focus future activities and to increase cost-effectiveness of monitoring protocols.

Further, we suggest that similar studies could be considered in other Danish harbours as well as in relevant hot spot areas such as the Wadden Sea and Limfjorden.

Regarding the applicability of biomolecular methods, the findings from the MONIS4 project provide a proof-of-concept for how the eDNA-based test systems developed can be used for NIS continuous monitoring. The results of the MONIS 4 project constitute a baseline for future studies in Danish ports and other hotspot areas in the Northeast Atlantic seas where NIS are thought to be present.

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Digital Biofouling Risk Assessment Using Big Data

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Abstract

Objectives: The objective of the paper is to demonstrate that digital risk assessments can be used for identifying ships that are likely to be carrying hull fouling. The risk assessment will allow relevant authorities to address the potential biosecurity risks in a proactive manner and to allocate resources effectively. This will benefit the environment by reducing the threat of invasive aquatic species while also facilitating efficient planning of port activities.

Results: The cumulative Fouling Challenge is obtained based on the historic activity profile of each vessel and the specific environmental conditions encountered during that period. The vessels can then be further examined in terms of biofouling management history to identify whether the challenge has been adequately managed. The Fouling Challenge of each individual vessel is combined with the effect of the known biofouling management strategy (Fouling Control Factors) to provide the relative risk a vessel poses in terms of the transport of hull fouling species. This paper presents a comparison between the output of a digital risk assessment system (PortShield) compared to the underwater hull condition of a range of commercial vessels. The condition of the underwater hull of the vessels was determined by visual inspections.

Conclusions: The case studies carried out to date indicate that digital risk assessment systems can effectively identify and rank vessels in terms of the risk of transporting hull fouling species. Such systems can be an effective low-cost solution for remotely monitoring and managing biosecurity risks associated with hull-borne species.

1. Introduction

The management of risk related to invasive aquatic species (IAS) can be addressed by high resolution, species-specific dive inspections, however the volume of port traffic means a complimentary assessment system for high-level down selection - such as PortShield - is needed. This assessment system needs to be individual, per vessel, and based on actual operational values.
These two systems work in parallel - PortShield using large datasets, modelled Fouling Challenge and risk to identify likely fouled vessels, which can then be inspected by diver or ROV if required. This can also act as a feedback loop, improving down-selection by reinforcing selection via inspection results. The prioritisation of higher risk vessels allows resources to be focussed. The feedback loop can be seen in Figure 1.

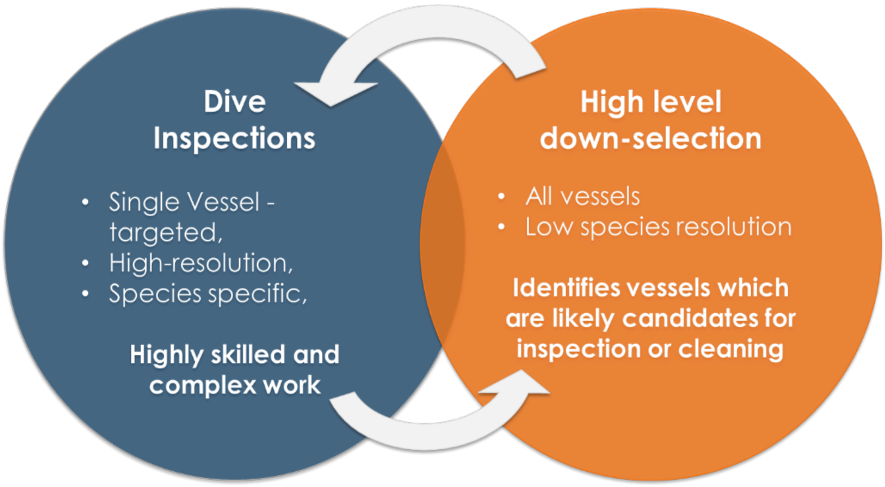


Figure 1. Complementary Approaches to Invasive Aquatic Species Risk Management

Risk Assessment

In order to carry out a biofouling risk assessment for a vessel to assist users to understand whether closer scrutiny is needed, multiple data sources are brought together. It is assumed that the extent of fouling and abundance of fouling taxa present increase the risk of translocating invasive species. The risk assessment procedure follows a standard 'Hazard' and 'Likelihood' model.

In the case of biofouling risk, the hazard – Fouling Challenge – is generated from individual vessel movement data and global datasets of environmental data.

The likelihood factor – Fouling Control Factors (FCFs) - for this assessment takes into account:

- Fouling control coating types,
- Extended static periods,
- Hull husbandry events (such as in water cleaning or grooming).

1.1. Fouling Challenge

Fouling Challenge allows us to compare the relative rating of fouling environment experienced by vessels – the cumulative hazard.

Fouling Challenge reflects the environment a vessel is exposed to during operation, derived from global environmental data and ship movement data (AIS).

The metric takes into account biological productivity and environmental conditions. The metric also takes into account the vessel activity and speed derived from AIS data.

In order to calibrate this dimensionless number, the operational profiles and Fouling Challenge values for over 1000 vessels were extracted. The actual fouling level of these vessels was considered in order to enable calibration. A single vessel cumulative Fouling Challenge chart is shown in Figure 2. The point where the Fouling Challenge originates is the start of the dry-docking cycle for the particular vessel.

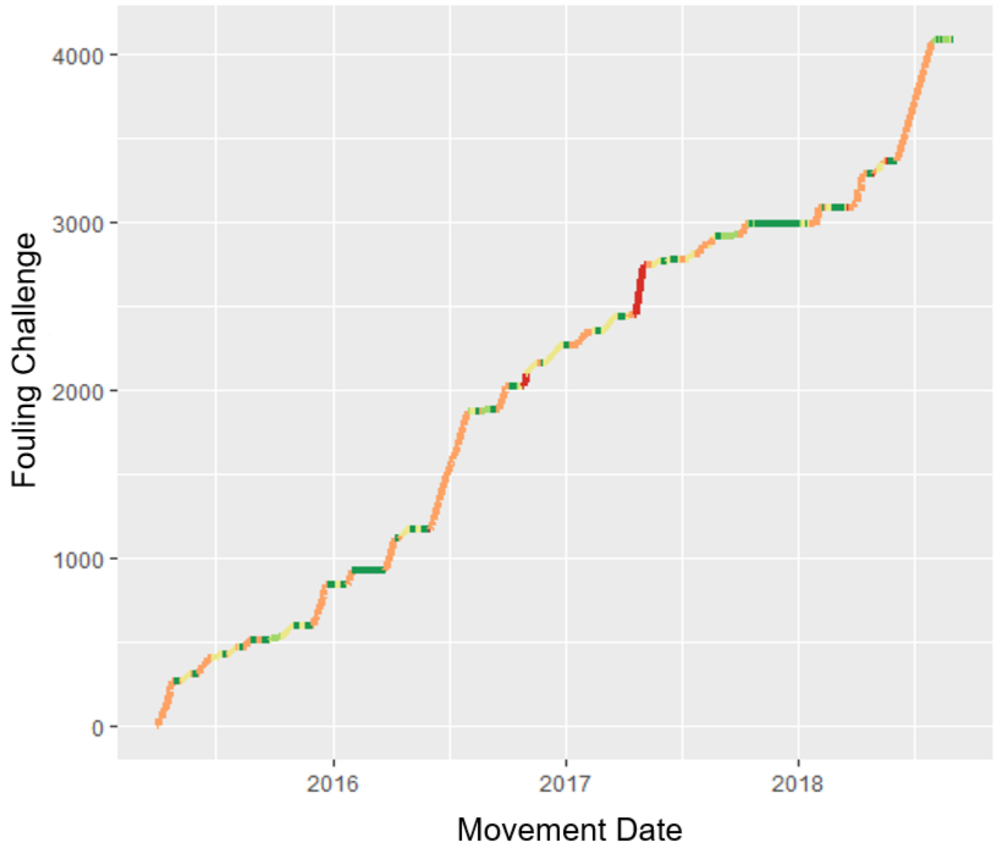


Figure 2. Fouling Challenge

Of these 1000 vessels, a calibration model can be fitted, however a vital part of model fitting is understanding the distribution. Normal Q-Q method of identifying outliers, which are extreme to the population distribution – a representation of which can be found in Figure 3, was used.

This analysis allowed identification of outliers that do not fit the defined population distribution. Investigating the identified outliers is key to prioritising vessels effectively in terms of biofouling accumulation.

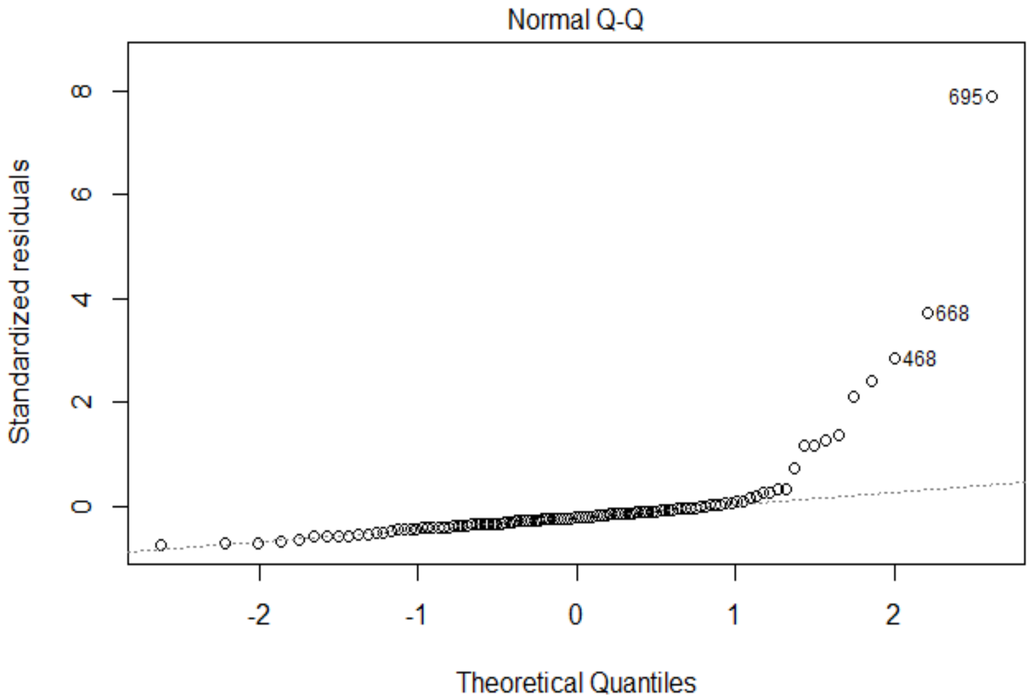


Figure 3. Identifying Outliers

Note: The numbers represented on the plot are the identifiers of the outliers within the sample.

1.2. Fouling Control Factors – Main Coating Related Assumptions

1.2.1. Type of Fouling Control Coating

If a vessel is operated in a manner consistent with the coating specification (optimal operating conditions), the general expectation is that it should be protected from accumulating significant amounts of fouling. Biofilm densities and micro- and macro-fouling settlement on different types of fouling control coatings have been investigated and there is evidence that the type of coating influences the likely extent and type of fouling accumulated under similar conditions (Callow, 1986; Cassé and Swain, 2006; Molino et al, 2009; Pelletier et al, 2009; Zargiel et al, 2011; Briand et al, 2012; Chen et al, 2013; Camps et al, 2014).

In order to take into account the performance of the type of fouling control coating, a number of commercially available products were examined and initially grouped into three broad categories intended to distinguish between expected long-term performance. The grouping is based on factors such as the type of technology (matrix ingredients), biocides content (weight, etc.), packages and release mechanism (if applicable).

The initial grouping was carried out based on a literature review on efficacy of different types of fouling control technologies (including information on static testing, test patches, efficacy against fouling taxa) coupled with focus groups comprising experts in carrying out failure investigations, specification reviews and/or with significant experience in coating formulation. Based on the literature review and focus groups, commercial products were grouped in three broad performance categories – ‘Economical’, ‘Medium’ and ‘High’ performance.

The groupings were then reviewed based on independent in-service performance data. Any discrepancies between the performance grade assigned to a product and the in-service data were reported back to the group of experts who participated in the initial grouping. The in-service results were then reviewed in detail and potential changes of the performance grade assigned to the specific products discussed. The existing database on in-service performance of different coating technologies and commercial products administered by independent parties is growing. However, there are still certain challenges to be addressed such as limited data on: (1) less commonly used products (regional markets) and (2) new/novel products and technologies without a significant in-service performance track record. Therefore, continuous refinement is required, and a conservative view was adopted in terms of newly released products until sufficient in-service track record is available.

Once the initial grouping of products was finalised, the performance grades assigned to products were tested against a different set of in-service performance data as part of the preliminary calibration of the digital risk assessment system[2]. A Fouling Indicator[3] was constructed based on extent and type of fouling. Fouling Indicator of 0 to 2 is consistent with light to medium microfouling and up to 1% macrofouling coverage (L/M (1)) as per NACE SP21421. The higher the Fouling Indicator, the greater the extent of fouling and the likelihood of macrofouling presence. Figure 4 shows the relationship between coating product grade and the Fouling Indicator towards the end of the scheme life based on visual inspections of 174 commercial vessels.

Although the sample size is relatively small, there appears to be an indication that 'Economical' and 'Medium' grade products, which are expected to perform to a lesser extent over time in general, were found to have accumulated more fouling compared to 'High' performance products. A more interesting trend is that 'High' performance products were found to exhibit less of a scatter when it comes to fouling accumulation, which is an indication that their performance may be more consistent and predictable over time. Based on the calibration sample, the results from a Kruskal–Wallis test showed that 'High' performance grade products are significantly different than the other two categories ($p<0.005$). The difference between 'Economical' and 'Medium' grade products was not statistically significant although the median Fouling Indicator, represented as a horizontal line through the respective box, corresponding to 'Economical' grade products is higher, which implies higher extent of fouling.

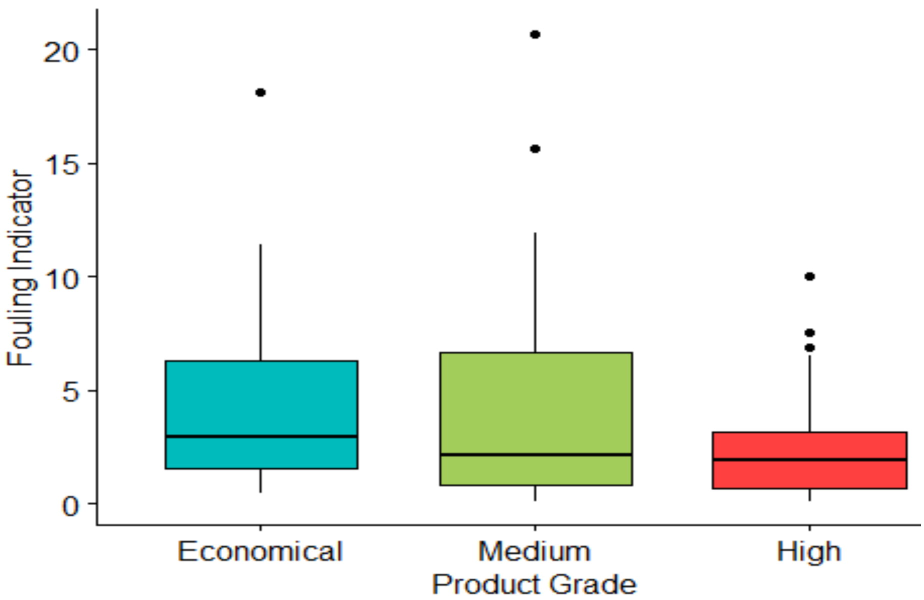


Figure 4. Relationship between Fouling Indicator and Coating Product Grade

[2] The sample used for the calibration, consisting of 174 ships, is referred to as the 'calibration sample'.
[3] Fouling Indicator and NACE SP21421: 0-2 ~ L/M (1); 2-5 ~ M (5); 5-20 ~ M/H (10-15+)

Although a detailed investigation including interactions between factors that could have an impact, such as ship types and sizes for example, based on larger representative samples is needed in the future, the current results seem to indicate that the initial grouping of technologies appears adequate in terms of expected antifouling efficacy/performance.

1.2.2. Extended Static Periods (ESPs) and Operational Profiles

Static periods, also referred to as residency periods or stationary periods, have been identified as a key factor in the colonisation and accumulation of biofouling (Railkin, 2003; Coutts and Taylor, 2004; Watson and Barnes, 2004; Davidson et al, 2018).

Extended static periods are periods that are in the range of or exceed static guarantees offered by coating manufacturers as it is assumed that the capability of coatings to deter the accumulation of biofouling has been significantly limited. The definition of 'extended static period' in terms of time varies by coating type as some technologies are more sensitive to static exposure than others. It should be noted that the static tolerance of fouling control coatings varies with environmental conditions - factors such as geographical location and seasonality impact performance. For the purposes of this preliminary study, however, extended static periods were defined as any static periods of 30 or more consecutive days.

In theory, the performance of fouling control coatings is optimal when the vessel is trading within a certain activity range, usually specified by the coating manufacturer. The activity of the vessel is a function of the time at sea and the time spent stationary.

Sylvester et al (2011) found that port duration and time at sea have a significant effect on determining propagule pressure.

As a result, the effects of extended static periods and operational profiles were investigated further in terms of in-service performance.

2. Risk Indicator: Preliminary Results

In order to investigate the effect of operational profiles, the calibration sample was split into four categories:

- Active ships (no ESPs and within recommended activity range);
- Ships with one or more ESPs (>30 days);
- Low activity[4] ships;
- Low activity ships with one or more ESPs.

Figure 5 shows the sample distribution by operational profile.

[4] Low activity is defined as vessel activity below 60% in this instance.

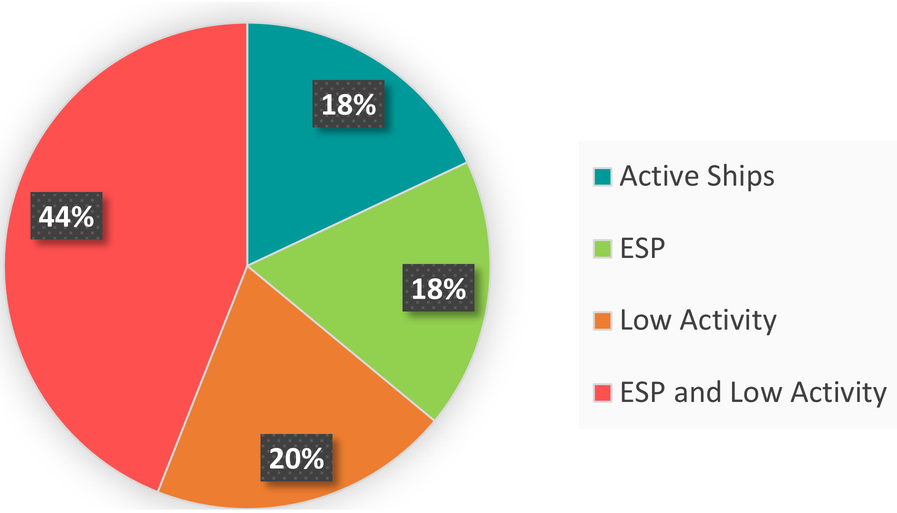


Figure 5. Sample Distribution by Operational Profile

In the case of the calibration sample, 44% of all vessels have had at least one extended static period (>30 days) and activity of less than 60% within the period from coating application to the date the inspection took place. Nearly half of the vessels have had at least one ESP and low activity, which is not surprising given the state of the shipping market over the last decade, but it is indicative of the fact that in reality vessel operation may deviate from the optimal operational conditions that coatings were specified for due to market pressures and other factors.

Figure 6 shows the relationship between fouling accumulation and operational profiles. According to Figure 6, active ships without significant interruptions to their operations, have on average the lowest fouling coverage, which is in line with expectations. It is worth noting that the outliers (the vessels with high Fouling Indicator ratings represented as dots above the respective boxes) are clustered in the other three categories and especially in the category of vessels that were not as active and had at least one extended static period (ESP and Low Activity) within their dry-docking cycle.

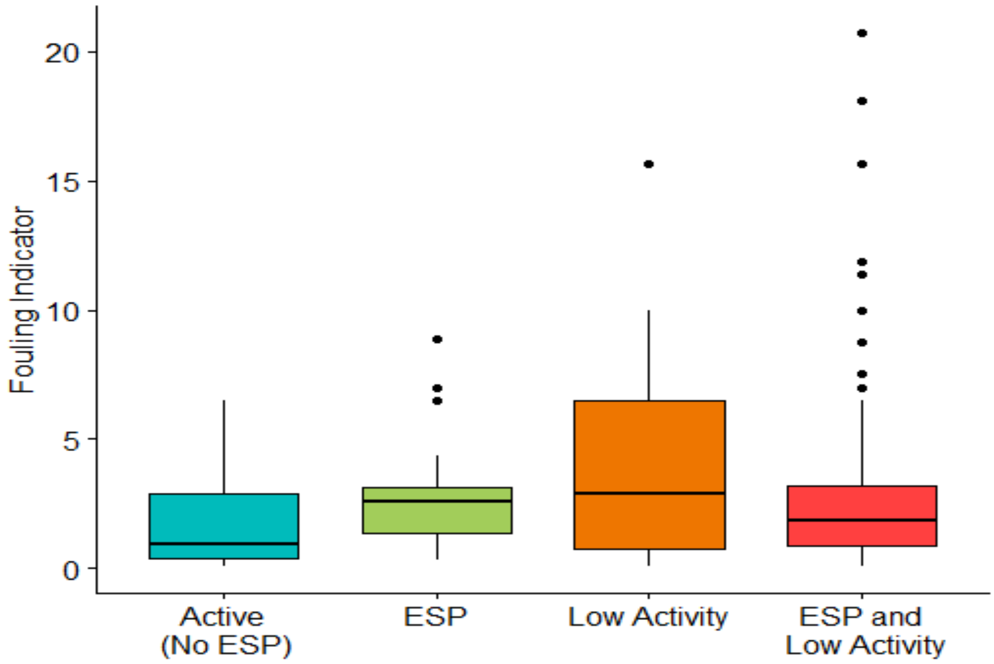


Figure 6. Relationship between Fouling Indicator and Operational Profiles

Figure 6 seems to indicate that predicting the rate of biofouling accumulation for vessels with irregular (not optimal) operational profiles is even more challenging due to the variation within these categories. One of the missing pieces of the puzzle in the current calibration of the risk assessment is the effect of biofouling management actions (hull husbandry events), which are likely to explain the relatively narrow spread for some categories. For example, it is possible that most owners/operators will ensure their asset's underwater hull is inspected after an extended static period and treated if the fouling present was found extensive and severe enough to have an impact on the hydrodynamic performance of the vessel. Such practices will explain the relatively narrow spread of Fouling Indicator ratings for the categories 'ESP' and 'ESP and Low Activity', where the outliers are ships with irregular operational profiles that may have not been subject to any hull-husbandry events prior to the visual inspection on which the Fouling Indicator rating was based.

Several case studies providing a more detailed representation of the condition of the underwater hulls of vessels with different operational profiles are shown in Appendix 1. The case studies were chosen randomly from the categories of vessels associated with different operational profiles within the calibration sample. Any vessel or coating product identifiers are kept anonymous.

3. Conclusions and Future Work

To obtain a representative and realistic assessment of risk of fouling in terms of extent and abundance, a number of factors related to operational and biofouling management histories of a vessel need to be taken into account. Carrying out detailed biofouling risk assessments for individual ships entering port requires dedicated resources and time.

A digital risk assessment system, such as PortShield, enables users to prioritise the vessels due to arrive in port and highlights the ones whose biofouling management history should be investigated in more detail. This will enable port authorities to contact vessels of interest prior to arrival and to request relevant information for a detailed biofouling risk assessment to be carried out. Once key events representing the most recent biofouling management history of the vessel are entered into the system, a risk indicator is generated. The whole process can be completed prior to arrival in port allowing for the relevant parties to plan and optimise any subsequent activities. The system is designed to store any previous events and data related to the biofouling management history of each vessel that may have been entered by other users. Users can also set a 'risk indicator threshold', which highlights all vessels whose risk indicator is above the set limit. The goal is to achieve the most comprehensive and representative assessment with minimum user input over time.

The work presented here is part of an ongoing large-scale study aimed to compare the output of a digital risk assessment system (PortShield) to the underwater hull condition of a range of commercial vessels.

The preliminary results link the grouping by coating type with biofouling accumulation rate and show that the groupings used behave as expected – i.e. 'High' performance coatings are associated with lower Fouling Indicator ratings (Figure 4). However, the preliminary results are based on a limited sample size (174 vessels) that was not controlled for factors such as ship type or operational patterns (routes).

The preliminary results also confirm that vessels with irregular operational profiles can be linked to significantly higher Fouling Indicator ratings (Figure 6 and Figure 7). Therefore, highlighting vessels with irregular operational patterns seems to be an adequate first tier prioritisation factor when dealing with assigning priority to vessels from a given population (i.e. the vessels entering a specific

port) in terms of biofouling risk assessments. This will help users focus on the biofouling management practices of prioritised vessels, which could optimise internal port processes and operations.
According to the preliminary results, the outliers in terms of fouling accumulation within the vessels with irregular operational profiles are mostly vessels with 'Economical' and 'Medium' grade products. It appears that coating type in combination with information on operational profiles can provide valuable insights on fouling accumulation and therefore improve the accuracy with which vessels are prioritised as part of the digital risk assessment. Assuming that data on coating type is already available in the system, the first tier prioritisation that a digital system can perform automatically with minimal user input becomes more accurate.

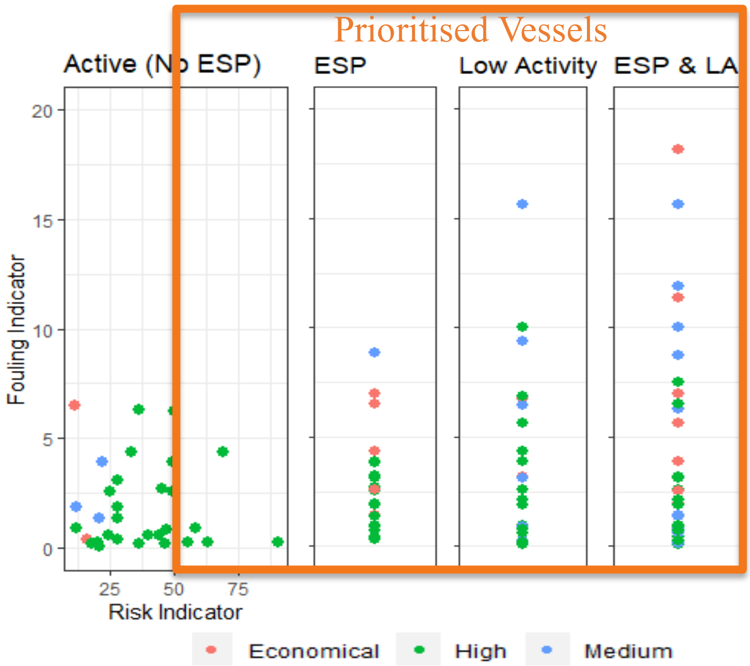


Figure 7. Vessel Prioritisation

The next step in calibrating the output of the system will be replicating the study with a larger sample controlled for factors such as ship type and size to confirm the reliability of the preliminary results. As part of the calibration process, the effect of the remaining components critical to accurately assessing the risk of fouling accumulation, such as the effect of hull husbandry events and hull complexity (niche areas), will be investigated and compared to in-service performance data related to the condition of the underwater hull.

Appendix 1: Case Studies

In this section several case studies, which aim to provide a more detailed representation of the hull conditions of vessels with different operational profiles, are included.

Case Study 1: Example of a ship with one or more ESPs and low activity

The coating, a 'Medium' performance grade with 60 months scheme life, was applied in December 2013. The visual inspection on which the Fouling Indicator rating is based took place in January 2018. The activity of the vessel during the period was 51.4%.

Several months before the visual inspection the vessel had an extended static period of 66 days. Upon inspection, significant areas of the underwater hull were found to be covered by macrofouling.

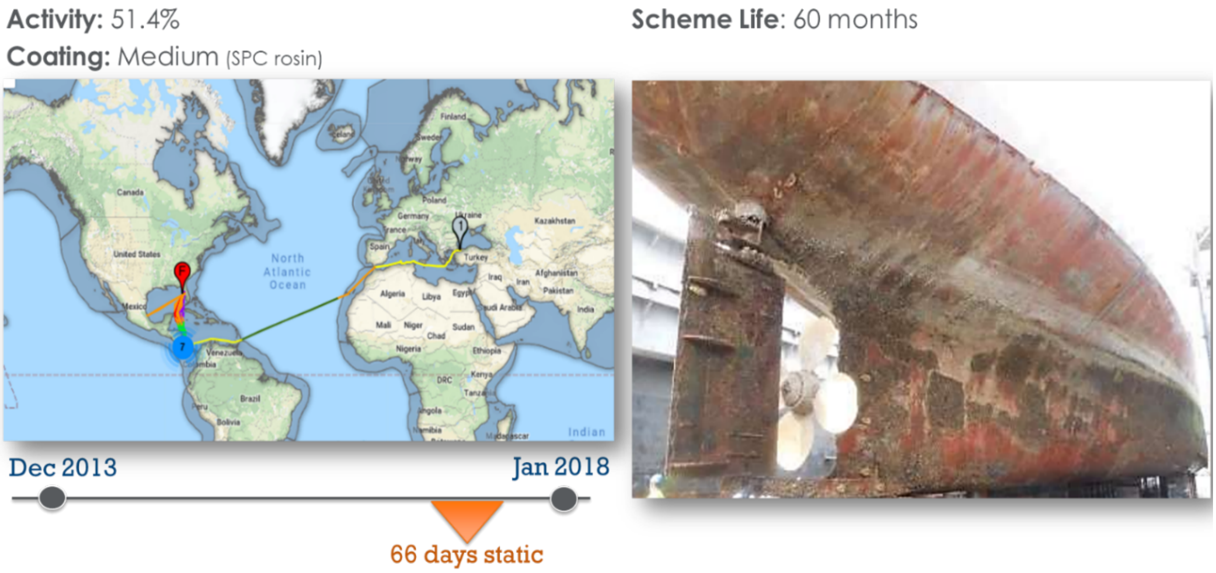


Figure 8. Case study 1: ESP and Low Activity

Case Study 2: Example of a low activity ship

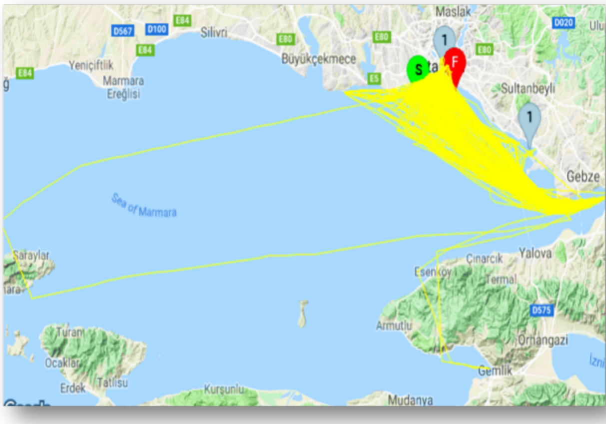
A 'High' performance coating (60 months scheme life) was applied in August 2009. The vessel was engaged in short-sea shipping mostly in the Sea of Marmara and surrounding areas. The vessel's activity is below 10%, which indicates that stationary periods (shorter than 30 days) and periods at ultra-low speeds dominate the vessel's operational profile.

The visual inspection on which the Fouling Indicator rating is based took place in April 2014. Upon inspection, significant areas of the underwater hull were found to be covered by slime and weed.

Activity: 7.5%

Scheme Life: 60 months

Coating: High (Self-Polishing Copolymer)



Aug 2009 — Apr 2014

Figure 9. Case study 2: Low activity ship

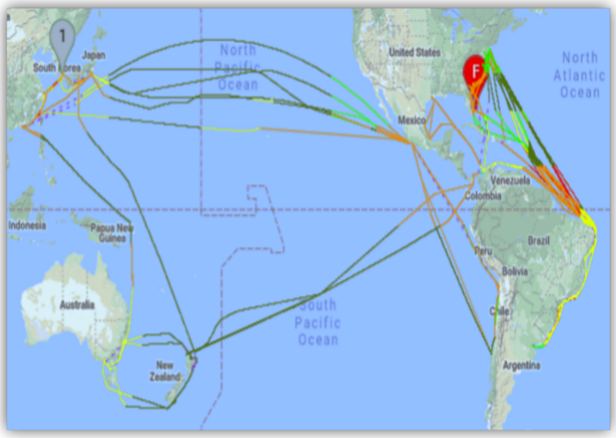
Case Study 3: Example of an active ship

A ‘High’ performance coating (60 months scheme life) was applied in July 2010. The vessel’s activity remained above 70%. The visual inspection on which the Fouling Indicator rating is based took place in February 2015. The vessel’s hull had limited fouling coverage.

Activity: 72.8%

Scheme Life: 60 months

Coating: High (Self-Polishing Copolymer)



Jul 2010 — Feb 2015

Figure 10. Case study 3: Active ship

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Assessment of national publications on biofouling and bioinvasion in Brazil

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Marine Biotecnology Program, Instituto de Estudos do Mar Almirante Paulo Moreira (IEAPM)/Federal Fluminense University (UFF), Brazil.

Abstract

A bibliographyc survey of Brazil using key words was done on biofouling/bioinvasion as part of the action of the GEF-UNDP-IMO GloFouling Partnerships project.

Studies in these areas started about 20 years ago with focus on control of biofouling in ship hull by AFS and with the description of introduced IAS. The number of experimental studies is small but is increasing over the years specially on the subject of invasive species. A significant set of the studies in these two areas are not published in indexed journals. Our results suggested that future studies in Brazil should be focused on experimental type of work, monitoring the arrival of ISA and specifically should address the environmental/economic and social impact of biofouling and bioinvasion.

Introduction

The introduction of Invasive Aquatic Species (IAS) in a new environment has been identified as a major threat to the world oceans and the conservation of biodiversity (Simberloff, 2011; Gilbert and Levine, 2013). The species transfer process involves multiple vectors, including the transport of species through biofouling in ship hulls (Williams et al, 2013). The increasing globalization and international trade intensified in the last decades contribute to aggravate the problem. Quantitative data shows that the rate of bioinvasions continues to increase at an alarming rate and new areas are being invaded all the time. Measures to reduce the transport of species by ship hulls are necessary and urgent in order to mitigate the environmental and economic impacts of IAS.

In order to develop these measures, it is important to know the state-of-the-art of research in these two areas, biofouling and bioinvasion, to allow the establishment of research guidelines to fill the gaps. The lack of knowledge in these areas, makes difficult to quantify impacts, preventive actions and define control strategies for bioinvasion problems at the regional and national levels. Due to the cases of bioinvasion clearly related to the transfer of biofouling, on July 15, 2011, IMO adopted ANNEX 26 of Resolution MEPC.207(62), which addresses the guidelines for the control and management of biofouling on ships, so that minimizes the transfer of species (IMO, 2011). The document includes new guidelines for handling the issue and suggests the implementation of biofouling management practices, including the use of anti-fouling systems and other operational management practices to reduce the development of fouling. More recently, IMO together with GEF-UNDP established a program similar to GloBallast, the GloFouling Project that deals with ships´ hull bioinvasion and drives actions to implement the IMO Guidelines, which provide a globally-consistent approach on how biofouling should be controlled and managed to minimize the transfer of IAS via ships' hulls.

Twelve Lead Partnering Countries (LPCs), representing a mix of developing nations and Small Island Developing States, have been selected to spearhead the work of the GloFouling Project. Brazil is one of these countries and in the present study we make a survey of national scientific publication in Brazil on biofouling/bioinvasion as part of the activities under the GloFouling Partnerships Project. The objective of this survey is to establish priorities on the development of these areas in the country. Therefore, our study aims to answer the following questions: What is the state-of-the-art of biofouling and bioinvasion research in Brazil? How to define which research should be developed in biofouling and bioinvasion in Brazil? And which areas should be prioritized?

Methodology

A bibliometric analysis

A survey by scientific publication was carried out using several databases in June 2019. However, after a preliminary evaluation, only searches conducted from Google Scholar and Scientific Capes database were used in this analysis, using the terms "marine biofouling" and "Brazil" and "marine bioinvasion" and "Brazil" in both English and Portuguese. Theses dissertations, monographs and dissemination texts were not included in the analysis. The original search retrieved a high number of publications. However, after an inspection procedure and qualification, this number was significantly reduced. For example, in the case of biofouling, the first run shows a total number of 1,844 publications, the majority as false positive or non-indexed publications. For the purpose of our analysis only indexed articles were used.

There was no restriction in terms of date of the publication. In our survey we excluded articles in languages other than English or Portuguese, articles related to freshwater biofouling or bioinvasion, and articles that were not performed in the Brazilian territory.

Results and discussion

Besides the mentioned studies and dissertations not included in the present analysis, several studies performed by the Institute of Marine Studies Admiral Paulo Moreira (IEAPM), in the Brazilian Navy Institute, were also not included since they are issued under security classification. Nevertheless, in the last three decades the IEAPM developed valuable studies in fouling control and management on Navy vessels. Among them we can mention several painting reports of ships and submarines of the Brazilian Navy, carried out to evaluate the performance of commercial antifouling systems (AFS), monitoring the biofouling in the hull, evaluation of the operational profile of the vessels, in-water hull inspection and monitoring of the environmental parameters in the anchoring areas of the vessels.

All those results are in an IEAPM database created to store this information and provide a tool for an objective management of Best Practices of biofouling organisms in the Brazilian Navy vessels.

Also, there are several studies on biofouling and bioinvasion done by oil companies in Brazil that were not published. Nevertheless, some of these results start to be communicated in the IMO documents (MEPC and PPR). In general, we could consider that biofouling and bioinvasion are recent science areas in Brazil. From our survey we observed a total of 142 articles published on biofouling starting in 1992 in Brazil and 118 bioinvasion articles from 2003 (Figure 1). There is a clear increase in the number of articles in the last 20 years in both areas. The increase on biofouling articles after 2003 may be associated with the International Convention on the Control of Harmful Anti-fouling Systems (AFS) on ships, in October 2001, that called the attention for the control of biofouling on ships. Brazil was an active player in this Convention. The high number of studies observed after 2008 can also be related to the banishment of TBT when the Convention entered into force. Nevertheless, it is clear that biofouling issues are an important topic in Brazil at the moment.

It is also important to observe that after 2010 there was an increase in articles on bioinvasion relative to biofouling, probably as a consequence of the high rate of introduction of IAS in the Brazilian coast. A first list of the IAS from the Ministry of Environment (Lopes, 2009) called the attention of Brazilian scientists about the problematic of the IAS.

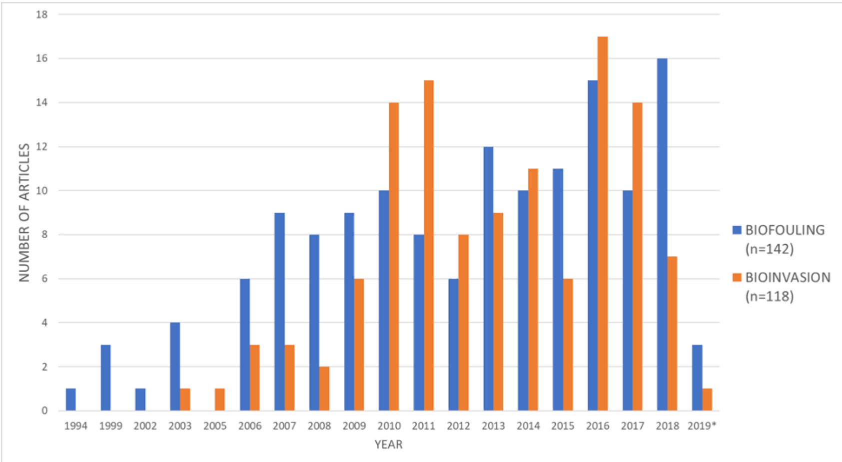

Figure 1 – Number of articles per/year of biofouling and bioinvasion
*until June/2019

Among the many different subjects related to biofouling, control and eradication are the majority areas of the studies being conducted in Brazil. This is probably because of tests or development paints to reduce the biofouling in submerged substrate (Figure 2).

Other important aspects were the interactions (biotic and abiotic) succession/taxonomy and fauna survey. Studies in these areas are traditional in Brazil because it is done by a large group of scientists specialized in different groups of marine organisms. On the other hand, there are only two studies that address the environment/economical/social impact of biofouling, and one on climate change, and no studies in genetic and dispersion, both highly important areas of biofouling.

The descriptive studies of succession/taxonomy and fauna survey were both the main topic found in the bioinvasion survey, followed by abiotic and biotic interaction, dispersion register, control, eradication and genetics. Therefore, most studies done in Brazil in the area of bioinvasion are related to new occurrence in the Brazilian coast or specific studies on the environmental conditions that allow the occurrence of such invasion. Again, like observed for biofouling, the environment/economical/social impact and climate change topics have virtually not been addressed in Brazil on bioinvasion.

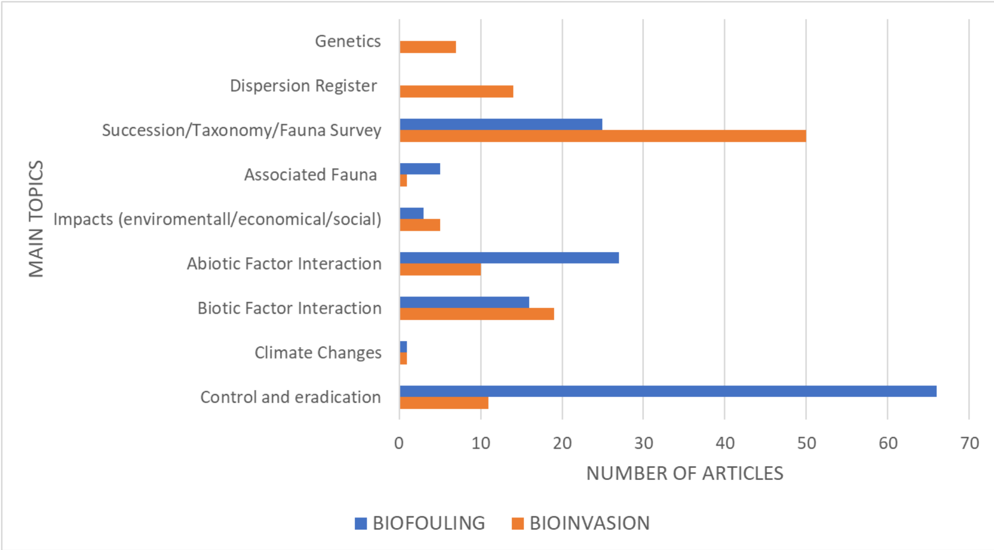

Figure 2 – Total number of articles by main topics on biofouling and bioinvasion

The analysis of the word cloud of biofouling shows that antifouling is the main focus in the studies in this area in Brazil. Several words in this subject also appear in the word cloud such as natural (compounds), paints, activity, defence, coatings, etc. Other words in relation to the survey and ecological studies can also be seen such as species, invertebrates, colonization, fouling, seaweed, etc.

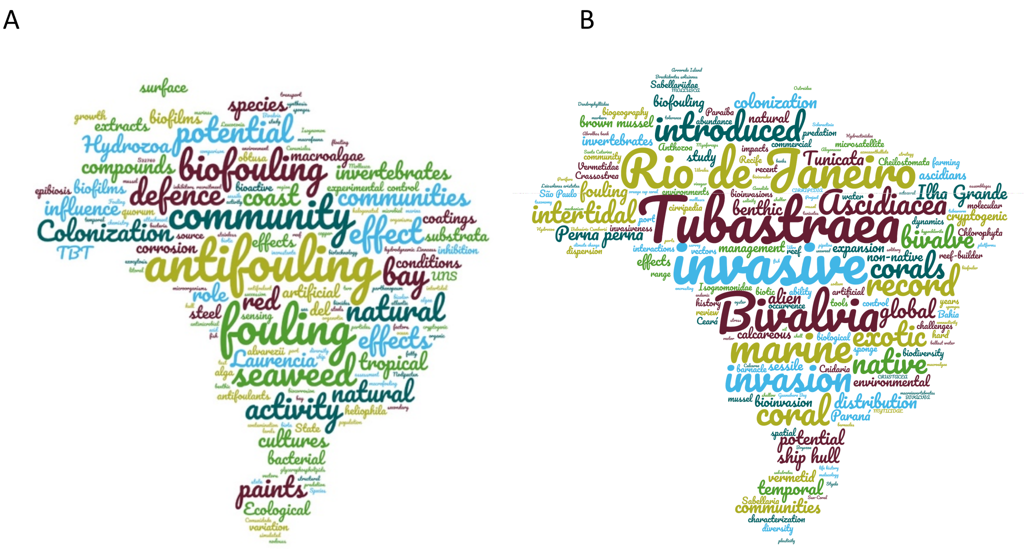

Figure 3 – Word cloud from survey on biofolouling (A) and bioinvasion (b) articles in Brazil

On the other hand, introduced species such as the sun-coral genus Tubastrea, and other invasive species like the Bivalve, Corals, Polychaeta and Ascidiacea are also the dominant words in the analysis. It is important to stress that most of the studies are located in the State of Rio de Janeiro (i.e., Ilha Grande), where a great number of studies (10% of the total) have been done with the invasion genero Tubastrea. Other words in relation to the ecological aspects (temporal distribution, fouling, effects, expansion and management) show low relevance in the word cloud.

In summary, studies on biofouling and bioinvasion in Brazil started about 20 years ago with the focus on control of biofouling on ships' hull by AFS and with the description of introduced IAS. The number of experimental studies is small but is increasing over the years, especially on the subject of invasive species. A significant set of the studies in these two areas are not published in indexed journals. Nevertheless, the ones published in journals with impact factor have an average value of 2.53.

Based on the survey we suggested that the research in biofouling and bioinvasion in Brazil should be focused on experimental type of work, monitoring the arrival of ISA (e-DNA for example) and specifically should address the environmental/economic and social impact of Biofouling and Bioinvasion in the Brazilian coast.

Reference

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Conference Presentations

NINA BLOECHER
Senior scientist
SINTEF Ocean, Norway

Dr. Nina Bloecher is a senior scientist at SINTEF Ocean, based on Trondheim, Norway, with a PhD in Marine Biology from the Norwegian University of Science and Technology. Nina has been working with biofouling in salmon aquaculture for the past 10 years. The focus of her work has been investigating the impacts of biofouling on fish health and exploring novel antifouling and biofouling management technologies for aquaculture nets. This includes extended research into in-situ net cleaning technology – its risks for fish health, impacts on the net, and the evaluation of possible new technologies. Nina works on these issues in collaboration with Norwegian and international research organisations, aquaculture farming companies, technology developers and regulatory agencies.

Impacts of biofouling in aquaculture

Biofouling is one of the main operational challenges that all marine aquaculture industries experience, independent of the cultured species. This talk will give an overview of how biofouling impacts finfish, shellfish, and seaweed culture and summarise recent avenues for mitigation. It will then focus in detail on the impacts of biofouling on salmon aquaculture, and the risks and challenges surrounding current in-situ net cleaning practices. Potential novel strategies for management of biofouling will be discussed, and current knowledge gaps will be identified to prioritise research needs.

ANZPAC workshop, Melbourne, 1.10.2019

The impacts of biofouling in aquaculture

Nina Bloecher

SINTEF Ocean, Norway

SINTEF

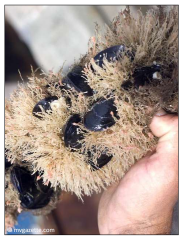
Biofouling in aquaculture

Finfish culture

- ➢ Fouling of equipment

Seaweed & shellfish culture

- ➢ Fouling of equipment
- ➢ Fouling of culture species



Impacts of biofouling

- Increased weight
  - Detachment, breakage
  - Buoyancy of mooring system

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- Physical damage
  - Susceptibility to parasites, disease, predation
  - Aesthetics

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- Reduction of fitness
  - Competition for food, oxygen, light, space, etc
  - Smothering, impairing valve function

Impacts of biofouling

- Increased weight
  - Detachment, breakage
  - Buoyancy of mooring system
- Physical damage
  - Susceptibility to parasites, disease, predation
  - Aesthetics
- Reduction of fitness
  - Competition for food, oxygen, light, space, etc
  - Smothering, impairing valve function
- Environmental impacts

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Prevention of biofouling

- Choice of substrate/culture method
- Stocking density
- Spatial & temporal avoidance
  → Modelling of biofouling settlement & development
- Inherent AF metabolites can be enhanced
- AF shell coatings (→ novel natural AF compounds)
- Timing of husbandry strategies
- Resistant genotypes
- 'Clean' seed stock



Treatment of biofouling

- Exposure to air, FW, heat, organic acid/bases
- Manual removal
- Biocontrol
- Cleaning of infrastructure = reservoir


Treatment of biofouling

- Exposure to air, FW, heat, organic acid/bases
- Manual removal
- Biocontrol
- Cleaning of infrastructure = reservoir

Shellfish

- Pressure washing
- Silicon release coatings
- Abrasive medium

Treatment of biofouling

→ Combinations of multiple treatments work best
- ➢ against a broader range of foulers
- ➢ lower intensities & exposure times

BUT! Treatments can impact cultured species more than the biofouling!

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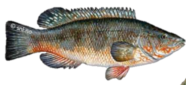
Biofouling in finfish culture

© SINTEF ACE

Biofouling on aquaculture nets

affects…
- Water exchange
- Cage stability
- Fish health ← pathogens
- Environment ← NIS
- Cleaner fish ??

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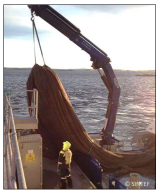
Bannister et al. 2019

Strategies against biofouling

Copper coating

Net cleaning



Net exchange

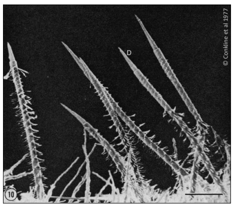
Bannister et al. 2019

Cleaning waste causes gill damage

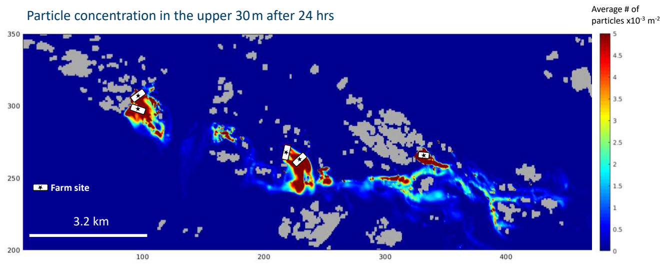
→ Gill damage visible for up to 7 days

Ectopleura larynx

Anthothoe albocincta

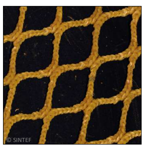


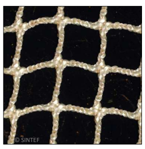
Spreading of cleaning waste



Pressure washing is abrasive

- 1x net cleaning damages 31% of the coating
- 35x net cleaning damages 90% of the coating





⇩ 1 250 t copper / year

Holes in the net after net cleaning

Moe Føre & Gaarder 2018, Bloecher et al. 2019

We need better biofouling management strategies!

1. Efficient **antifouling** without cleaning

2. Antifouling **combined** with intermittent cleaning

3. Grooming of nets without antifouling

Options for future biofouling management strategies

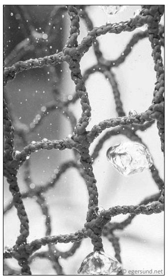
1. Efficient antifouling without cleaning

Advantages
- No cleaning-related impacts
- Predictable cost

Challenges
- Efficacy across taxonomic spectrum
- Environmental toxicity
- Entanglement of drifting biomass

Current status
- Today's coatings may work in low-intensity regions

R&D needs
- Develop novel coatings / net materials
  - Efficient
  - Benign
  - Good leaching control
  - Highly robust



Options for future biofouling management strategies

2. Antifouling combined with intermittent cleaning

Advantages
- Reduced cleaning-related impacts

Challenges
- Cleaning-related impacts
- Environmental toxicity

Current status
- Copper alloy nets have potential but need more research
- Potential gentle cleaners: low pressure or cavitation cleaning

R&D needs
- Cleaning waste collection

Options for future biofouling management strategies

3. Grooming of nets without antifouling

Advantages
- No cleaning-related impacts
- No contamination

Challenges
- Energy efficiency

Current status
- Durable nets are available
- Net grooming technology is available but needs validation

R&D needs
- Novel cleaning technology:
  - Autonomous
  - Good cleaning efficacy
  - Energy efficient
  - No impact on fish

Biofouling in aquaculture: summary & outlook

- Balance benefit vs. costs of biofouling management ← More research needed!
- Monitoring and modelling tools are improving → predict and mitigate biofouling
- Combination of treatment methods is promising
- More research needed
  - Genetic resistance
  - Variety of culture species – especially for finfish!
  - New habitats – offshore, closed systems
  - …

Bannister et al. 2019

More information:
Nina.Bloecher@sintef.no

Funded through
SINTEF ACE – full-scale test laboratory

Thank you!

…and thanks to:
Jana Bannister, Michael Sievers, Flora Bush

Bannister, Sievers, Bush, Blocher (2019): Biofouling in marine aquaculture: a review of recent research and developments. *Biofouling 35:631-648*

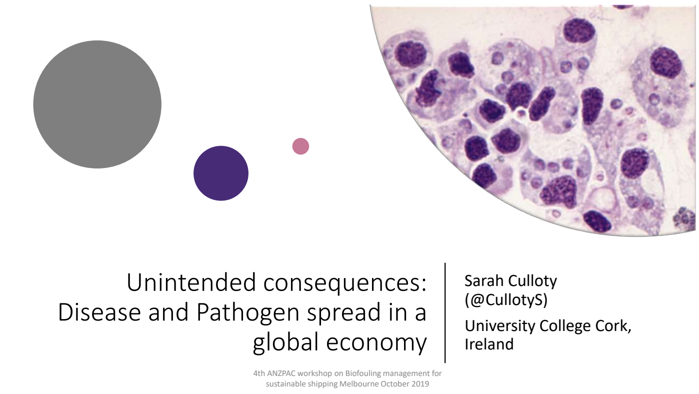
SINTEF

SARAH CULLOTY
Director, Environmental Research Institute
University College Cork, Ireland

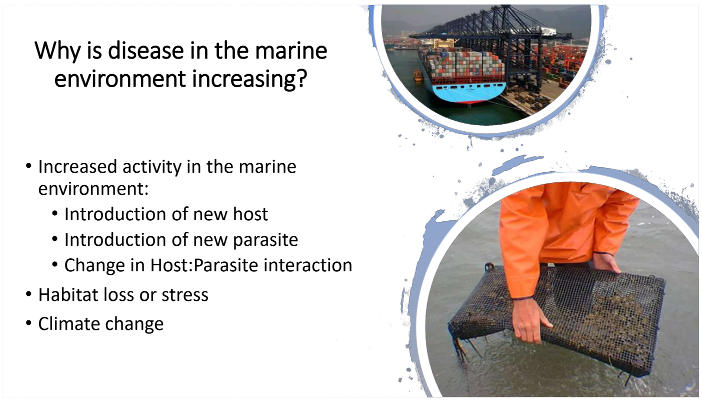
Sarah Culloty has worked on shellfish pathology and diseases for over 25 years having started her career with a PhD, on an emerging disease in oysters, Bonamia ostreae, and its introduction to Ireland in the 1980s. Her work focuses on disease dynamics, epidemiology and understanding the drivers of disease development particularly in bivalve molluscs. In particular she has worked on factors that facilitate disease transmission such as transmission routes and the potential ways that disease can be incidentally transmitted and then maintained in introduced areas. Working at University College Cork she leads a team of PhD students and research staff working on a number of significant pathogens for shellfish. She has published over 100 papers, supervised over 40 masters and PhD students. She is currently Director of the Environmental Research institute at UCC.

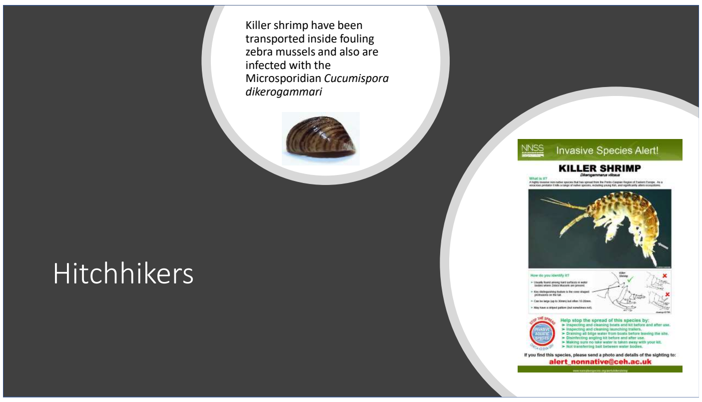
Unintended consequences: Disease and pathogen spread in a global economy

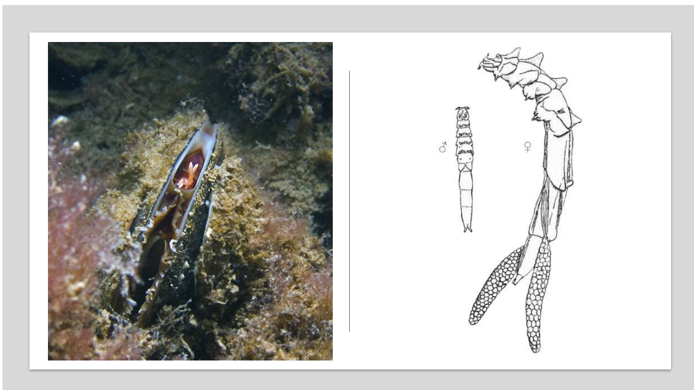
Disease events in the marine environment are increasing due to a range of factors including intensified activity, transport and a changing marine environment. The aquaculture industry has suffered some severe mortality events and losses as the industry has intensified, many due to pathogens and disease. Many of these diseases have been introduced to different regions via aquaculture practices and unintended transport of infected animals. Understanding how these diseases have developed and become established is a primary focus to enable control and eradication methods to be developed. In the shellfish industry in Europe, viruses, bacteria and a range of parasites have become established causing severe impacts. Many of these have spread to Ireland and understanding how they were introduced and established is a focus of the research. Our research has demonstrated that many factors are involved in the initial introduction of the parasite and its establishment. Many marine organisms in the vicinity of the disease can act as unintended carriers or reservoirs of infection, ensuring that the disease is maintained and becomes established in the area and may facilitate being unintentionally transported to new areas. Biofouling organisms due to their close association with aquaculture equipment can act as potential carriers of disease. In addition, invasive species are becoming an increasing challenge due to a changing environment and may facilitate the spread of new or current diseases. The current BLUEFISH project which is focussing on aquaculture and fisheries in the Irish Sea is understanding some of the drivers of infection in that region and consequences into the future for the industry.


Unintended consequences:
Disease and Pathogen spread in a global economy
Sarah Culloty (@CullotyS)
University College Cork, Ireland
4th ANZPAC workshop on Biofouling management for sustainable shipping Melbourne October 2019


Otago Daily Times
No sign of parasite in wild oysters
NewScientist
The mysterious diseases killing starfish, sea fans and shellfish
THE CONVERSATION
A deadly herpes virus is threatening oysters around the world
Oysters Can Get Herpes, And It's Killing Them
BBC NEWS
Burry Inlet cockle deaths mystery enters 13th year
Increased disease incidence in the ocean


Why is disease in the marine environment increasing?
• Increased activity in the marine environment:
• Introduction of new host
• Introduction of new parasite
• Change in Host:Parasite interaction
• Habitat loss or stress
• Climate change


Killer shrimp have been transported inside fouling zebra mussels and also are infected with the Microsporidian *Cucumispora dikerogammari*
Hitchhikers
NNSS
Invasive Species Alert!
KILLER SHRIMP
alert_nonnative@ceh.ac.uk


♂
♀

Disease Spread – between geographical regions

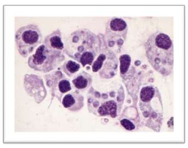
- Green-lipped mussels *Perna canaliculus*
- Pathogenic *Vibrio parahaemolyticus* isolated from biofouling on commercial vessels and harbour structures

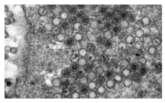
Role of biofouling organisms in transmission

- ❑They may have parasites
- ❑They may have no parasites;
- ❑ They can be parasites themselves;

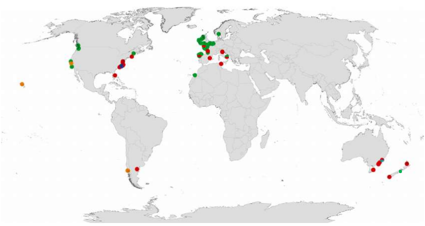
Bonamia ostreae

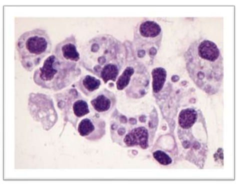
Herpes Virus

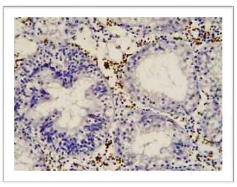




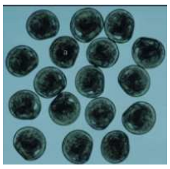
Bonamia ostreae







Cork harbour as a model system

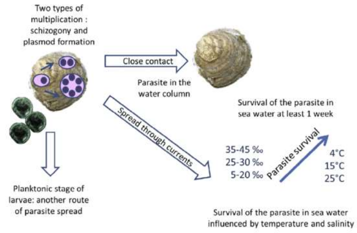


Transmission of B. ostreae

- Oysters can be infected for months
- Brooding larvae can be infected
- Parasite v resilient externally
- Successful eradication has not been effected

Bonamia life cycles

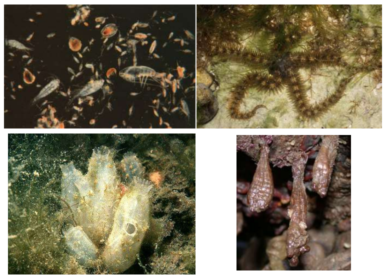
Reservoirs? Carriers?



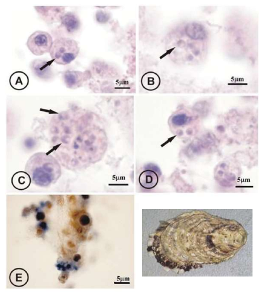
Carnegie and Arzul

Shell cavity detection

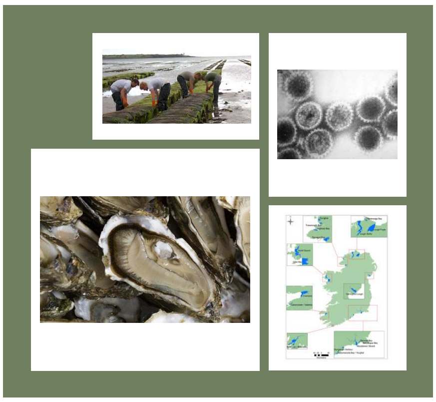
Reservoir hosts



Lynch et al 2006 Mar Biol 149, 1477-1487
Lynch et al 2007 Exp Parasitol 115, 359-368

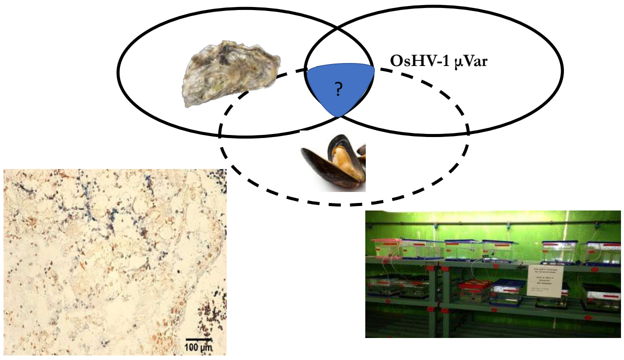


Lynch et al 2010 Parasitology 137(10), 1515-1526



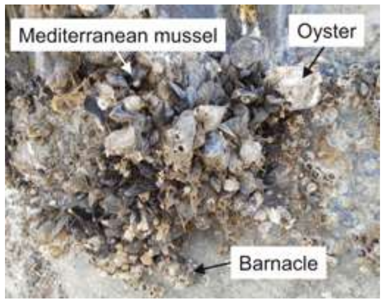
Pacific oyster mortalities due to Herpes virus

Field Surveys - mussels



O'Reilly et al 2018 Parasitology

Potential for *Bonamia* and OSHV1 to be transmitted



Acknowledgements

- Babette Bookelaar and Amy O'Reilly, former PhD Students
- The Department of Agriculture, Food and the Marine FIRM funded project REPOSUS
- European Union Horizon 2020 project VIVALDI

UCC
Coláiste na hOllscoile Corcaigh, Éire
University College Cork, Ireland

Environmental Research Institute

JEFF ROSS
Senior research scientist
Institute for Marine and Antarctic Studies (IMAS), Australia

Jeff is a Senior Research Scientist at the Institute for Marine and Antarctic Studies (IMAS). Over the past decade his work has increasingly focused on understanding the environmental impacts and interactions of finfish aquaculture in Tasmania. However, he has a long history in marine pest research in Australia. Soon after his undergraduate and honours degrees at the University of Melbourne and Monash University he began working on marine pests. Initially working with Prof Michael Keough on a review of introduced fouling species in Port Phillip Bay, before moving to Hobart to undertake his PhD at UTAS/CSIRO (CRIMP) on the impacts of the introduced Japanese seastar Asterias amurensis. *He then moved back to Melbourne to take up a postdoctoral position at the University of Melbourne investigating the effects of marine pests on key nutrient cycling processes in Port Phillip Bay. Along the way, this included participating in several CRIMP port surveys and conducting research on the impacts of a wide range of pests including* Asterias amurensis, Sabella spallanzanii*,* Carcinus maenas*,* Maoricolpus roseus*,* Styela clava *and many others. Another trip across Bass Strait has seen him settle in Hobart and although salmon research takes up most of his time, he has supervised several student projects investigating the impacts of marine pests and he is often called upon by government for advice in the event of any recent incursions.*

Are all marine pests equal?

In the mid- late 1990s the occurrence and threat of marine pests in Australian waters gained much attention. Establishing the impacts of our invasive species became an important research focus, notably for the high- profile invaders such as Asterias amurensis, Undaria pinnatifida, Sabella spallanzanii and Carcinus maenas. Fortunately, of the 250 introduced marine species known from Australian waters the majority have negligible impact. After the initial emphasis on determing the status and impacts of marine pests in Australian waters attention quickly shifted to biosecurity to minimise the risk of introductions, establishment and spread. In this talk I'd like to revisit some of our learnings on the impacts of our established pests, sharing the stories of three invaders to Tasmania that have similar origins and places of arrival but very different trajectories.

Are all marine pests equal?

Dr Jeff Ross

4th ANZPAC Workshop on Biofouling Management for Sustainable Shipping
30 September – 4 October 2019

Impacts of marine pests in Australia

- mid- late 1990s the occurrence and threat of marine pests in Australian waters gained much attention e.g. establishment of CRIMP
- establishing the impacts of our invasive species became an important research focus
- high-profile invaders e.g. *Asterias amurensis, Undaria pinnatifida, Sabella spallanzanii and Carcinus maenas*
- fortunately, of the 250 introduced marine species known from Australian waters the majority have negligible impact.
- emphasis on prevention and surveillance
- what have we learnt about pest impacts in Australia

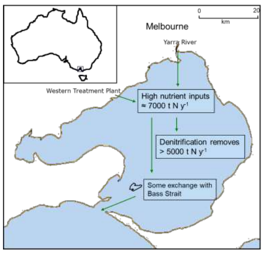


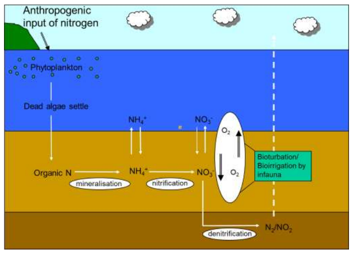

European fan worm (*Sabella spallanzanii*)

- first discovered in Western Australia in 1965, since recorded in Victoria, South Australia, Tasmania and NSW (found in New Zealand in 2008).
- found on both hard and soft substrates
- potential to compete with native filter-feeding organisms for food and space
- fouls infrastructure
- impacts documented on benthic assemblages in both hard and soft sediment habitats e.g. Holloway & Keough 2002; O'Brien, Ross & Keough 2007
  - on hard substrates recruitment of several sessile taxa affected including barnacles, bryozoans, and sponges
  - abundance of planktonic organisms, including larvae, was lower beneath fan worm canopies and water flow rates were decreased
  - impact typically when at high densities
- In Port Phillip Bay, Victoria, concern on effects on nutrient cycling processes, due to their high filtering capacity
  - > 100 introduced pests in Port Phillip Bay alone

European fan worm (*Sabella spallanzanii*)

Nutrient cycling in Port Phillip Bay





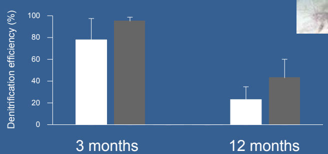
- Changes in infauna
- Assemblages living on tubes
- Shading of microphytobenthos
  - decline in nutrient assimilation and oxygen availability
- Canopy effects on water flow
  - transport of nutrients at sediment-water interface altered
- Worm effects on nutrient processing
  - metabolism and excretion into water column

European fan worm (*Sabella spallanzanii*)

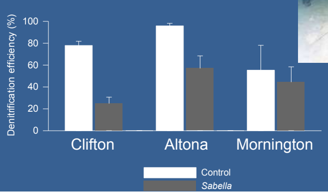
Chamber incubation

Infaunal sample

Random distribution



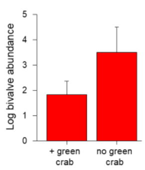
Clumped distribution

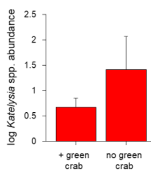


European Green Crab (*Carcinus maenus*)

- first recorded in Victoria ca. 1900 but not discovered in Tasmania until 1993
- occurs in sheltered low energy embayment's
- highly abundant on east coast,
  - e.g. 100-200 per day per trap
- now occurs through south east, now in Macquarie Harbour on the west cost
- voracious predator of native crabs (e.g. *Paragrapsus gaimaridi*)

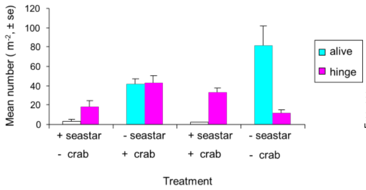
- voracious predator of bivalves
  - mussels (small mussels = 14 per hour in lab trials)
  - hard-shell clams (cockles = 5-6 per hour in lab trials)
- large scale negative correlation between *Katelysia* (and other bivalves) and green crab on east coast
- predation is size-specific
- Driver not tracker !!!!!

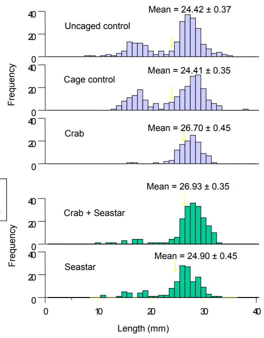




European Green Crab (*Carcinus maenus*)

Interaction of two introduced predators in SE Tasmania: Impact of *Asterias* and *Carcinus* on the bivalve *Fulvia tenuicostata*





The story of 3 pest species in Tasmania

Asterias amurensis *Undaria pinnatifida* *Mya japonica*

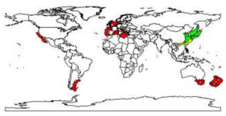
- share the same origin – North Pacific
- likely same place of arrival
- woodchip loading facility at Triabunna.
- shipments from Triabunna were exclusively woodchips for the Japanese market and international shipping occurred from the early 70s until the facility closed in 2011
- *Undaria* first recorded in 1988, Asterias *1995* and Mya 2018

- very different trajectories……

Undaria pinnatifida

- first identified in 1988 near Triabunna
- First survey estimated at least 400 tonnes of the algae limited to the Triabunna-Rheban region (10 km of coast). By 1994 infestation had spread to over 80 km of coast,. Now found along the east and south east coast. Also found in Victoria and New Zealand
- based on the movement of outbreaks it is evident that human intervention is spreading the algae in Tasmania.

- In 1994 the Tasmanian Government acknowledged that eradication program was not feasible. As a control measure the Department made provision for three licences to wild harvest, process and sell *Undaria*

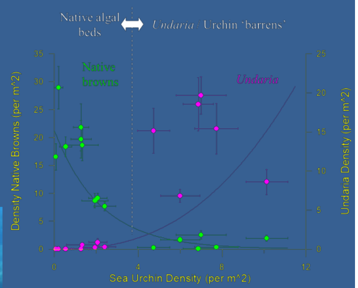


Undaria pinnatifida

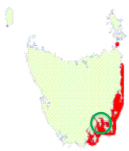
- *Driver* or *tracker* of ecological change ?
- Dense monospecific stands indicated *driver*

Observation: Undaria occurs at high densities at disturbed sites:

- urchin 'barrens'
- shallow subtidal wash zone
- sand scour zone on edge of reefs
- unstable substrata (especially *Maoricolpus roseus)*



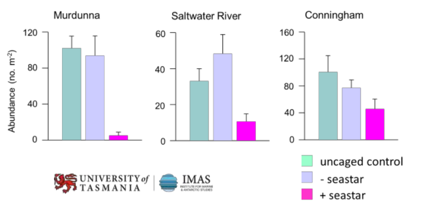
Northern Pacific Seastar (*Asterias amurensis*)



- first detected in the Derwent Estuary, Tasmania in 1993 (PPB 1994)
- estimated arrival in 1980s, possibly Triabunna woodchip terminal
- soft sediment and rocky reef
- generalist predator with environmental tolerances

Common challenges in determining impacts:

- lack of baseline data prior to arrival/detection
- confounding with other anthropogenic stressors (e.g. port environment)
- limitations of single approach to impact assessment



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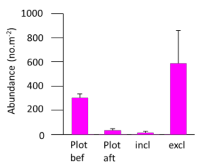
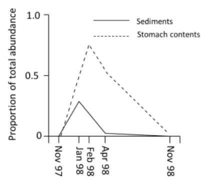
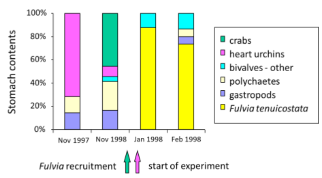
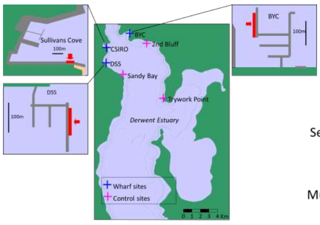
Northern Pacific Seastar (*Asterias amurensis*)

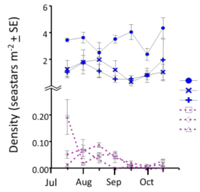


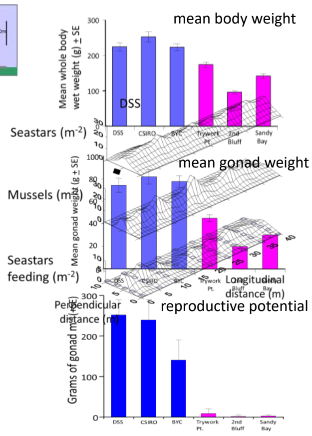


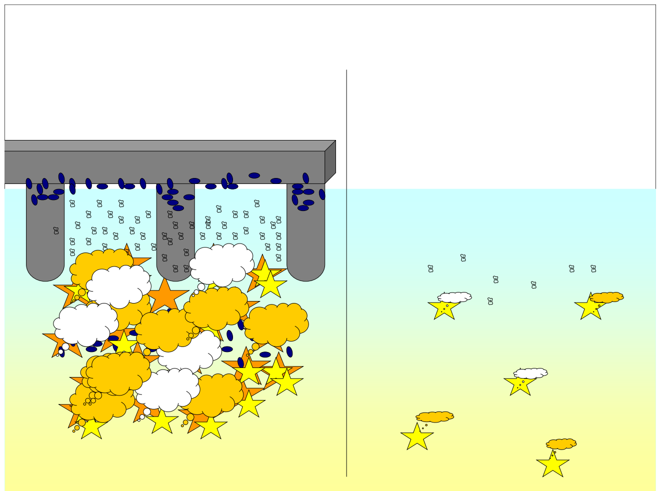


Northern Pacific Seastar (*Asterias amurensis*)









Northern Pacific Seastar (*Asterias amurensis*)

	Single Spawning at Wharves	2 Spawnings at wharves
Scenario 1: • perfect synchrony in spawning • 100% of animals spawn	53%	70%
Scenario 2: • spawning synchronous over 16.5 minutes • 25% of animals spawn	66%	85+%

Journal of Applied Ecology

Journal of Applied Ecology 2012, 49, 733–741 doi: 10.1111/j.1365-2664.2012.02133.x

Hotspots of exotic free-spawning sex: man-made environment facilitates success of an invasive seastar

Scott D. Ling[1*], Craig R. Johnson[1], Craig N. Mundy[2], Alice Morris[3] and D. Jeff Ross[2]

[1]Institute for Marine & Antarctic Studies, University of Tasmania, Hobart 7005, Tas., Australia; [2]Institute for Marine & Antarctic Studies, University of Tasmania, Taroona 7053, Tas., Australia; and [3]Department of Primary Industries, Parks, Water and Environment, 1 Franklin Wharf, Hobart 7001, Tas., Australia

Summary

1. The introduction of exotic species to new areas poses a major threat to the environment. For those introduced species that establish and survive beyond the short term, the opportunities to manage the risk of continuing spread often rest with limiting reproductive output. The introduced northern Pacific seastar *Asterias amurensis* is an ecologically important pest that has established in the Derwent Estuary (Australia). Driven by oversupply of bivalve prey, it is persistent, abundant and fecund when associated with man-made structures such as docks, marinas, jetties and piers, that is, 'wharves'.

2. As a free-spawning invertebrate, fertilization by *A. amurensis* is a critical life-history stage constrained by strong Allee effects. Eggs must be released in close proximity to sperm sources because the chances of achieving fertilization drastically reduce with increasing distances of spawner separation.

3. Investigation of zygote production in the Derwent Estuary using a spatially explicit model of free-spawning fertilization shows that *A. amurensis* at wharves, while representing <10% of the total population in the estuary and concentrated in <0·1% of the total area, may contribute >90% of total zygote production. Given the seastars' long-lived and highly dispersive larvae, we show that wharves not only represent important sites of invasion but also facilitate propagule pressure promoting secondary invasions.

4. *Synthesis and applications.* In the absence of effective pest control solutions, focusing on reproductive hotspots has the potential to reduce further spread of established marine pests and to alleviate ongoing ecological impacts. In the case of the northern Pacific seastar, elimination of highly localized wharf populations annually prior to spawning can reduce overall zygote production by up to estimated ~90%. The long-term protection of key sources of larval production is a common goal

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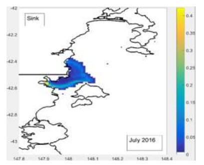
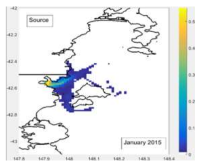
Soft-shell clam *Mya japonica*

- first detected at Prosser River, at Orford in 2018.
- first detection of this species, *Mya japonica*, in the Southern Hemisphere
- likely present in the waterway for some time -Mya shell found in the area in 2013
- grow up to 150 mm living buried up to 50 cm deep.
- density up to 350 m^{-2} was recorded at a depth of 3.5m and equates to a biomass of 10.7 kg m^{-2}.

- CONNIE dispersion modelling





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Are all marine pests equal ?

- information on the ecological interactions of many pest species remains limited
- fortunately the impacts are likely to be negligible for most (but not all)

What about our high profile invaders:

- impacts now reasonably well known despite the challenges
- nature and magnitude of impacts variable and depends on:
  - e.g. density, distribution, habitat, environment
- some are ***trackers*** and other are ***drivers*** of ecological change
  - Implications for management
- trajectories often difficult to predict

- indirect effects of biofouling
- domestic challenges e.g. implications for aquaculture

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Graeme Inglis

Principal scientist

New Zealand National Institute of Water & Atmospheric Research Ltd (NIWA), New Zealand

Graeme Inglis is a Principal Scientist at the New Zealand National Institute of Water & Atmospheric Research Ltd (NIWA) and leads NIWA's Marine Biosecurity research programme. He is also Science Leader of an international collaborative research programme on marine biosecurity, that involves scientists from New Zealand, Australia, Canada and the USA.

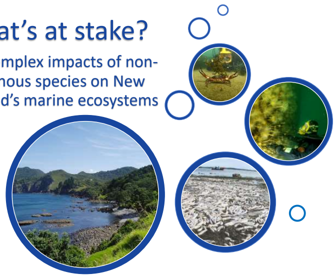
Graeme has published more than 140 peer-reviewed scientific papers, technical reports and popular articles and has provided training and technical advice on the management of invasive marine species in New Zealand, the Middle East, South East Asia, the Pacific, Europe, South America and Australia, including as a Technical Advisor to the GEF/UNDP/IMO Global Ballast Water Management Programme (GloBallast). His research has included developing tools to characterise, assess and manage risks from invasive species in shipping pathways and the design and implementation of post-border surveillance.

What's at stake? Studies on the impacts of non-indigenous species on New Zealand's marine ecosystems

We view the impacts of non-indigenous species (NIS) and other changes to our natural environments through the lens of how they affect things that we value. Predicting the potential consequences of marine invasions is problematic because there is usually a high level of uncertainty about which species will arrive and be successful, the novelty of their interactions within the ecosystems that they invade and the complex and sometimes competing environmental, social, cultural and economic values that are at stake. In this presentation, I provide an overview of some of the outcomes from a 4-year study that examined the effects of a suite of non-indigenous species on New Zealand's marine ecosystems. Collectively, they reveal a range of different types of impacts on native species, important ecosystem services, industries and people. Some are subtle and indirect, some intermittent, while others are pernicious and persistent. Our results demonstrate why single-species assessments of risk are insufficient when dealing with complex, multi-species vectors such as biofouling and ballast water.

What's at stake?

The complex impacts of non-indigenous species on New Zealand's marine ecosystems



[1]Graeme Inglis
[2]Kia Maia Ellis
[1]Michael Townsend
[1]Drew Lohrer
[1]Leigh Tait
[1]Kelly Ratana
[3]Javier Atalah
[3]Oli Floerl

1 NIWA
2 MANAAKI TE AWANUI
3 CAWTHRON The power of science
4 THE UNIVERSITY OF WAIKATO Te Whare Wānanga o Waikato

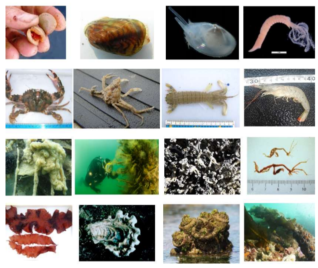
New Zealand Government
Funded by the Ministry of Business, Innovation and Employment

A perspective from Ngāi Tukairangi

MANAAKI TE AWANUI

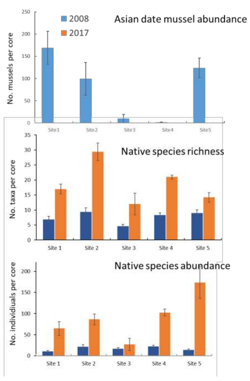
Risk assessment and the business case for management

- Single species assessments
- Costs of prevention, eradication & control are calculable (and often large)
- Benefits of action often uncertain and less quantifiable
  - Lack of available information
  - Variety of values held for marine environments
  - Context-dependence of impacts



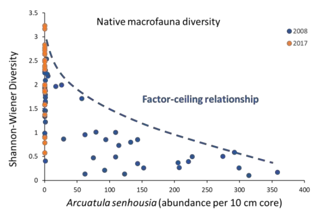
Habitat modification

Asian date mussel, *Arcuatula senhousia*



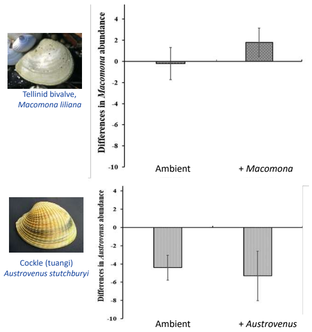
Impacts on native biodiversity

- Large abundance of date mussels appears to limit diversity
- Effects vary in time and space with abundance
- Resilience varies among native species



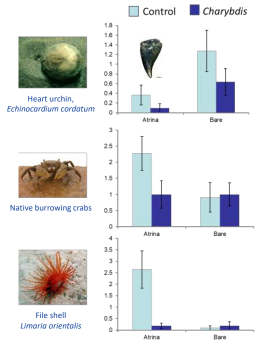
Impacts on key species
- direct effects


Asian paddle crab, *Charybdis japonica* (Image: Serena Cox, NIWA)

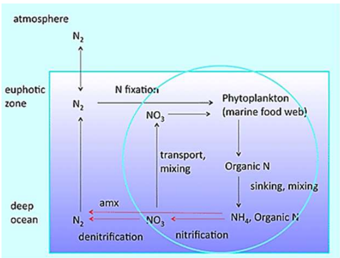


Impacts on key species
- Interactive effects


Asian paddle crab, *Charybdis japonica* (Image: Serena Cox, NIWA)

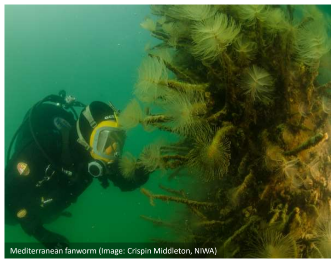


Effects on nutrient cycling

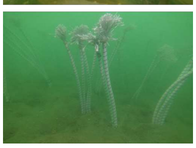


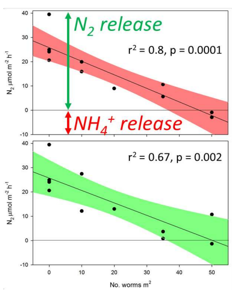
Mediterranean fanworm - *Sabella spallanzanii*


Mediterranean fanworm on vessel keel (Image: Marlborough Sounds Marinas)


Mediterranean fanworm (Image: Crispin Middleton, NIWA)

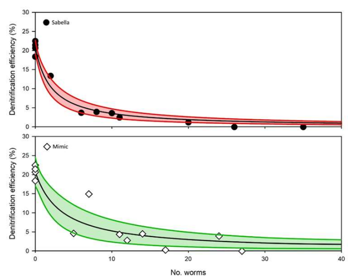
Mediterranean fanworm - *Sabella spallanzanii*





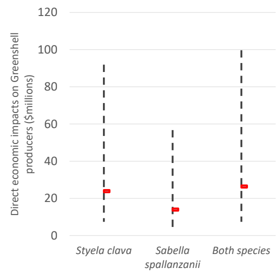
Changes in nutrient cycling

- Switched the system from net N_2 release to net NH_4^+ release
- Increasing density of worm tubes (real or fake) reduced denitrification



Densities can be very large

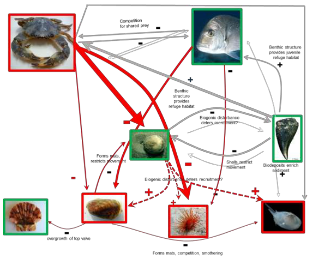
Economic impacts
- competition with mussels



Soliman, T., Inglis, G.J. (2018) Forecasting the economic impacts of two biofouling invaders on aquaculture production of green-lipped mussels *Perna canaliculus* in New Zealand. *Aquaculture Environment Interactions*, 10: 1-12. https://doi.org/10.3354/aei00249

Summary

- Impacts are difficult to anticipate
- Range of economic, environmental, social and cultural values that can be affected
- Effects are influenced by abundance of the invader (which varies in space and time)
- They can be direct, indirect and are cumulative
- Not all are easily quantified



Acknowledgements

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MANAAKI TE AWANUI
MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT HĪKINA WHAKATUTUKI
C01X1511 – What's at stake?

Peter Wilkinson
Assistant Director, Marine Biosecurity Unit
Department of Agriculture, Water and the Environment, Australian Commonwealth, Australia

Peter Wilkinson has worked on marine biosecurity within the Department of Agriculture for the past 8 years. He is currently an Assistant Director in the Marine Biosecurity Unit, leading policy development to improve the department's management of the biosecurity risks associated with biofouling. Peter has previously worked on ballast water policy and led the Australian Government Review of National Marine Pest Biosecurity. Peter holds a Bachelor of Laws and Bachelor of Science from Deakin University in Melbourne, Victoria. He is an Australian Lawyer and Officer of the Supreme Court of Victoria.

Australia's biofouling management requirements: managing risk and regulatory burden

The Australian Government Department of Agriculture (the department) is proposing policy changes to the regulation of biosecurity risks associated with biofouling on all vessels arriving into Australian waters. The department release a Consultation Regulation Impact Statement for full public consultation from 1 April 2019 to 31 May 2019. Feedback received is informing the development of a Regulation Impact Statement for government decision, with policy being proposed to more effectively, efficiently and consistently use statutory powers under the Biosecurity Act 2015 to manage biosecurity risks associated with biofouling. Policy options will seek to ensure all vessels arriving in Australian territory adopt biofouling management practices that address the biosecurity risks associated with biofouling. The department is working with stakeholders to progress towards a nationally and internationally consistent regulatory approach to biofouling management and to minimise regulatory burden associated with Australia's biofouling management requirements.

Australian Government
Department of Agriculture

Australia's biofouling management requirements: minimising risk and regulatory burden

Session 3:

Biofouling regulations and requirements

Peter Wilkinson LLB, BSc
Marine and Aquatic Biosecurity

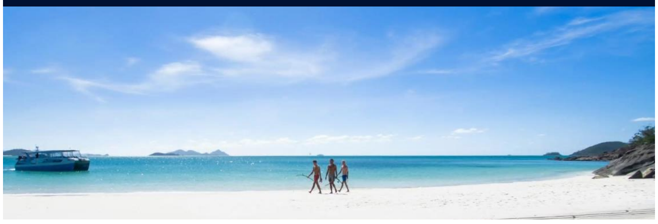
1 October 2019

Presentation overview

Current management of biosecurity risk associated with biofouling

Proposed changes to regulation

International consistency and minimising regulatory burden



Australia's biofouling requirements

- International vessel arrivals
- International vessels with interstate movements
- Not domestic vessels

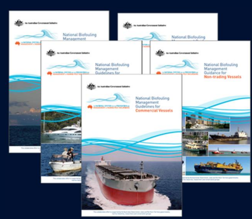
Current policy

Biosecurity Act 2015

- Extensive powers to manage biosecurity risk

Encourage voluntary uptake of national biofouling management guidelines

- (Aquaculture, non-trading, commercial, recreational, commercial fishing, petroleum industry)



Consultation on policy change

- Review of National Marine Pest Biosecurity - 2015
  - Focus on prevention
  - Mandatory biofouling management requirements
  - Move away from species-based
- Consultation Regulation Impact Statement - April 2019
  - 82% identified need for greater clarity
  - 78% indicated preference for policy focussed on biofouling management practices

Preferred policy - objectives

Primary objective – effectively manage biosecurity risk by minimising amount of biofouling on vessels arriving in Australia

Preferred policy – Proactive biofouling management practices

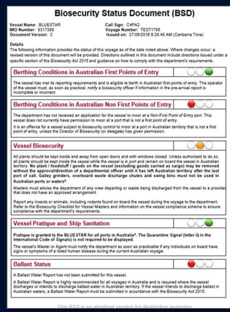
Proactive biofouling management practices policy:

- Mandatory pre-arrival reporting
- Vessels assigned intervention status (likelihood of being inspected)
- Implement biofouling management plan and record book to be LOW-intervention status

Preferred policy: Pre-arrival reporting and Status

Pre-arrival reporting:

- Biofouling management
- Biosecurity risk questions


Biosecurity Status Document (BSD)

Vessel Name: BLUESTAR Call Sign: C4PA2
IMO Number: 9317389 Voyage Number: TEST1795
Document Version: 2 Issued on: 27/06/2016 9:28:48 AM (Canberra Time)

Details
The following information provides the status of this voyage as of the date noted above. Where changes occur, a revised version of this document will be provided. Directions outlined in this document include directions issued under a specific section of the *Biosecurity Act 2015* and guidance on how to comply with the department's requirements.

Berthing Conditions in Australian First Points of Entry
The vessel has met its reporting requirements and is eligible to berth in Australian first points of entry. The operator of the vessel must, as soon as practical, notify a biosecurity officer if information in the pre-arrival report is incomplete or incorrect.

Berthing Conditions in Australian Non First Points of Entry
The department has not received an application for the vessel to moor at a Non-First Point of Entry port. This vessel does not currently have permission to moor at a port that is not a first point of entry.
It is an offence for a vessel subject to biosecurity control to moor at a port in Australian territory that is not a first point of entry, unless the Director of Biosecurity (or delegate) has given permission.

Vessel Biosecurity
All plants should be kept inside and away from open doors and with windows closed. Unless authorised to do so, all plants should be kept inside the vessel while the vessel is in port and remain on board the vessel in Australian territory. **No plant / foodstuff / goods on the vessel (excluding goods carried as cargo) may be removed without the approval/direction of a departmental officer until it has left Australian territory after the last port of call. Galley grinders, overboard waste discharge chutes and swing bins must not be used in Australian ports or waters.**
Masters must advise the department of any crew departing or waste being discharged from the vessel to a provider that does not have an approved arrangement.
Report any insects or animals, including rodents found on board the vessel during the voyage to the department. Refer to the Biosecurity Checklist for Vessel Masters and information on the vessel compliance scheme to ensure compliance with the department's requirements.

Vessel Pratique and Ship Sanitation
Pratique is granted to the BLUESTAR for all ports in Australia. The Quarantine Signal (letter Q in the International Code of Signals) is not required to be displayed.
The vessel's Master or Agent must notify the department as soon as practicable if any individuals on board have signs or symptoms of a listed human disease during the current Australian voyage.

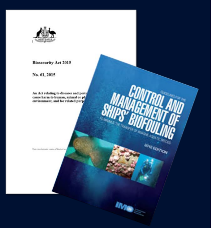
Ballast Status
A Ballast Water Report has not been submitted for this vessel.
A Ballast Water Report is highly recommended for all voyages in Australia and is required where the vessel discharges or intends to discharge ballast water in Australian territory. If the vessel intends to discharge ballast in Australian waters, a Ballast Water Report must be submitted in accordance with the Biosecurity Act 2015.

This BSD is an abridged version for illustration purposes

Preferred policy: Biofouling management plan

Biofouling management plan and record book:

- Consistent with IMO biofouling management guidelines
- Vessel specific and effective
- Represent best practice



Proposed policy: Inspection

Initial Inspection
(verification of pre-arrival report)

↓

Detailed inspection
(looking for additional evidence or documentation that biofouling has been managed)

↓

Where necessary – in-water inspection
(level of fouling)

Preferred policy: Other interventions

Actions to manage risk – administrative and statutory consider range of factors, e.g.:

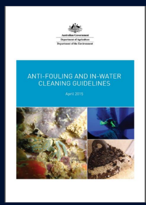
Biofouling management practices + Compliance history + Activity + Length of stay + Level of fouling

Minimise regulatory burden:

99 %

In-water cleaning

Sonia Gorgula
Session 11, Thursday afternoon



Be proactive

implement an effective Biofouling Management Plan

and Biofouling Record Book

EUGENE GEORGIADES
Principal Adviser, Biosecurity Risk Analysis
Ministry for Primary Industries, New Zealand

Eugene Georgiades completed his PhD in marine ecotoxicology in 2004 at RMIT University in Melbourne, Australia. After a post-doc in Canada, he joined the New Zealand Environmental Protection Authority hazardous substances team to conduct environmental risk assessments on pesticides, veterinary medicines and anti- fouling biocides.

Eugene moved to the Ministry for Primary Industries, Risk Analysis Team in 2009 to work on marine biosecurity. In particular Eugene delivers the scientific advice underpinning the development and implementation of the world's first standard for vessel biofouling. Because of his background in both marine biosecurity and ecotoxicology, Eugene has led MPI's investigation of the efficacy and risks of tools for vessel biofouling prevention and its reactive management, particularly in-water cleaning.

Evidence-based decision making to underpin New Zealand's CRMS for vessel biofouling

Over the past two decades the Ministry for Primary Industries' (MPI) has been proactive in commissioning research and providing science and technical advice to investigate the risks associated with vessel biofouling, identify potential risk vessels and inform options to manage those risks. In 2010, MPI consulted on options to manage the biofouling risks on all vessels entering New Zealand waters, with mandatory requirements being the preferred option. In 2014, New Zealand became the first country to introduce mandatory biofouling requirements, albeit with a four-year lead-in period to enable communication of the requirements to facilitate stakeholder readiness and uptake. In parallel, MPI has commissioned further research to investigate proactive and reactive approaches to biofouling management and provided technical advice to inform stakeholders of what constitutes best management practice to meet these regulatory requirements. This presentation summarises MPI's commissioned research and science and technical advice to investigate the risk associated with vessel biofouling and its management, and the procedures followed to produce New Zealand's biofouling regulations.

Image: MPI

New Zealand's resources may be at risk

- Non-indigenous species associated with biofouling pathway
  - New Zealand: 69-87% (Cranfield et al. 1998; Kospartov et al. 2008)
  - Coastal North America: 70% (Fofonoff et al. 2003)
  - Japan: 42% (Otani 2006)
  - Hawai'i: 74% (Eldredge and Carlton 2002)
  - Port Phillip Bay: 78% (Hewitt et al. 2004)

Should we care? What do we value?

- **Environmental**
  - Isolation from other landmasses ~ 83 million years
  - Marine biodiversity "hotspot"
  - 80% native biodiversity
  - > 50% of marine species are endemic
- **Economic**
  - Fisheries and aquaculture exports $1.8 billion (2018)
- **Social/Recreational**
  - Majority NZ live < 5 km from the sea
- **Cultural**
  - Treasure
  - Integral to culture, identity, spirituality and mythology
  - Food, hospitality, prestige

New Zealand government commissioned research

- > 3000 vessels annually
  - Merchant (70%), Recreational (20%),
  - Fishing (3%), Passenger (3%), other (3%)
- Biofouling risk of each vessel type **unknown**
- Vessel biofouling research programme (2004 – 2007; 2009)
- Objectives
  - Identity, origin and extent of biofouling
  - Relationship between presence of non-indigenous species (NIS) and biofouling extent
  - Factors that influence the presence of NIS and biofouling extent

New Zealand government commissioned research

- Vessels sampled (*n* = 528)
  - Merchant (270)
  - Passenger (50)
  - Recreational (182)
  - Fishing (11)
  - Barges and slow movers (15)
- > 70% of sampled vessels were fouled
- NIS ~60% of vessels
- NIS not established in New Zealand on > 30% of vessels

Inglis et al. 2010


Image: NZ Diving and Salvage Ltd

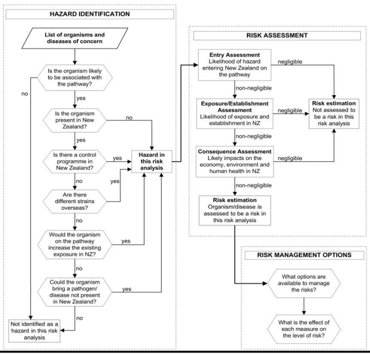
New Zealand government commissioned research

- All major vessel types likely to be fouled
- Common fouling species
  - Barnacles, bryozoans, tubeworms, macroalgae, bivalves
- Niche areas – abundant and diverse fouling
- ↑↑↑ biofouling = ↑↑↑ likelihood of NIS
- Key indicators of NIS presence
  - > dry dock interval
  - > number of days in port

Inglis et al. 2010

Risk Analysis

- Informed by:
  - New Zealand Government commissioned research
  - International findings
- The Risk Analysis process
  - Hazard identification
  - Risk assessment
  - Risk management options



MPI (2006). Risk Analysis Procedures

Risk Analysis

- Hazard Identification
  - > 2000 species vessel hulls
  - 20 broad taxonomic groups (traits)
- Criteria
  - Known
    - Components marine biofouling assemblages
    - Introductions to new locations
    - Impacts to core values
- Risk = Likelihood x Consequence
- Risk estimation
  - Likelihood of entry
  - Likelihood of establishment
  - Consequence assessment
- Risk management options

Risk Analysis

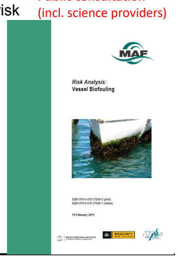
- > 2000 species associated with vessel biofouling
- 12 of 20 groups identified as posing a non-negligible risk to New Zealand values
- Potential to modify ecosystem structure and function, or have economic impacts
  - Ecosystem change (e.g. bivalves, crustaceans, bryozoans, macroalgae, bristleworms)
  - Predation (e.g. mobile predators - crustaceans, gastropods, seastars)
  - Smothering/competition (e.g. sea squirts, bryozoans, bristleworms, macroalgae, bivalves)

Risk taxa		
Amphipods and Isopods	Bryozoans	Gastropods
Barnacles	Crabs	Hydroids
Bivalves	Echinoderms	Macroalgae
Bristleworms	Flatworms	Sea squirts

Risk Analysis - Conclusions

- Recommendations
  - Presence of biofouling (> slime layer) indicative of biosecurity risk
  - Consistent with antifouling system technology
- Based on
  - > 2000 species associated with vessel hulls
  - Difficulties with *in situ* identification
    - Resources and expertise - ports of origin and arriving vessels
  - Clearance of vessels at the border (rapid)
  - ↑↑↑ biofouling = ↑↑↑ likelihood of NIS
  - Not all NIS have measureable impacts
  - Difficult to predict the identity of future NIS and their impacts
  - Disease? Climate change?

Peer reviewed by recognised experts
Public consultation (incl. science providers)



Draft standard

- **Options for managing the biosecurity risk**
  - Await international solution
  - Voluntary measures for arriving vessels
  - Mandatory requirements for arriving vessels
- **Mandatory requirements**
  - Highest net benefit to New Zealand
  - Rapid change
- **Arrival into New Zealand with a "clean" hull**
  - Clean = slime layer
  - Compliance achieved by following best practice (i.e. IMO Guidelines)

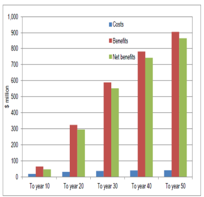
Consultation
6 May to 16 June 2010
Stakeholder meetings
Auckland, Wellington, Whangarei

Consultation

- **Review of submissions**
  - 29 submissions received
  - 25 acknowledged MPI rationale for preventive approach
  - 20 did not oppose mandatory requirement
  - 8 opposed mandatory requirements
  - 6 submitters requested cost-benefit analysis
  - Is the slime layer standard achievable?

Cost Benefit Analysis

- Benefits of mandatory action outweigh costs within 10 years
- Net benefit (50 years): $520 – 865 m
- Beneficiaries
  - Aquaculture (90% of benefits)
  - Recreational fishing (3%)
  - Recreational use of beaches (2.7%)
- Cost
  - Non-compliant vessels (77 – 83%)
    - Freight vessels (95% of above cost)



Branson 2012

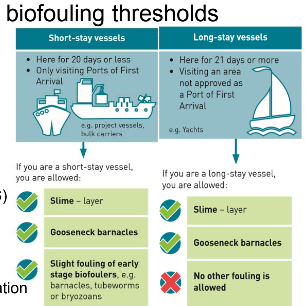
Evidence-based decision making – biofouling thresholds

- **When does macrofouling become a biosecurity risk?**
  - Slime layer manages the biosecurity risks identified in the Risk Analysis
  - Presence of macrofouling on newly antifouled and well maintained vessels
  - Niche areas (not antifouled or protected from drag)
- **Can we manage biosecurity risk without penalising vessels using best practice?**
- **Considerations**
  - Macrofouling type
  - Ability of the allowed macrofouling to establish (abundance, maturity)
  - Vessel surfaces (wind/water-line, hull and niche areas)
  - Vessel itinerary

Evidence-based decision making – biofouling thresholds

Rationale

- Limit opportunities for successful reproduction
  - NIS too few or too far apart
  - Different areas, different fouling pressure
- Limit fouling maturity
  - ↓↓↓ species richness (presence of other NIS)
  - ↓↓↓ spawning, drop-off or escape
- Vessel itinerary
  - ↑↑↑ stay – ↑↑↑ spawning, drop-off or escape
  - Species likely encountered – 4 week maturation
  - 4 weeks inclusive of travelling time



Conclusions

- NIS arriving via vessel biofouling pose a non-negligible risk to NZ values
- All major vessel types likely to be fouled (unless proactive management undertaken)
- ↑↑↑ fouling = ↑↑↑ probability of NIS presence
- Niche areas prone to fouling ~ ↑↑↑ biosecurity risk relative to hull
- Fouling level approach
  - Protects from known and unknown NIS
  - Less resource and expertise intensive (↑↑↑ practically and feasibility)
  - Aligned with ↑↑↑ fuel efficiency, ↓↓↓ emissions, ↓↓↓ asset depreciation, ↑↑↑ safety
- Decision making – transparent, evidence-based and peer reviewed

Acknowledgements

- **Service providers**
  - ES Link Services Pty Ltd
  - NIWA Ltd
  - Cawthron Institute
  - Biofouling Solutions Pty Ltd
  - Golders Associates
  - New Zealand Diving and Salvage Ltd
- **In kind support**
  - Dept. of Fisheries Western Australia
  - Australian Dept. of Agriculture
  - California State Lands Commission
  - Hawaii Dept. Land and Natural Resources
- **MPI**
  - MPI Operational Research Team, Border and Biosecurity Systems, Facilities and Pathways, Surveillance and Incursion Investigation, Response, Long-term Incursion Management, *et al.*

TRACEY BATES
Senior Adviser
Ministry for Primary Industries, New Zealand

Tracey is a Senior Adviser at the Ministry for Primary Industries (MPI) in New Zealand. She works in the area of MPI responsible for setting biosecurity requirements for imports, and ensuring these requirements are technically justified and adhered to by New Zealand's trading partners. Over the last two years Tracey's main role has been to implement the Craft Risk Management Standard for Biofouling. This has involved managing various work streams across the Craft Risk Management Standard for Biofouling at New Zealand's border. Tracey is also the portfolio lead for New Zealand's regulation for topside vessel risks, and the development of supporting standards such as in-water treatments and approval of hull survey providers. Tracey has a Master of Science from Victoria University of Wellington on marine sponges and is a keen diver.

What's going on down under: verification and enforcement of New Zealand's biofouling requirements

Vessel biofouling is one of the largest biosecurity risks to New Zealand's marine environments. On 15 May 2018, New Zealand became the first country in the world to begin enforcing national regulations to manage the biosecurity risks associated with vessel biofouling. The Craft Risk Management Standard for Biofouling (CRMS- BIOFOUL) requires vessels to provide evidence of biofouling management to the Ministry for Primary Industries (MPI) prior to arrival in New Zealand. The success of the CRMS-BIOFOUL depends on MPI's ability to identify vessels that pose potential biofouling risks. As biofouling cannot be adequately assessed during routine on board vessel inspections, MPI has developed a set of process to allocate resource, audit and enforce the CRMS on those vessels that cannot provide proof of biofouling management prior to arrival. This presentation summarises MPI's risk profiling and enforcement processes at the border, current approaches to tackling non-compliance, and directions moving forward.

The CRMS for Biofouling

To reduce risk of biofouling by requiring operators to take preventative measures to manage biofouling before arrival into NZ.

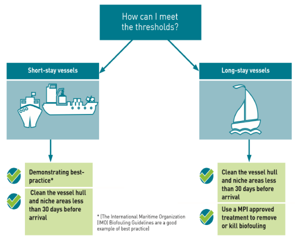
Vessels must carry **documentation** showing that one of the three measures in the standard has been conducted:

a) The vessel has been continually maintained following best practices*, **or**

b) The vessel has been cleaned <30 days prior to arrival, **or**

c) The vessel is booked to be hauled out within 24 hours of arrival at an MPI-approved facility

*following the IMO Biofouling guidelines is recognised as an example of best practice



Risk Profiling and Verification

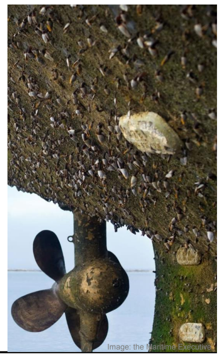
Vessel submits pre-arrival documents

Assessed as having Low, Medium, or High risk indicators

A percentage of vessels from each risk category selected for audit of documentation (100% high risk)

Vessel passes audit- meets requirements

Vessel fails audit- referred to border staff for verification (i.e. hull inspection) and/or action



MPI's compliance approach

Action taken based on level of fouling (biosecurity risk):

- Issuing educational material
- Hull inspection
- Itinerary restriction
- Direction to leave NZT

VADE Model
Voluntary Assisted Directed Enforced

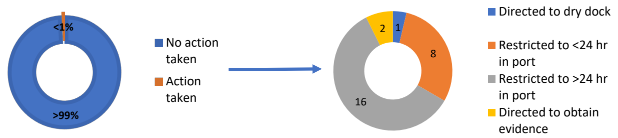
Internal processes to action based on:

- Based on level of fouling
- Itinerary
- Class of vessel (commercial, passenger, recreational)

	Vessel type	LOF 0& 1	LOF 2*	LOF 3*	LOF 4*
Long-stay	Recreational	Compliant	Non-compliant Compliance option X, Y, Z	Non-compliant Compliance option X, Y, Z	Non-compliant Compliance option X, Y, Z
	Passenger	Compliant	Non-compliant Compliance option X, Y, Z	Non-compliant Compliance option X, Y, Z	Non-compliant Compliance option X, Y, Z
	Commercial	Compliant	Non-compliant Compliance option X, Y, Z	Non-compliant Compliance option X, Y, Z	Non-compliant Compliance option X, Y, Z
Short-stay	Recreational	Compliant	Compliant	Non-compliant Compliance option X, Y, Z	Non-compliant Compliance option X, Y, Z
	Passenger	Compliant	Compliant	Non-compliant Compliance option X, Y, Z	Non-compliant Compliance option X, Y, Z
	Commercial	Compliant	Compliant	Non-compliant Compliance option X, Y, Z	Non-compliant Compliance option X, Y, Z

Fifteen months in: action taken

- Compliance has been high
  - 27 Notices of Direction issued out of 3386 arrivals since CRMS went live
  - 2 Notices of Direction out of 704 recreational vessel arrivals



Impact on Industry & trade

- No documented effect on NZ trade
- Continual maintenance measure
  - Designed to allow compliance by following IMO guidelines
- Potential increase in inspection/cleaning frequency
- Some operators positioning newer vessels on NZ routes

Image: Dive Co.

Communication is key

Need to ensure stakeholders understand rules

- Guidance
- Media Releases
- Social Media
- Posters, handouts
- Stakeholder communications
  - Agents
  - Importers/Exporters
  - Vessel owners
  - Recreational boaties

Taking action on non-compliant vessels

The thresholds in an operational context

- Standard has a biological "thresholds" to be met→ to limit likelihood of NIS introductions
- MPI wants industry to focus on complying by continually managing biofouling
- Used in situations where a vessel cannot provide evidence of compliance

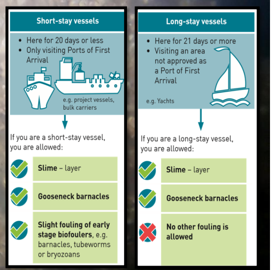


Image: Dive Co.

The thresholds in an operational context

- Do not need to ID specimens → faster decision making at the border
- Robust if challenged
- Account for unknowns

Image: Dive Co.

Devonport Dry Dock

CHRIS SCIANNI
Senior environmental scientist, Marine Invasive Species Program (MISP)
California State Land Commission, USA

Chris Scianni is a Senior Environmental Scientist with the California State Lands Commission's Marine Invasive Species Program (MISP). During his 12 years with the MISP, Chris' work has focused on biofouling management policy and research. He led the development of California's biofouling management regulations and continues to work with MISP scientists and inspection teams to implement and enforce these regulations. Chris is also a scientific diver trained and certified by the American Association of Underwater Scientists and is one of a small group of scientific divers in North America with experience diving and collecting biological samples from commercial ships. Chris received a Bachelor of Science degree in Marine Biology from California State University, Long Beach and a Master of Science degree in Marine Science with an emphasis in Biological Oceanography from Moss Landing Marine Laboratories through California State University, Stanislaus.

Lessons learned through implementing and enforcing California's biofouling management regulations

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

Lessons Learned:
Implementing and Enforcing California's Biofouling Management Regulations

4th ANZPAC Workshop on Biofouling Management for Sustainable Shipping
Melbourne, Victoria, AUS | 1 October 2019

Chris Scianni
CALIFORNIA STATE LANDS COMMISSION
MARINE INVASIVE SPECIES PROGRAM

California's Biofouling Management Regulations

Approved
20 April 2017

Effective
1 October 2017

Implementation

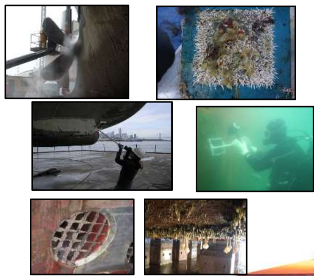
1 October 2017: Annual Vessel Reporting Form

1 January 2018: Remainder of the regulations became effective

- Phased-in implementation based on:
  - Regularly scheduled dry docking (or delivery) on or after 1 January 2018
- Why phased-in?
  - Effective biofouling management is dependent on Biofouling Management Plans and preventive practices best implemented in dry dock

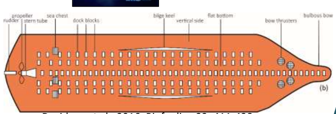
Regulation Development Process

- Legislative mandate in 2007
- Developed in consultation with stakeholders through a technical advisory group since 2010
- Informed by 8+ years of vessel-reported data on biofouling management and operational practices
- Informed by 10+ years of funded biofouling research
- Public process: three rulemaking actions



Original Overarching Goals

- Consistency with IMO Guidelines
- Niche areas – Forethought and management
- Extended residency periods



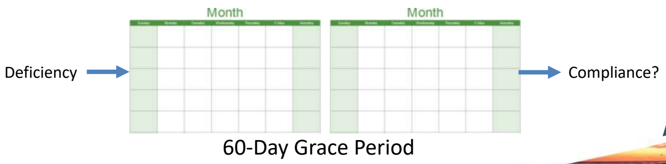
Davidson et al., 2016. Biofouling 32: 411-428

Regulatory Components

- Biofouling Management Plan and Biofouling Record Book
  - Consistent with IMO BFMP
  - Vessel-specific
  - Current as of most recent out-of-water maintenance (or delivery)
  - Expected effective coating lifespan
  - Niche area management practices (8 specific niches)

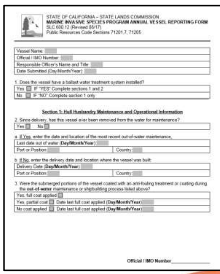
Regulatory Components

- Biofouling Management Plan and Biofouling Record Book



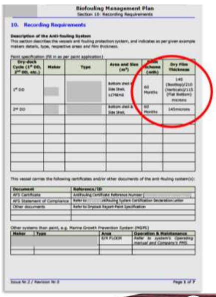
Regulatory Components

- Annual Vessel Reporting Form
  - 24 hours in advance of the first California port arrival of a calendar year
  - Builds off 10-year dataset
  - Prearrival weighted risk assessment to prioritize inspections



Regulatory Components

- Biofouling management
  - Best Practices:
    - Ensure AF/FR within effective coating lifespan
    - Document biofouling management actions if outside of effective coating lifespan (follow up in Biofouling Record Book)
  - Specify biofouling management actions for 8 specific niche areas (follow up in Biofouling Record Book)



Regulatory Components

- Extended Residency Periods
  - 45+ days in the same location
  - Manage biofouling consistent with Biofouling Management Plan
  - Follow up in the Biofouling Record Book

Regulatory Components

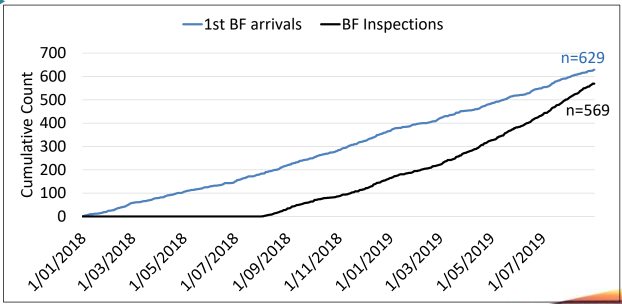
- Alternatives and Emergency Exemptions
  - Alternatives
    - Blueprint for how to petition for alternative approaches to achieve the goals of the regulations
  - Emergency Exemptions
    - Specific criteria for exemptions under emergency situations

How are California Biofouling Regulations Being Implemented Across the Fleet?

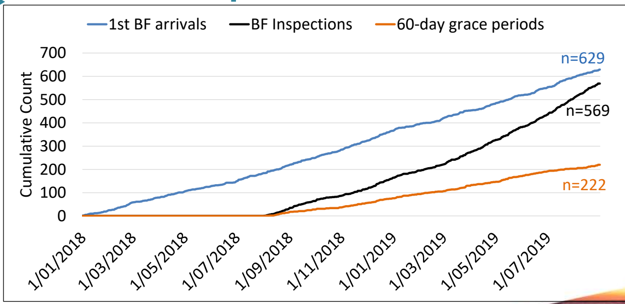
Inspections

- What are we seeing?
- How often are we issuing 60-day grace periods?
- How steep is the learning curve?

Implementation



Implementation



Implementation

Up-To-Date Numbers (Through 31 August 2019):
- 222 Grace Periods granted
- 71 Re-inspected after 60-day Grace Period expired
- 3 violation after re-inspection

Outreach: What Have We Already Done?

- Guidance Document (Sept 2017): http://www.slc.ca.gov/Programs/MISP/4_8_GuidanceDoc.pdf
  - Summary, FAQ, Example Biofouling Management Plan
- Webinar (Sept 2017): https://www.youtube.com/watch?v=4r6Bi3Bfolc&feature=youtu.be
- Customer Service Meetings (Sept 2017):
  - Southern and Northern CA
  - Shipping agents

Outreach: What Have We Already Done?

- Information sheets
  - Vessel crews
  - Management requirements: http://www.slc.ca.gov/Programs/MISP/InfoShts/BiofoulingBallastWater_Management.pdf
  - Reporting and Recordkeeping: http://www.slc.ca.gov/Programs/MISP/InfoShts/Reporting_RecordKeeping.pdf

Outreach: How to Address Gaps?

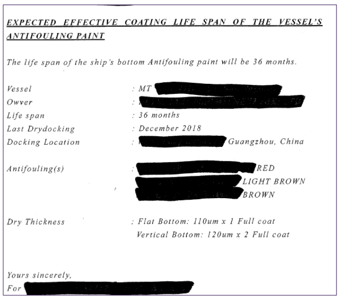
What were we missing?
- Outreach to Vessel ownership/management
- Crews aren't the ones developing Biofouling Management Plans

https://www.youtube.com/watch?v=CpRjRNED8yM&t=7s

Next Steps

- Continue Outreach
- Implement weighted risk assessment for inspection prioritization
- Implement more detailed inspection process
- Data comparison with New Zealand MPI

Lessons Learned



EXPECTED EFFECTIVE COATING LIFE SPAN OF THE VESSEL'S ANTIFOULING PAINT

The life span of the ship's bottom Antifouling paint will be 36 months.

Vessel	: MT [redacted]
Owner	: [redacted]
Life span	: 36 months
Last Drydocking	: December 2018
Docking Location	: [redacted] Guangzhou, China
Antifouling(s)	: [redacted] RED LIGHT BROWN BROWN
Dry Thickness	: Flat Bottom: 110um x 1 Full coat Vertical Bottom: 120um x 2 Full coat

Yours sincerely,
For [redacted]

- All vessels have BFMP/BFRB
- Better documentation

Lessons Learned

Different paradigm than ballast water

- Ballast Water
  - Crew is responsible for BW Management actions
- Biofouling
  - Ownership/management is responsible for developing BF Management Plan

www.slc.ca.gov

THANK YOU & QUESTIONS

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Biologist, Office of Wetlands, Oceans and Watersheds
US Environmental Protection Agency, USA

Juliette Chausson is a biologist in the Office of Wetlands, Oceans, and Watersheds at the U.S. Environmental Protection Agency in Washington, D.C. Juliette started at EPA in the Ocean Dumping Management Program, supporting disposal site monitoring research and policy development. In her current role, Juliette is developing national standards of performance for biofouling management under the newly-enacted Vessel Incidental Discharge Act (VIDA). Juliette received her Bachelors degree from McGill University and her Masters in Marine Biology from James Cook University.

Biofouling Management of Commercial Vessels in the United States: from VGP to VIDA

On December 4, 2018, the President of the United States signed into law the Vessel Incidental Discharge Act (VIDA). VIDA restructures the way U.S. Environmental Protection agency (USEPA) and the U.S. Coast Guard (USCG) regulate incidental discharges from commercial vessels into waters of the United States and the contiguous zone. VIDA requires the USEPA to develop new national standards of performance for commercial vessel discharges by December 2020 and the USCG to develop corresponding implementing regulations two years thereafter. This talk will provide an overview of the shift in regulatory framework from the previous Vessel General Permit (VGP) to VIDA, and the implications of this regulatory shift for biofouling management of commercial vessels in the United States.

Federal Biofouling Management of Commercial Vessels in the U.S.A

From VGP to VIDA

Juliette Chausson
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2019

Disclaimer

The following EPA presentation is intended to provide information to the public on the recently enacted Vessel Incidental Discharge Act (VIDA) and currently in-force statutes, permits and regulations. Neither the slide presentation nor remarks of the presenter represent final agency decisions regarding implementation of VIDA.

Overview

- Regulatory History
- VGP: Biofouling Management Highlights
- VIDA: Overview
- VGP to VIDA

History: U.S. Vessel Discharge Regulations

- Numerous federal, state, and local requirements regulate discharges from vessels.
- EPA regulation of **incidental discharges** from **commercial vessels:**
  - ~ 30 incidental discharges
  - **Vessel General Permit** (vessels > 79 ft) – issued 2008, 2013
  - **small Vessel General Permit** (vessels < 79 ft) – issued 2014

VGP: Incidental Discharges

- Anti-Fouling Hull Coatings and Leachate
- Aqueous Film Forming Foam
- Ballast Water
- Bilgewater/Oily Water Separator Effluent
- Boat Engine Wet Exhaust
- Boiler/Economizer Blowdown
- Cathodic Protection
- Chain Locker Effluent
- Deck Washdown and Runoff
- Distillation and Reverse Osmosis Brine
- Elevator Pit Effluent
- Exhaust Gas Cleaning System Washwater
- Firemain Systems
- Fish Hold Effluent
- Freshwater Layup
- Gas Turbine Washwater
- Graywater
- Hull Fouling and Cleaning
- Inert Gas Scrubber Washwater
- Motor Gasoline Compensating Discharge
- Non-Oily Machinery Wastewater
- Oil-to-Sea Interfaces
- Pool or Spa Water
- Refrigeration and A/C Condensate
- Seawater Cooling Overboard Discharge
- Seawater Piping Biofouling Prevention
- Sonar Dome Discharge
- Well Deck Discharges

VGP: Biofouling Management Highlights

VGP Biofouling Management: General

- *"Vessel owners/operators must minimize the transport of attached living organisms when traveling into U.S. waters from outside the U.S. economic zone or between Captain of the Port (COTP) zones."*
- Requires best practices to prevent and remove biofouling on the hull, in seawater piping, on anchor chains, etc.
- Requires selection, use, and maintenance of antifouling systems, including antifouling coatings, biocides for seawater piping, etc.

VGP Biofouling Management: Coatings

- Consider use of hull coatings with the lowest effective biocide release rates, rapidly biodegradable components, or non-biocidal alternatives
- Consider alternatives to copper-based antifoulant paints when spending 30+ days/ year in copper-impaired waters
- Prohibit discharge of tributyltin (TBT) from any source or any other organotin compound used as a biocide

VGP Biofouling Management: Cleaning

- Use cleaning tool with appropriate rigidity
- Use vacuum or other control technologies when available and feasible
- Minimize release of copper-based antifouling paints
- Prohibit cleaning of surfaces coated with copper-based antifouling paints in copper-impaired waters within the first year
- Conduct rigorous cleaning in drydock or at a land-based facility when possible

VGP Biofouling Management: Inspections

- Comprehensive annual inspections of the vessel hull, including niche areas, for:
  - fouling organisms;
  - flaking anti-foulant paint; and
  - exposed TBT or other organotin surfaces.
- Dry-dock inspection reports, including:
  - proper cleaning of chain locker;
  - inspection and cleaning vessel hull and niche areas; and
  - proper application, maintenance, and/or removal of antifouling coatings.

Vessel Incidental Discharge Act (VIDA): Overview

What is VIDA?

- The **Vessel Incidental Discharge Act (VIDA) of 2018** changes the U.S. framework for regulating incidental discharges from commercial vessels.
- Intended to streamline the patchwork of federal, state, and local requirements for the commercial vessel community.

VIDA: Future Regulations

1) The EPA to develop national standards of performance (by December 2020); and
2) The USCG to develop corresponding implementing, monitoring, and enforcement regulations (two years thereafter).

VIDA: Future EPA Regulations

- Generally at least as stringent as the existing 2013 VGP requirements
- Technology-based
- Numeric, best management practices, or a combination of both
- May distinguish between class, type, size, and age of vessels

VIDA: Future U.S. Coast Guard Regulations

- Generally, at least as stringent as the existing EPA VGP and USCG requirements
- Inspections, monitoring, reporting, sampling, recordkeeping
- Design, construction, testing, approval, installation, use of devices to achieve the EPA standards

VGP to VIDA

IMMEDIATE

- Maintains existing vessel discharge requirements for most large vessels
- Maintains **only** ballast water provisions for small commercial vessels and fishing vessels of all sizes

FUTURE

- Extends regulated area for future regulations (from 3nm → 12)
- Establishes programs, grants, and frameworks for invasive species monitoring and response

VGP to VIDA: State Authorities

VIDA requirements will generally preempt adoption or enforcement of more stringent federal, state, or local regulation of incidental discharges from vessels regulated under VIDA.

State Provisions:

- Enforcement authority (under CWA 309)
- Establishment of No-Discharge Zones
- Petition for more stringent requirements
- Emergency orders

VGP to VIDA: Biofouling Management

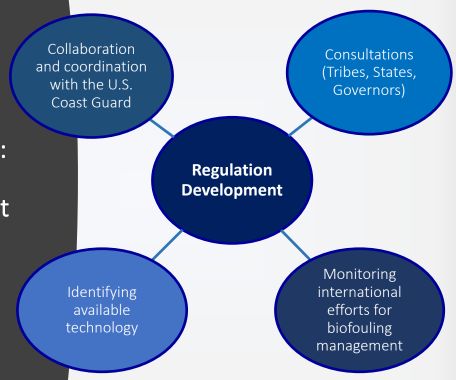
Environmental

- Aquatic nuisance species
- Biocides (metallic and non-metallic)

Regulatory

- At least as stringent as 2013 VGP requirements
- Technology-based

VGP to VIDA: Biofouling Management



Wendy Simmons
Policy Advisor
Transport Canada, Canada

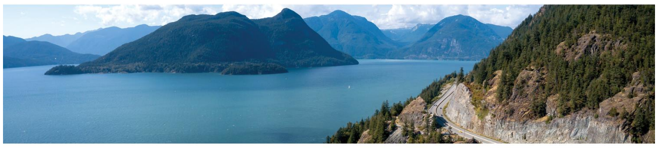
The state of biofouling management in Canada

Overview of Biofouling Management and Maintenance Practices and Technologies in Canadian Waters

4th ANZPAC Workshop on Biofouling Management for Sustainable Shipping

Melbourne, Australia

October 2019



Transport Canada Transports Canada

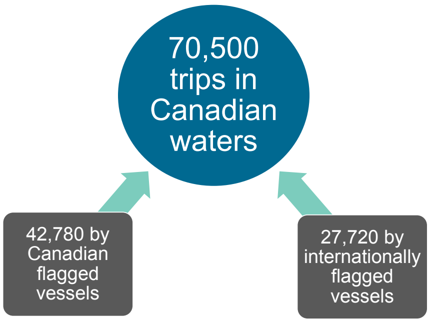
Canada

The Canadian Context

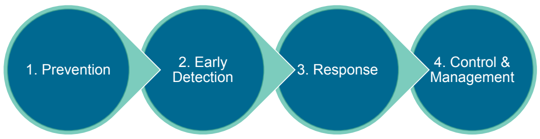
Canada has vast marine and freshwater resources, with the longest coastline in the world

- 557 port facilities, 882 fishing harbours and 126 recreational harbours all with different ownership and governance structure
- 3 Coasts
- Prior difficulties with AIS (like the Zebra Mussel)
- Commitment internationally and domestically to control and manage biosecurity risks of potential aquatic invasive species associated with Ballast Water

Vessel Traffic in Canadian Waters



Canada's 4 Action Pillars for AIS



Legislation in Canada Related to AIS

In Canada legislative jurisdiction is divided between the federal, provincial and territorial governments. There are:

- 34 pieces of Canadian legislation,
- covering 26 different facets of AIS,
- created by 6 Federal Departments as well as 10 provincial and 3 territorial governments.

Federal Legislation and Regulations

- Fisheries Act
- Canadian Environmental Protection Act
- Pest Control Products Act
- Aquatic Invasive Species Regulations
- Vessel Pollution and Dangerous Goods Regulations
- Ballast Water Control and Management Regulations

Transport Canada

Transport Canada recognizes practices to control and manage biofouling are key to:

- reducing the risk of transferring new aquatic invasive species,
- improving ship efficiency and performance, which over time can lead to decreases in a ships greenhouse gas (GHG) emissions, as well as other air emissions.

Transport Canada commissioned a study to provide an overview of biofouling management and maintenance practices and technologies in Canadian waters.

Green Marine Study

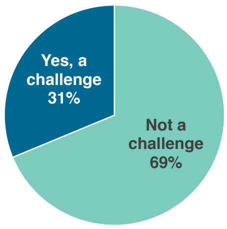
- Completed from May – October 2018
- Included a literature review
- Consists of 2 surveys: Shipowners & Ports
- Based on the IMO's Questionnaire for data collection (MEPC.1/Circ.811)
- Members of Green Marine were surveyed
- Provides a set of 10 recommendations

Shipowner Survey Results

- Responses from 17 Canadian shipowners
- Unknown number of vessels represented
- 70% average response rate per question

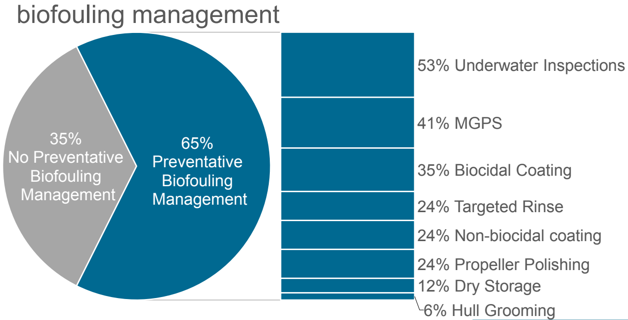
Biofouling Management Practices

Biofouling is not seen as an operational challenge



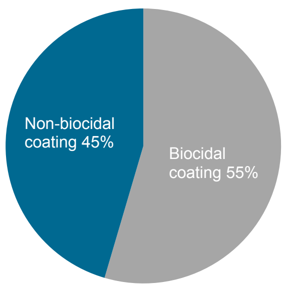
Biofouling Management Practices in Canada

Most respondents practice preventative biofouling management



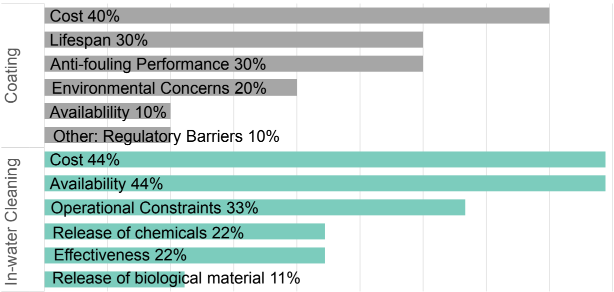
Biofouling Management Practices

Biocidal coating use varies by region



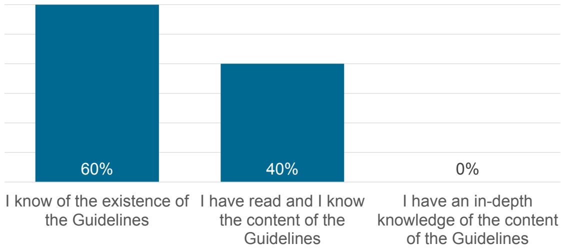
Biofouling Management Practices

Cost is the biggest challenge for both Coatings and In-water Cleaning



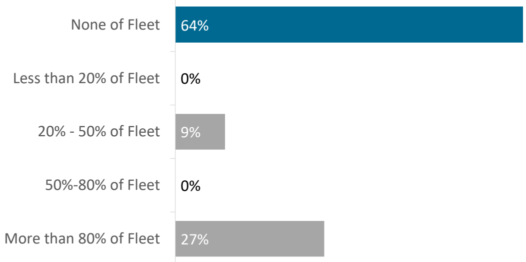
Awareness of IMO Biofouling Guidelines

Respondents generally have basic knowledge of the Guidelines



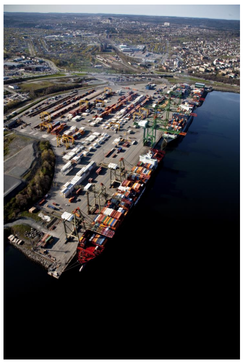
Biofouling Management Practices

Most respondents do not keep Guidelines-recommended plans and record books



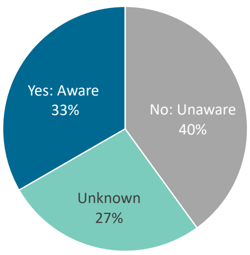
Port Survey Results

- 15 respondents
- Including 13 of 17 Canadian Port Authorities
- 93% average response rate per question



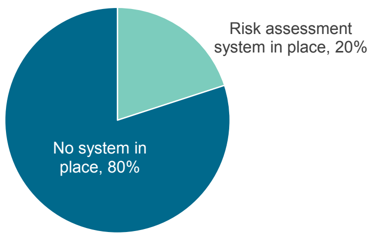
Port Survey Results

Low Awareness of IMO Guidelines



Port Survey Results

Most ports do not have a risk assessment system in place



Port Survey Results

- Practices amongst ports differ, even within the same geographical area.

Region	In-water cleaning NOT authorized	In-water cleaning authorized (restrictions may apply)
Canada East Coast	2	4
Great Lakes/St. Lawrence	5	0
Canada West Coast	2	2
Total	**60%**	**40%**

Port Survey Results

- Just over half of ports do not monitor **AIS** introductions but some participate in monitoring programs led by external entities, such as DFO.

Monitor or recording of invasive species	Yes	No
Canada East coast	1	5
Great Lakes/St. Lawrence	3	2
West Coast	3	1
Total	**47%**	**53%**

Port Survey Results

- Comparing ports that monitor invasive species and also allow in-water cleaning

	East Coast	Great Lakes/ St. Lawrence	West Coast
Monitors for AIS	1	3	3
Authorizes in-water cleaning	4	0	2

Conclusions

The Green Marine report summarizes 10 recommendations for consideration focusing on:

- Further exploring the impacts of specific risk factors as well as environmental and operational co-benefits of managing biofouling
- Technologies and best practices
- Communications/collaborations and working groups with industry
- Call on experience and expertise gained in countries more advanced on this issue, and develop guidance domestically.

Next Steps

Internationally

- Canada is an active participant in the review the IMO 2011 Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species.
- Canada is a strategic partner in the GloFouling project.

Domestically

- Mapping out science advisory needs with federal partners
- Explore the development of an action plan based upon the recommendations

Next Steps

Government of Canada will be issuing a Request for Information (RFI) to solicit details on technical availability for in-water vessel cleaning services in Canada and abroad.

Next steps

Posting on Government Electronic Tendering System (GETS).

Buy and Sell GETS:
https://buyandsell.gc.ca/procurement-data/tenders

Monitor for additional details on the Buy and Sell GETS (link listed above).

Thank you

Wendy Simmons
Senior Policy Advisor
Environmental Policy
Transport Canada
wendy.simmons@tc.gc.ca

TIM CARTER
Marine scientist
NOPSEMA, Australia

Tim Carter is a marine scientist with a Bachelor of Science (Marine Science) with First Class Honours. Tim has extensive experience in marine environmental management across offshore energy activities and coastal development projects in temperate and tropical waters of Australia. His career started in fish and fisheries research before moving into coastal planning and his first exposure to invasive marine species (IMS) management. The assessment and management of IMS risks continued to be a theme during Tim's time as a marine environmental consultant to the offshore petroleum and coastal development industries. In this role, Tim implemented and managed a large-scale marine environmental monitoring program, which included the design of invasive marine species detection programs for use in sensitive marine environments on the North West Shelf.

Tim currently holds the position of Environment Specialist at the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA). Since commencing in this position in 2012 Tim has completed technical assessments of environment plans and targeted environmental compliance inspections for offshore petroleum activities to ensure environmental impacts and risks are effectively managed. This assessment and inspection work has covered a broad range of topics and impact pathways, including the potential for invasive marine species introductions from vessels, rigs and facilities involved in offshore petroleum activities. In addition to this core regulatory work, Tim is also involved in promoting and advising on best practice invasive marine species management. This has included engagement with industry and State and Commonwealth marine biosecurity agencies to facilitate shared understanding of relevant legislative requirements and effective collaboration to enhance marine biosecurity management outcomes.

Regulation of biofouling risks in the offshore petroleum industry

The National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) is the Australian offshore energy regulator, with responsibilities for environmental and workforce protection, and facility integrity. The Environment Regulations that NOPSEMA administer require activity proponents to assess and manage invasive marine species (IMS) risks presented by vessels and facilities operating in this sector. The jurisdiction of NOPSEMA covers all petroleum activities in Australian Commonwealth waters seaward of State and Northern Territory coastal waters. Due to the extent of this area, NOPSEMA's jurisdiction overlaps numerous marine biosecurity jurisdictions and is very biodiverse. This complex jurisdiction, environmental and operational setting presents a number of challenges for effective marine biosecurity management.

Unlike other regulatory systems, NOPSEMAs regulations do not prescribe a 'one size fits all' approach to environmental management. Rather the regime provides flexibility for proponents of offshore petroleum activities to manage IMS risks based on particular activity circumstances. Proponents must demonstrate in an environment plan that the environmental management approach applies all practicable control measures and will be effective in reducing risks to acceptable levels.

An effective management approach requires proponents to have a clear and consistent understanding of different jurisdictional requirements, including the connections and where they exist, the gaps, among this suite of requirements. However, NOPSEMA has observed that this is not always the case and attempts are being made to demonstrate effective IMS management using legislative requirements that don't address all risk elements.

Challenges to effective IMS management, such as jurisdictional complexity, will be explored using specific case examples. Opportunities to address these challenges will be highlighted with a focus on identifying commonalities between different activity types and jurisdictions. This common ground provides an opportunity to cut through complexity, focus on areas of importance and facilitate more consistent and efficient demonstrations of effective IMS risk management.

Regulation of biofouling risks in the offshore petroleum industry

NOPSEMA
ANZPAC Biofouling Workshop – October 2019

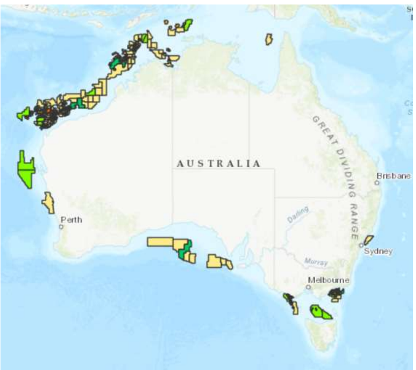
NOPSEMA

nopsema.gov.au

NOPSEMA

Outline

- NOPSEMAs regulatory approach
- Key challenges - IMS risk assessment and management
- Opportunities to streamline and improve IMS management



NOPSEMA – What, Who, Where

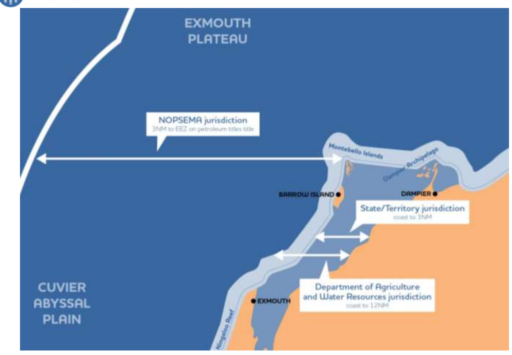
What: Administers Act and environment regulations, petroleum activities, ALL impacts and risks inc IMS

Who: Titleholders (not rig operators)

Where: only on title in Commonwealth waters

NOPSEMA

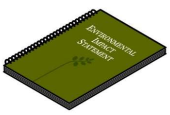
Jurisdictional boundaries



NOPSEMA

NOPSEMAs regulatory approach

Subject matter experts



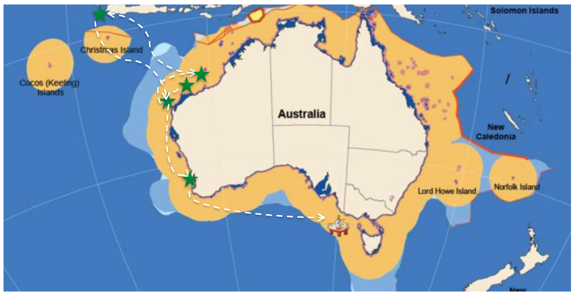
Activity proponents

NOPSEMA

Risk assessment stage	Biosecurity risk factor examples
• Understand environment • Understand activity	• Environment (source and receptor) • Facility / vessel history • Fouling surfaces (m^2) and levels • IMS present? • Anti-fouling systems?
• Determine likelihood • Predict potential consequence • Select management	• Likelihood of species of concern? • Likelihood of introduction and establishment • Environmental receptors potentially affected • Mitigation measures needed to reduce risk to an acceptable level
• Implement • Monitor • Review • Adapt	• Evidence of management success • Adaptive management evaluated • Records of compliance

Challenges – Activity Types

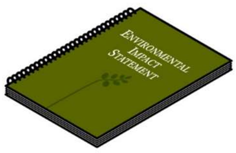
Challenges - Mobile facilities



Challenges – complex and changing requirements

- Understanding and addressing all legislative/policy requirements
- Requirements are evolving
- Misunderstanding is common

Challenges – Titleholder v Operator



Opportunities – Reduce complexity

"Any darn fool can make something complex; it takes a genius to make something simple."

- Simple, but important factors:
  - The environmental protection goal
  - The IMS risk factors

Opportunities - Common goal

- Environmental protection goal – no introduction and establishment of invasive marine species
  - IMO Guidelines
  - National Biofouling Management Guidelines
  - State/territory policies & guidelines
  - Environment Plans

NOPSEMA

Opportunities - Common IMS risk factors

- The risk of IMS introduction from the biofouling pathway is determined by common risk factors
  - Operating history
  - Treatment history
  - Status of hull/wetsides
  - Environmental characteristics

NOPSEMA

Opportunities - A simple, proactive approach

- Integrate biofouling management and record keeping into business as usual – a proactive approach will pay dividends.
- Benefits:
  - Readiness to engage in offshore petroleum activities
  - Readiness to comply with new requirements

Thank you

NOPSEMA

nopsema.gov.au

JOHANN VAN DER MERWE
Senior environmental advisor
Chevron Australia, Australia

Johann Is currently the Senior Environmental Advisor for Chevron and, as part of the senior leadership group from the 'early days' of planning the Gorgon Gas Project, he was responsible for the planning, the environmental approval of the Gorgon Quarantine Management System (QMS) and the implementation of the QMS – a system that is designed to protect the conservation values of Barrow Island, an Class A Nature Reserve since 1908. This management system is the largest non-government biosecurity program in the world.

Prior to Chevron, was the Parks Director for South African National Parks (SANParks), an organisation responsible for the management of all the national parks in South Africa. Oversaw the largest expansion in national parks since its formation in 1926 by establishing 5 new national parks and expanding 8 existing national parks. Has a track record as a highly successful strategist and with successful completion of numerous mega-projects in conservation and tourism developments in Southern Africa, Southeast Asia (and lately in Australia).

Has also managed some of the world's largest invasive species clearing and some of the world's most virulent veterinary diseases including anthrax, bovine tuberculosis, foot and mouth disease and feline AIDS. Developed several successful world-class models involving sustainability in protected areas, tourism development and community upliftment, and also made significant contributions to the conservation of rare and endangered species, notably, white rhino, roan, cape mountain zebra, tiger fish and the breeding of disease-free buffalo.

Currently also leads an initiative that seeks to balance the co-existence of business and biodiversity – Harry Butler Legacy Initiative. Also a member of the Harry Butler Science Institute. Currently serves as a member of the CSIRO Health and Biosecurity advisory committee. Was a member of the Western Australia Biosecurity Council. Deputy Chair of the financial consultancy, FinUCAre. Was a member of WWF Southern Africa Executive Committee, The Peace Park Foundation, the African Science Centre, ex-officio-member of the South African Nation Parks Board as well as the National Parks Trust. Also a board member of the Northern Province Parks and Tourism Board, acted as an advisor to a strategic development initiative (BPAMP) for the World Bank in Southeast Asia, etc.

Biofouling management: a shifting paradigm and the value of refocussing on critical safeguards in managing biofouling risk – an industry perspective

Shipping is the Achilles heel of any island nation. It is also the life blood of projects that unlock the economic potential of nations which improves the quality of life of many communities. Managing the diverse array of trading vessels, exploration vessels and construction fleets as potential pathways for the introduction of marine pests to national and state waters. The impact of such introductions are well published. What is not published is the impact that efforts to mitigate the likelihood of such introductions. The past decade witnessed many attempts to construct a shared marine pest list and yet no consensus on the way forward, nor any evidence that such a list would contribute to preventing the introduction of an invasive marine species. In this presentation an industry perspective on a novel yet proven alternative is presented, namely the focus on critical safeguards that addresses biofouling in general that achieves and acceptably low level of risk.

Agenda

Barrow Island

A special place home to the Gorgon natural gas facility

Barrow Island declared a Class A Nature Reserve in 1910
- Oilfield managed by Chevron since 1964
- Home to Australia's largest single resource project, Gorgon natural gas facility

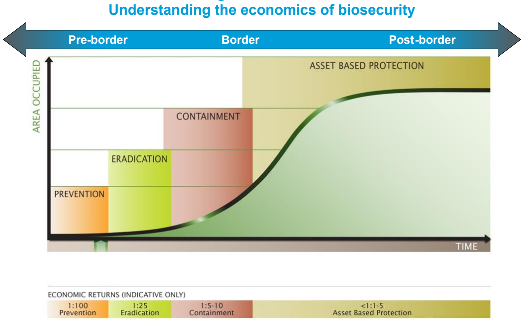
Relatively intact ecosystem
- Best 'island example' on the WA coast

No known loss of biodiversity

Suite of endemic and endangered species
- Many of which are now extinct on the mainland

Knowing where to invest

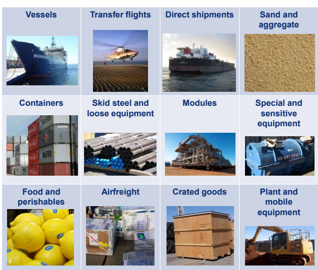
Understanding the economics of biosecurity



Understanding our risks

Risk pathways on Barrow Island

Chevron has identified 13 high risk pathways through which risk material could reach Barrow Island.



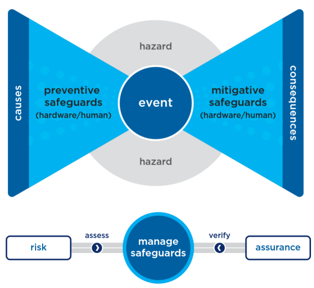
Understanding our risks

Assessment and assurance of safeguards

Safety is embedded in everything we do. **We do it safely or not at all**, and there is always time to **do it right**.

We focus on preventing high-consequence incidents and impacts by understanding and mitigating risks and maintaining and assuring safeguards.

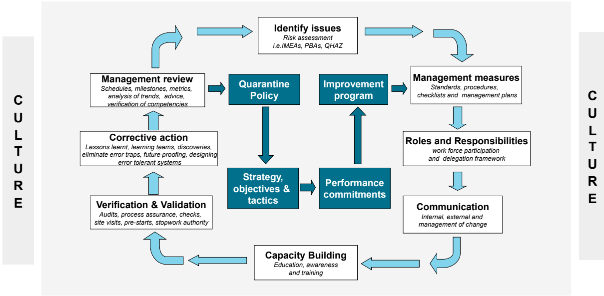
Chevron **recognises the importance of biodiversity conservation** globally and understands the long-term and high-consequence risks associated with biosecurity.



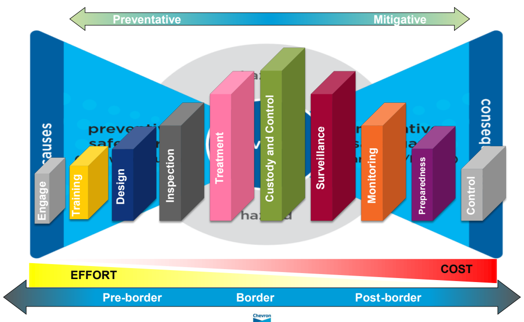
Understanding our risks
Definitions

Introduction	Survival	Detection	Eradication	Level
Infection is extremely remote, highly unlikely	Cannot survive	Virtually certain to detect early enough to consider eradication	Virtually certain to eradicate without significant impacts	1
Infection is remote, unlikely	Highly unlikely to survive	Very high likelihood of detection early to consider eradication	Very high likelihood of eradication without impacts	2
There is a slight chance of infection	Unlikely to survive	High likelihood of detection early to consider eradication	High likelihood of eradication without significant impacts	3
⬇	⬇	⬇	⬇	
An occasional number of infections expected yearly	Environment suitable for a number of species	Medium chance of detecting early enough	Low chance of eradicating without significant impacts	5
⬇	⬇	⬇	⬇	
Infection will occur continuously	Will definitely survive	Cannot detect early enough to consider eradication	Will not eradicate	10

Quarantine Management System



The bowtie and the structure of the QMS



Marine vessel safeguards

commitment to always be free from marine pests

- Neutral ballast water in clean tanks
- Manage secondary fouling
- Focus on antifouling paints
- Vessel history
  - Drydocking
  - Schedules
  - Passages
- Events at sea
- Port history past 12 months
- Insistence on dive reports if slipping was not possible

Barrow Island
Vessel requirements

7 day rule
Vessels at BWI >7d must depart origin <7d of deslipping and new AFC

30 day rule
Vessels discharging cargo from Australia or approved ports. Desktop assessment or inspection <1 month

90 day rule
Vessels mobilise 8-31 days discharging cargo. Must be cleaned in water or re-slipped. Also inspected.

180 day rule
Re-inspected and free from secondary biofouling.

What did we learn?
681 vessels risk assessed and 6935 vessel movements by end of 2018

Premobilisation checks

- Gateway dredger: *A. improvisus* and *B. pulchellus*. Cleaned in Singapore.
- Cornelius Zanen: Several *Perna viridis*. Systems treated and re-inspected.
- Bluefin 1: *B. pulchellus*. Cleaned out of water.
- Westsea 99: *P. viridis*. Apr. 2013. Cleaned out of water.

Post-mobilsation under 7, 30 & 90 day rules

- Pacific Blade: 6 *P. viridis*. Cleaned out of water.
- Hako Esteem: 1 *P. viridis*
- Bluefin 1: several *P. viridis*. Cleaned out of water.
- Westsea 95, 96,97. 1-46 *P. viridis*. All not sexually active. Discharged cargo and returned to Indonesia for cleaning.

refocussing on critical safeguards

- Ballast water there is no change
- Clean and free from secondary fouling at the 'start of your life' with Gorgon
- Drydocking, cleaning and reapplication of correct antifouling is always preferred
- Role for in-water cleaning
- Type of antifouling relating to type of vessel and nature of work
- Plimsol line – maximum load line
- The Barrow Island 'Rules' for marine vessels
- Notifiable events
- Marine pest list/s are counterproductive and does not guide our thinking
- Early warning – monitoring and surveillance of our ports
- High level of preparedness to respond

What did we learn?

Surveillance and preparedness

Early detection key to eradication

Species Action Plans

6 plans: Perna viridis, Sargassum muticum, Balanus spp., *Hemigrapsus* spp., *Hydroides* spp., *Mytilopsis sallei*

Refocussing on critical safeguards

Conclusion

Chevron

human energy®

ANGELA GILLHAM
Deputy CEO
Maritime Industry Australia Ltd, Australia

Angela Gillham joined MIAL in 2003 and has worked across the organisation in various roles, but always with a focus on safety and environment and sustainability policy. Currently employed as MIAL's Deputy CEO, Angela has a background in environmental science and has managed and coordinated industry input into several shipping related research and development projects and represents the interest of the Australian shipping industry to government. Angela also participates in international forums including the International Chamber of Shipping and as industry adviser to the Australian delegation to the International Maritime Organization.

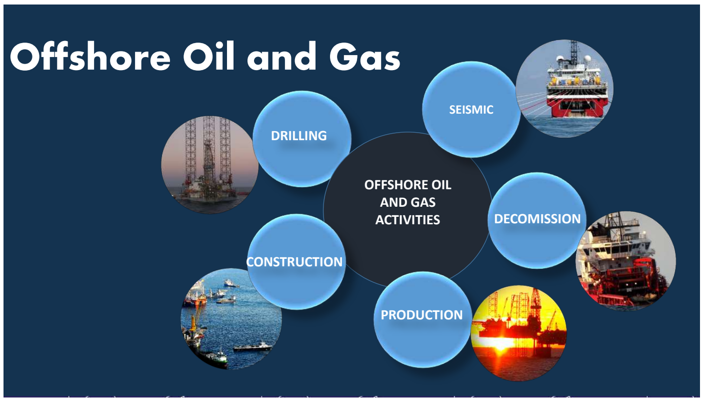
Offshore vessel marine biosecurity – agreeing on best practice

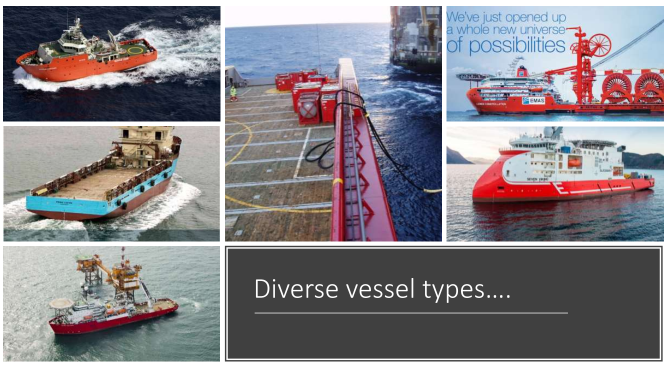
The cross jurisdictional nature of marine contractor operations in Australia's offshore petroleum industry means that vessel operators need to comply with both State, Northern Territory and Commonwealth legislation, as well as additional, and sometimes more stringent requirements imposed by titleholders. Given the diverse and dynamic nature of offshore vessel operations, regulating for marine biosecurity in this sector is challenging. Gaps in scientific understanding of marine biosecurity risk in relation to the interaction between offshore installations and vessels servicing them, and information opacity regarding reasons behind these requirements exist. As a result, confusion and duplication occurs, which can result in either noncompliance, increasing the risk of marine pest introduction or 'overcompliance', leading to management practices and processes that go well beyond what might be considered reasonable to reduce marine biosecurity risk, resulting in perverse outcomes, project inefficiencies and cost blowouts for contractors. Maritime Industry Australia Ltd is coordinating work to collaborate across the Australian offshore petroleum industry and regulators to develop best practice guidance for marine biosecurity management of vessels servicing offshore petroleum industry. The guidance will take the form of a 'Reference Case' for titleholders to address marine biosecurity issues within their Environment Plans, and as a guide to marine contractors on what ballast water and biofouling management measures are required to reduce marine biosecurity risk to as low as reasonably practical (ALARP).


MARITIME INDUSTRY AUSTRALIA LIMITED
ANZPAC 2019
Offshore vessel marine biosecurity – agreeing and implementing best practice
Angela Gillham
Maritime Industry Australia Ltd


MARITIME INDUSTRY AUSTRALIA LTD
MEMBERS
ASSOCIATE MEMBERS


MIAL and IMS Policy


Offshore Oil and Gas
SEISMIC
DRILLING
OFFSHORE OIL AND GAS ACTIVITIES
DECOMISSION
CONSTRUCTION
PRODUCTION


We've just opened up a whole new universe of possibilities
Diverse vessel types….


Jurisdictional Complexity
NOPSEMA
State Gov.
DoA
AMSA

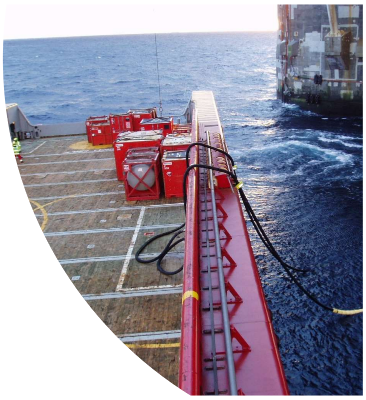
Unique Challenges

- **Variable activity**
- **Relatively unknown risk**
- **Unscheduled drydocks**
- **Uncertainty leading to 'Hypervigilant' approach**

Consistency - Clarity - Certainty

- Industry wide agreement on best practice – environment plan content
- Multi jurisdictional acceptance

Environment Plans (EP's)



- Required to be produced by titleholder /accepted by NOPSEMA
- Identifies environmental risks, controls and mitigation, measurement
- Activities must be conducted in accordance with EP
- Marine biosecurity aspects heavily reliant on risk assessment tools

Offshore Reference Cases

- Identify common content across EP's
- Reduce duplication in effort, reduce inconsistency
- Increase overall industry efficiency
- Developed by industry / accepted by NOPSEMA
- Able to be simply referenced on EP's

Environment Plan Reference Case
Marine Biosecurity Management of Vessels Servicing the Offshore Oil and Gas Industry

Working group participants / Review group

- **Titleholders**: Woodside, Inpex, Shell, Chevron, Quadrant
- **Vessel Operators:** DOF, Solstad, Swire Pacific Offshore Maersk Supply, MMA
- **Government**: NOPSEMA, Dept. Agriculture, WA, NT, Victoria

Agreement on best practice – adoption of BFMP and Record Book

The way forward…

- **Finalisation of reference case**
- **Public consultation and regulatory review (NOPSEMA)**
- **NOPSEMA acceptance and adoption by industry - 2019**

Thanks
mial.com.au

HAOLIANG CHEN
Technology Leader I, Marine Hydrodynamics
AkzoNobel, Singapore

Predicting and monitoring the impact of fouling control coatings on vessel efficiency and emissions

Predicting the impact of fouling control coatings on vessel efficiency and emissions

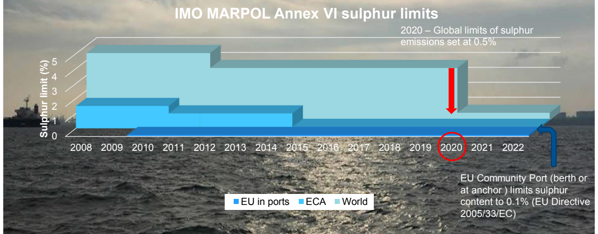
Oct 2019

Haoliang Chen; Barry Kidd

AkzoNobel

Environmental regulation timeline – SOx.

AkzoNobel



❑ Two main compliance options:
- Fuel switching;
- Exhaust cleaning options (scrubbers).

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Strategies to improve vessel efficiency

One reference (of many), DNV GL "Eco Retrofit" highlights 4 areas commonly reviewed which can provide the highest impact and best return on investment:

- Bow shape
- Engine and auxiliary systems
- Propeller
- Energy-saving devices (ESDs) and appendages

Other potential options include:

- Air lubrication systems
- Flettner rotors
- Etc.

International

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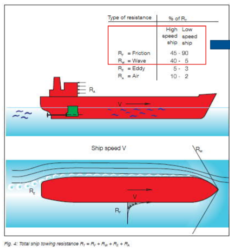
Hydrodynamics…Let's keep it simple



*Basic Principles of Ship Propulsion, Man Diesel and Turbo

Some Key factors:
- Hull form design (vessel type and size)
- Vessel Speed
- Hull & Propeller Condition

International

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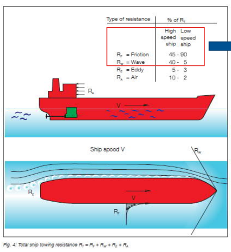
Hydrodynamics…Let's keep it simple



*Basic Principles of Ship Propulsion, Man Diesel and Turbo

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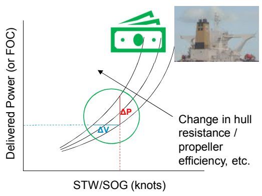
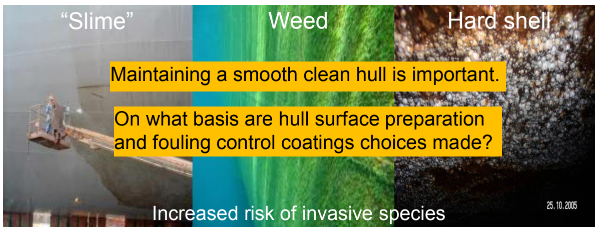


International

AkzoNobel

The Effect of Fouling on Ship Performance



Increased frictional resistance

0 - 5% +	5 - 15% +	Anywhere up to 40%+

International

Towards a Better Decision of Fouling Control Coatings Choices

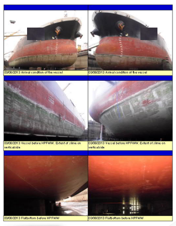
AkzoNobel

- Key factors:
  - Global fouling challenge
  - Operational profile of the vessel
  - Vessel type and size
  - Choice of fouling control coating and scheme selection
  - Substrate preparation
  - Hull husbandry

International

New Coating Performance Models

AkzoNobel



STENSON, P.A.; KIDD, B.; FINNIE, A.A. (2013), *Measurement and impact of surface topology and hydrodynamic drag of fouling control coatings*, 3rd Int. Conf. Advanced Model Measurement Technology for the EU Maritime Industry, Gdansk

STENSON, P.A.; KIDD, B.; CHEN, H.L.; FINNIE, A.A.; RAMSDEN, R. (2014), *Predicting the impact of hull roughness on the frictional resistance of ships*, Int. Conf. Computational and Experimental Marine Hydrodynamics (MARHY), Chennai

Coating Performance (Dataplan® and ERS)

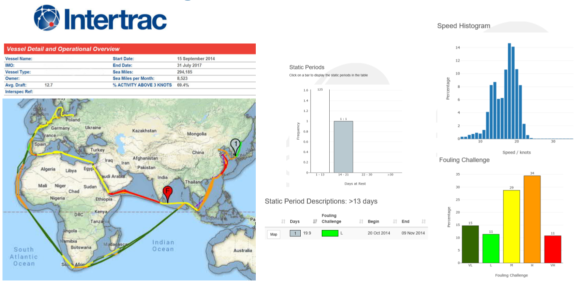
>250k vessel inspections records

International

Understanding Ship Operations

AkzoNobel

Intertrac



International

Understanding Ship Operations

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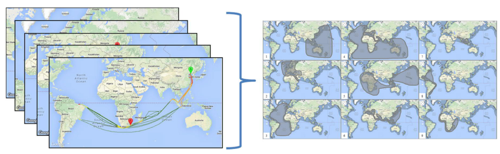
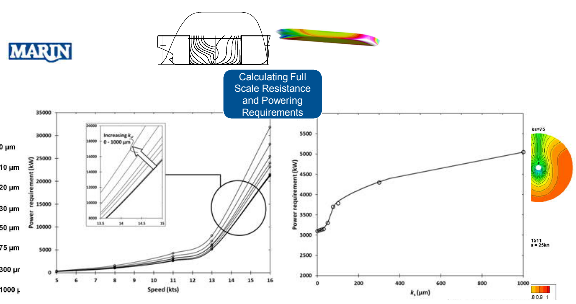


Vessel Tracking (Intertrac®)

Power Requiring of a Full Scale Ship

AkzoNobel

MARIN



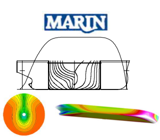
Calculating Full Scale Resistance and Powering Requirements

International

Developing predictive models

AkzoNobel

MARIN



Calculating Full Scale Resistance and Powering Requirements

Performance Prediction
Intertrac Vision

Predictive models

Coating Performance (Event Reporting)

Vessel Tracking (Intertrac®)

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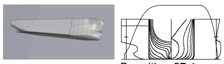
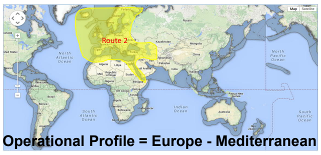
Prediction Case Study

Chemical/Product Carrier



DWT = 37,764
LPP = 176 m

Breadth = 27.4 m
Draught = 11.3 m



Prediction Parameters:

Average Speed = 12 kts

Vessel Activity = 60%

SMM = 5,256

FOC: 22 MT/day

Fuel costs = $500 MT

Question: What is the relative predicted difference between 3 different fouling control coating choices?

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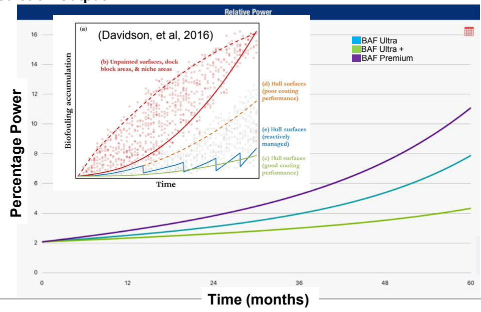
Prediction Case Study

Prediction Output:



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Prediction Case Study

Relative predicted output over 60 months:

	Power / FOC (%)	Speed (kn)	CO2 emissions (MT)	Accumulated FOC Cost Saving ($)
BAF Premium	Baseline			
BAF Ultra	-3.2	+0.7%	-900	-105,000
BAF Ultra +	-6.8	+1.9%	-1650	-200,000

Please note: this prediction is specific!
A balanced drydock investment is needed

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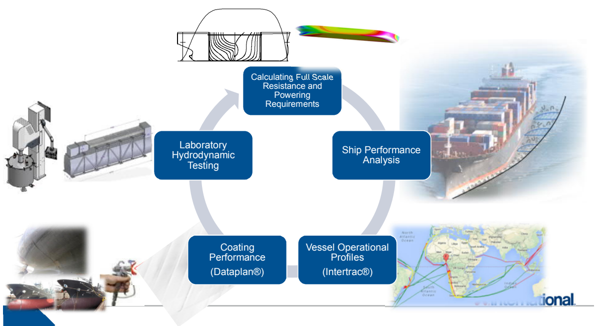
Integrated Data Analytics



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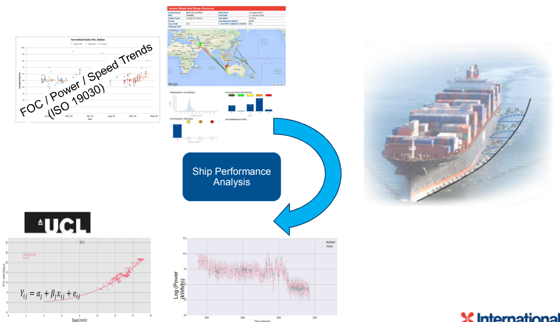
Ship Performance Analysis



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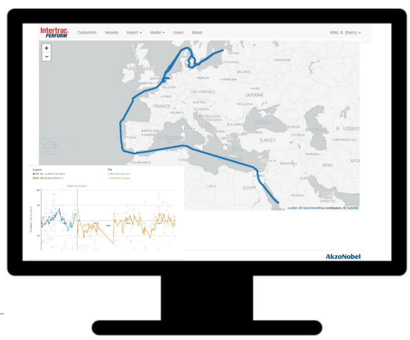
Reviewing Vessel Performance



International

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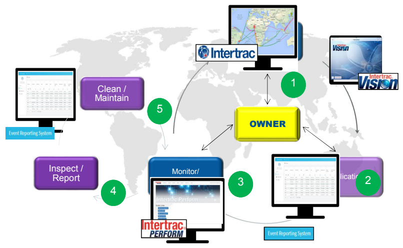
A Holistic Process



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Summary

- Choosing and correctly applying the optimal fouling control coating can, through a clean, smooth hull
  - Save money for the whole industry; which will reduce costs for everyone
  - Reduce emissions (CO_2/NOx/SOx)
  - Minimise the risk of invasive species

- It is vital to have a right coating choice for a right ship; there are many factors to consider - we can help
- Better prediction and management of hull and propeller condition is a holistic process

International

YIGIT KEMAL DEMIREL
Lecturer, Naval Architecture, Ocean and Marine Engineering Department
University of Strathclyde, United Kingdom

Dr Yigit Kemal Demirel is a Lecturer in the Naval Architecture, Ocean and Marine Engineering Department at the University of Strathclyde. Dr Demirel's expertise and research interests lie in computational (CFD) and experimental hydrodynamics. He is actively engaged in fundamental and industry-focused research on the effect of roughness (hull fouling and fouling control coatings) on ship performance, energy efficiency of ships, hull-propeller optimisation and energy saving devices. He has experience in working on numerous projects such as EU funded FP7 FOUL-X-SPEL, FP7 SHOPERA, H2020 Erasmus+ MATES Projects, EPSRC funded Shipping in Changing Climates and Low Carbon Shipping-A Systems Approach Projects, British Council funded SUVESIN Project. Dr Demirel is an Editorial Board member of GMO Journal of Ship and Marine Technology and the journal Brodogradnja / Shipbuilding. In 2017, Dr Demirel was appointed to the International Towing Tank Conference (ITTC) Resistance and Propulsion Committee for duration of three years, which sets best-practice standards for large-scale hydrodynamics facilities worldwide.

Effect of biofouling on ship performance and energy efficiency

Marine biofouling is an increasing problem from both economic and environmental points of view in terms of increased fuel consumption, increased GHG emissions and transportation of harmful non-indigenous species. The fuel consumption of a ship is strongly influenced by her frictional resistance, which is directly affected by the roughness of the hull's surface, i.e. biofouling. Increased hull roughness leads to increased frictional resistance, causing higher fuel consumption and CO2 emissions. It would, therefore, be very beneficial to be able to accurately predict and quantify the effects of biofouling on ship performance and energy efficiency. However, it is a major challenge to relate fouling-control coatings and the effect of biofouling, to full-scale ship resistance and powering, in order to accurately evaluate their effects on energy efficiency, fuel consumption and hence CO2 emissions. The answers to the question, *"How might the roughness of biofouling and fouling- control coatings be related to full-scale ship resistance and powering?"* will be discussed thoroughly. The state- of-the-art and novel experimental and numerical methods will be presented, along with the future directions in research on the issue.

Effect of biofouling on ship performance and energy efficiency

Dr Yigit Kemal Demirel

Department of Naval Architecture, Ocean and Marine Engineering
University of Strathclyde

4th ANZPAC Workshop on Biofouling Management for Sustainable Shipping
2 October 2019

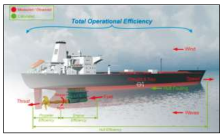
News:

"Beard swimming cap launched after men blame facial hair for slow speeds in the water"

Source: https://www.mirror.co.uk/incoming/gallery/innovative-swim-cap-bearded-men-5809518

Introduction

Fouling → Roughness → Increase in Resistance → Increase in required Power and Fuel consumption



Increase in GHG Emissions

Negative Effects on Environment

Biocide accumulation and negative effects on non-target species

To avoid fouling

Biocidal antifouling coatings → Biocide releasing to environment

Introduction

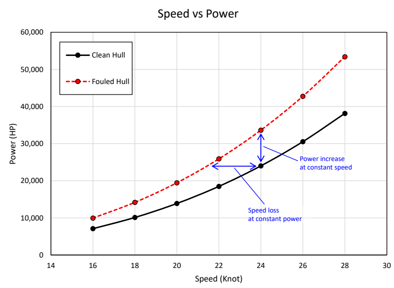
10% 7%

Marine Coatings —Literature→ Turbulent boundary layer / skin friction of **lab-scale plates**

?

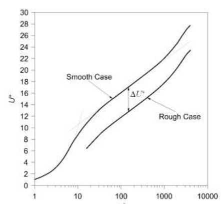
"How might the roughness of coatings and biofouling be related to full-scale?"

Introduction



Introduction

Roughness Effect on Flow



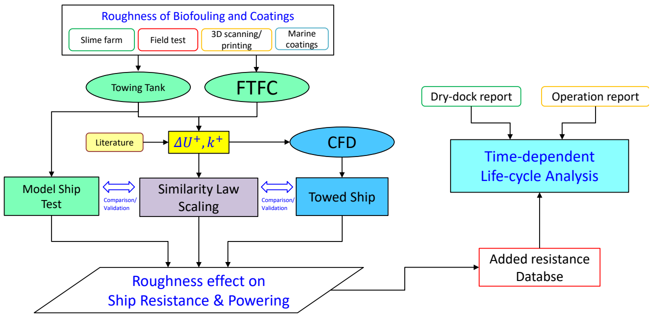
ΔU^+ → Roughness function

$$\Delta U^+ = U^+_{smooth} - U^+_{rough}$$

$$U^+ = f(y^+) \xleftarrow{smooth} \text{Law of the wall for inner layer} \xrightarrow{rough} \frac{U}{U_\tau} = f\left(\frac{yU_\tau}{\nu}, \frac{kU_\tau}{\nu}\right), \quad U^+ = f\left(y^+, k^+\right)$$

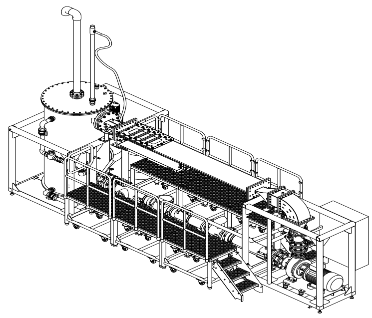
$$U^+ = \frac{1}{\kappa}\ln y^+ + B \xleftarrow{smooth} \text{Logarithmic velocity profile} \xrightarrow{rough} U^+ = \frac{1}{\kappa}\ln(y^+) + B - \Delta U^+(k^+)$$

Methodology for predicting the roughness effects of marine coatings and biofouling on ship resistance



Fully Turbulent Flow Channel

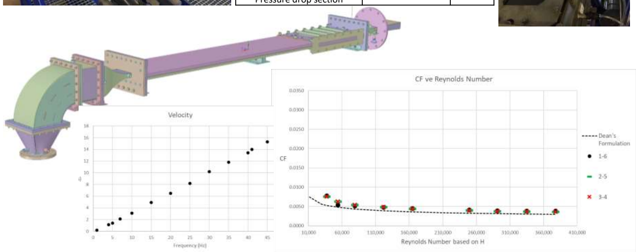
- We have designed and recently commissioned a ***Fully Turbulent Flow Channel (FTFC)*** at the Kelvin Hydrodynamics Lab' which allow us to measure flow and drag characteristics of various surfaces covered with different control fouling systems as well as drag reduction mechanisms including the effect of marine biofouling



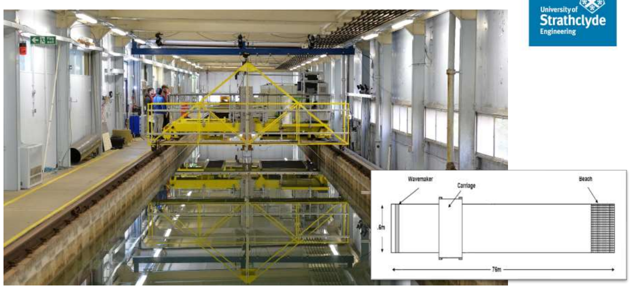
Fully Turbulent Flow Channel

Main Features of FTFC

Upstream Length:	2.40	m
Test Plate Length:	0.60	m
Channel Width:	0.18	m
Channel Height:	0.0225	m
Bulk Velocity Range:	~ 0.5 – 15.0	m/s
Reynolds Number Range:	~ 10.000 – 350.000	
Pressure taps No & range	6 taps & 20 -1000	mbar
Tank capacity	2.6	m^3
LDA & PIV Access through Pressure drop section	600 x 180 x 22.5	mm



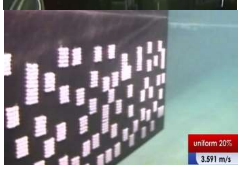
Towing tank



- Towing tank at Kelvin Hydrodynamics Laboratory
  - Dimensions of 76m x 4.6 m x 2.5 m
  - Carriage speed: up to 5m/s
  - High-performance multi-flap active absorbing wave-maker

Experiments

- **Marine Coatings including commercially available silicone-based coatings and SPC, novel FOUL-X-SPEL Paints**
- **3D printed artificial barnacles (different coverage configurations)**

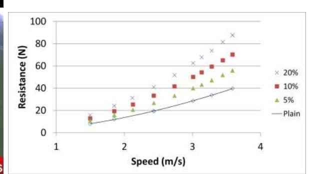


3D scanning

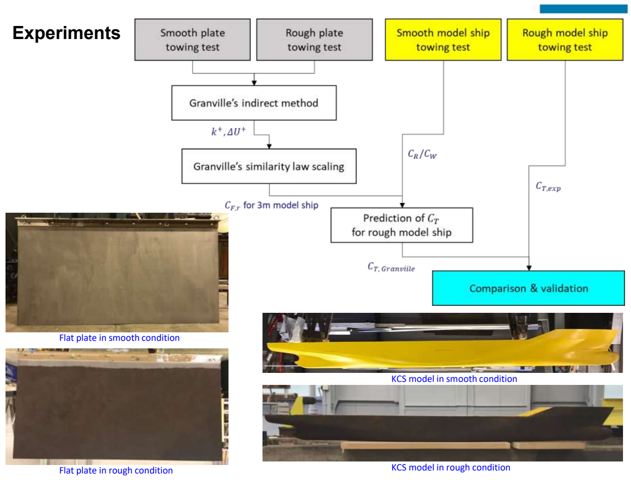
3D printing

- Demirel, Y.K., Uzun, D., Zhang, Y., Fang, H., Day, A.H., Turan, O., 2017. Effect of barnacle fouling on ship resistance and powering. Biofouling, 33:10, 819-834
- Turan, O., Demirel, Y. K., Day. S., Tezdogan, T. (2016), "Experimental Determination of Added Hydrodyanmic Resistance Caused by Marine Biofuling on Ships", Transportation Research Procedia, 14: 1649-1658

Experiments



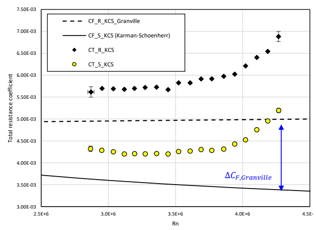
Experiments

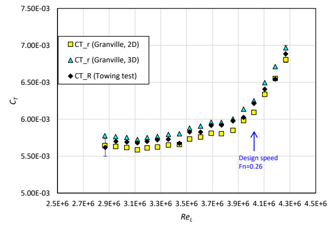


- Song, S., Dai, S., Demirel, Y. K., Atlar, M., Day, S., & Turan, O. (2019). "Experimental and theoretical study of the effect of hull roughness on ship resistance". Journal of Ship Research (under review).

Experiments

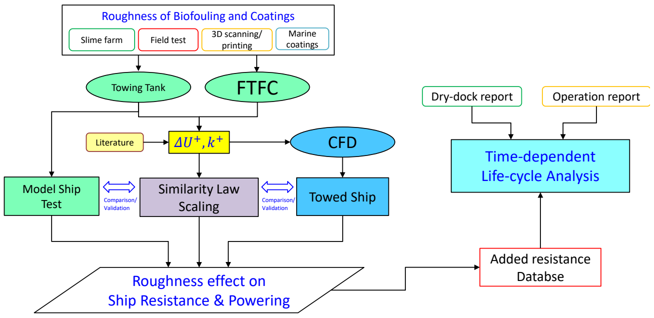
- Total resistance coefficients were predicted using the Granville's extrapolation & smooth model ship result
  - 2D method
    - $C_{T\_Rough} = C_{T_{Smooth}} + \Delta C_{F,Granville}$
  - 3D method
    - $C_{T\_Rough} = C_{T_{Smooth}} + (1+k)\Delta C_{F,Granville}$
- Compared with rough model ship result
  - 3D method shows better agreement compared to 2D method
    - Can be attributed to the roughness effect on viscous pressure resistance
    - 3D method shows slightly higher CT than the experiment, which is in correspondence with Song et al. (2019a)



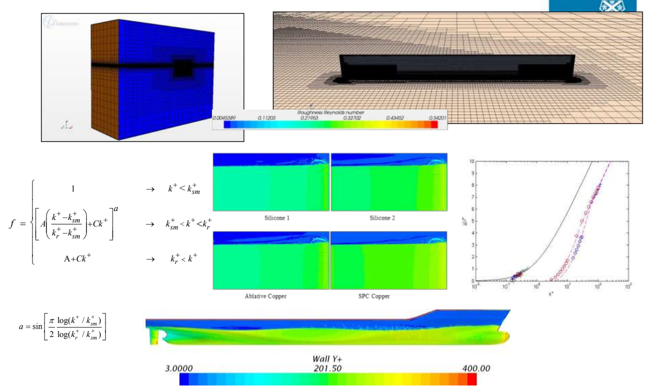


- Song, S., Dai, S., Demirel, Y. K., Atlar, M., Day, S., & Turan, O. (2019). "Experimental and theoretical study of the effect of hull roughness on ship resistance". Journal of Ship Research (under review).

Methodology for predicting the roughness effects of marine coatings and biofouling on ship resistance

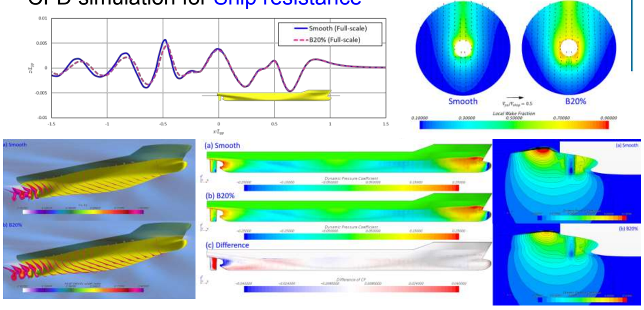


CFD Approach



- Demirel, Y.K., Khorasanchi, M., Turan, O., Incecik, A., 2014. CFD approach to resistance prediction as a function of roughness. In: Proceedings of Transport Research Arena Conference 2014, 14 - 17 April 2014. Paris La Défense, France.
- Demirel YK, Khorasanchi M, Turan O, Incecik A and Schultz MP. (2014). A CFD model for the frictional resistance prediction of antifouling coatings. Ocean Engineering.89:21-31.

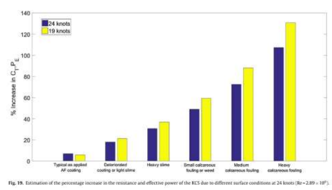
CFD simulation for Ship resistance

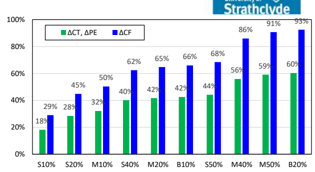


- Up to 93% and 60% increase in C_F and P_E observed
- Roughness effect on different resistance components were investigated
  - C_{VP} increases while C_W decreases due to surface fouling
- Roughness effect on other ship hydrodynamic characteristics were found (Form factor, stern wake, wave profile, …)

- Demirel, Y. K., Turan, O., Atilla, I. (2017b). "Predicting the effect of biofouling on ship resistance using CFD", Applied Ocean Research, 62: 100-118
- Song, S., Demirel, Y. K., Atlar, M. (2019a). "An investigation into the effect of biofouling on the ship hydrodynamic characteristics using CFD." Ocean Engineering 175: 122-137.

CFD simulation for Ship resistance

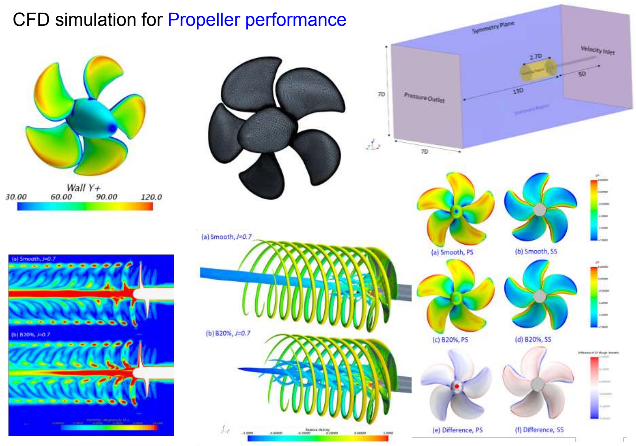




- Demirel, Y. K., Turan, O., Atilla, I. (2017b). "Predicting the effect of biofouling on ship resistance using CFD", Applied Ocean Research, 62: 100-118
- Song, S., Demirel, Y. K., Atlar, M. (2019a). "An investigation into the effect of biofouling on the ship hydrodynamic characteristics using CFD." Ocean Engineering 175: 122-137.

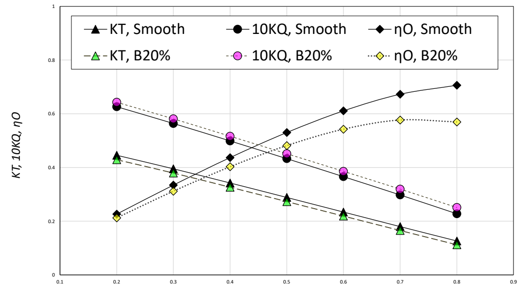
- 40% increase in effective power, P_E, due to *'heavy slime'*
- 130% increase in effective power, P_E, due to *'heavy calcareous fouling'*
- 68% increase in effective power, P_E, due to *'small barnacles, 50% coverage'*
- 91% increase in effective power, P_E, due to *'medium barnacles, 50% coverage'*
- 93% increase in effective power, P_E, due to *'big barnacles, 20% coverage'*

CFD simulation for Propeller performance



- Owen, D., Demirel, Y. K., Oguz, E., Tezdogan, T., Incecik, A., (2018), "Investigating the effect of biofouling on propeller characteristics using CFD". Ocean Engineering, 159 (1): 505-516
- Song, S, Demirel, Y. K., Atlar, M. (2019b). "An investigation into the effect of biofouling on full-scale propeller performance using CFD". OMAE, Glasgow.

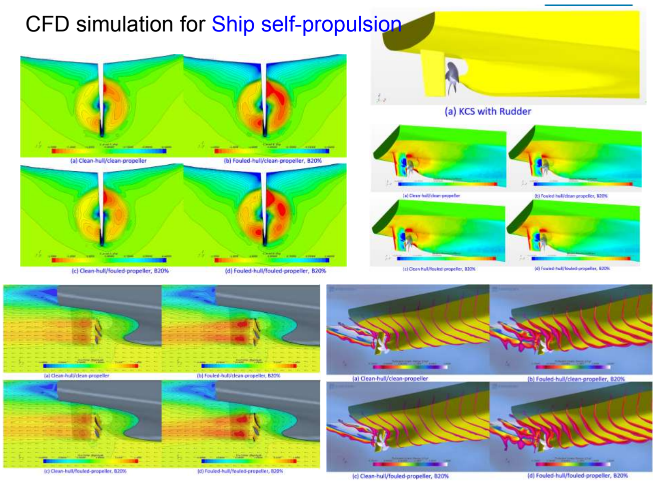
CFD simulation for Propeller performance



- Due to '*big barnacles with 20% coverage*'
  - Up to 11.1% thrust loss
  - Up to 10.8% torque increase
  - Up to 19.3% efficiency loss

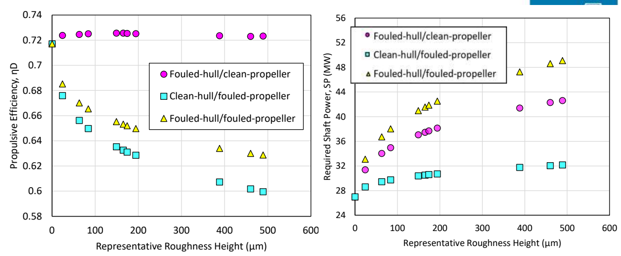
- Song, S, Demirel, Y. K., Atlar, M. (2019b). "An investigation into the effect of biofouling on full-scale propeller performance using CFD". OMAE, Glasgow.

CFD simulation for Ship self-propulsion



- Song, S., Demirel, Y. K., & Atlar, M. (2019). "Penalty of hull and propeller fouling on ship self-propulsion performance". Applied Ocean Research (under review)

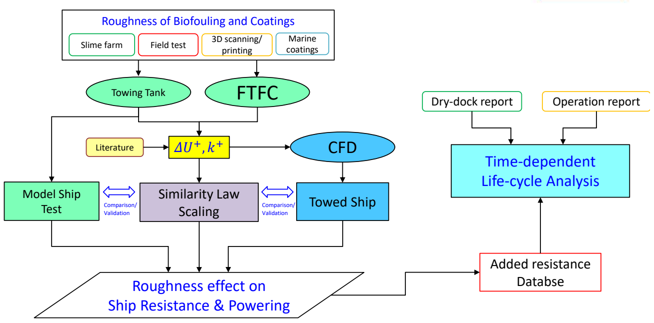
CFD simulation for Ship self-propulsion



- Effect of hull and/or propeller fouling
  - 23% increase in required shaft power due to the mildest condition (S10%)
  - 81.8% increase in required shaft power due to the most severe conditon (B20%)
  - 5.7% loss in propulsive efficiency, η_D, due to the mildest condition (S10%)
  - 16.4% loss in propulsive efficiency, η_D, due to the most severe condition (B20%)

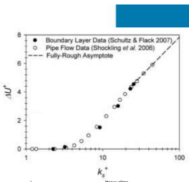
- Song, S., Demirel, Y. K., & Atlar, M. (2019). "Penalty of hull and propeller fouling on ship self-propulsion performance". Applied Ocean Research (under review)

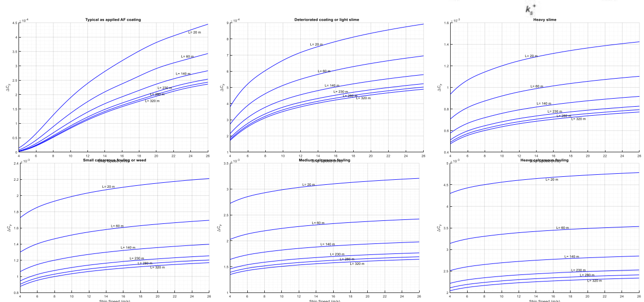
Methodology for predicting the roughness effects of marine coatings and biofouling on ship resistance



Granville's similarity law analysis

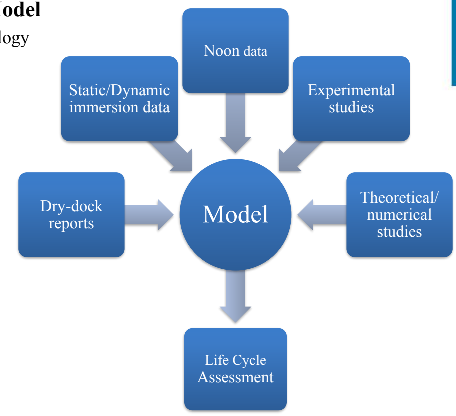
Description of condition	NSTM rating*	k_s (μm)	Rt_{50} (μm)
Hydraulically smooth surface	0	0	0
Typical as applied AF coating	0	30	150
Deteriorated coating or light slime	10-20	100	300
Heavy slime	30	300	600
Small calcareous fouling or weed	40-60	1000	1000
Medium calcareous fouling	70-80	3000	3000
Heavy calcareous fouling	90-100	10000	10000



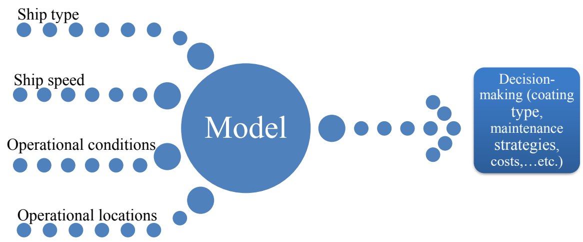


- Demirel, Y.K., Song, S., Turan, O., Incecik, A., (2019). Practical added resistance diagrams to predict fouling impact on ship performance. Ocean Engineering 186, https://doi.org/10.1016/j.oceaneng.2019.106112

LCA Model
Methodology



LCA Model
User Input



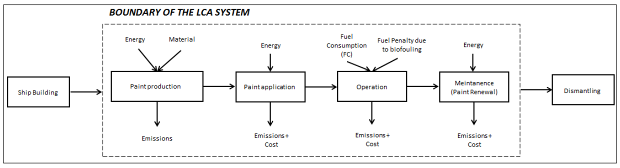
LCA Model
Stages

Major stages of LCA of an AF coating.

Stage	Activities
1. Production of AF coatings	Activities related to the extraction and acquisition of natural resources, including mining non-renewable material required to produce the different system components and transporting this materials to processing facilities.
2. Application	Application of antifouling coatings on ship hulls.
3. Operation of ships with AF coatings	Extra fuel is consumed due to the effects of antifouling coatings/fouling
4. Maintenance of ships (Hull cleaning and recoating)	System maintenance activities (dry-dock and in water hull cleaning).
5. End-of-Life	Dismantling of a ship

• Demirel, Y.K., Uzun, D., Zhang, Y., Turan, O., (2018). Life Cycle Assessment of Marine Coatings Applied to Ship Hulls, in: Ölçer, A.I., Kitada, M., Dalaklis, D., Ballini, F. (Eds.), Trends and Challenges in Maritime Energy Management. Springer International Publishing, Cham, pp. 325-339 (533 pages). https://doi.org/10.1007/978-3-319-74576-3_23

LCA Model



1. A representation of voyages and anchorages of the ship in question. The representation should describe the time and location of the ship over its lifetime.
2. Model of temperature-dependent and time-dependent growth of fouling.(1)
3. Model of variation of sea-temperature with location.(1)
4. Model of the costs and effects of hull maintenance activities.(2)
5. Model of fuel-consumption behaviour of the ship.(1)

• Demirel, Y.K., Uzun, D., Zhang, Y., Turan, O., (2018). Life Cycle Assessment of Marine Coatings Applied to Ship Hulls, in: Ölçer, A.I., Kitada, M., Dalaklis, D., Ballini, F. (Eds.), Trends and Challenges in Maritime Energy Management. Springer International Publishing, Cham, pp. 325-339 (533 pages). https://doi.org/10.1007/978-3-319-74576-3_23

Case Studies

An existing handy-size bulk-carrier was operated in 3 real bulk carrier operations.

Table I. Ship characteristics

Vessel type	Bulk-carrier
Deadweight	40 k ton
Length	179 m
Breadth	28 m
Design draft	10.6 m
Wetted surface area	7350 m^2
Engine power	6.6 kW
Endurance	25k NM
Fuel type	HFO
FO consumption(t/day) @design draft and speed	20.4

• Uzun, D., Demirel, Y.K., Coraddu, A., Turan, O., (2019). Life cycle assessment of an antifouling coating based on time-dependent biofouling model. 18th Conference on Computer Applications and Information Technology in the Maritime Industries. 25 – 27 March 2019. Tullamore, Ireland.

Case Studies

Ship operating profiles and ship routes

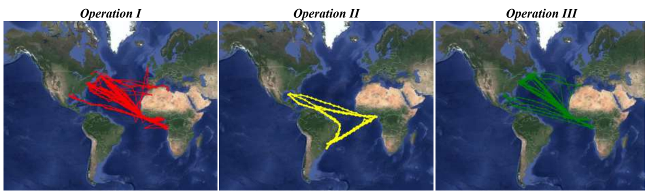
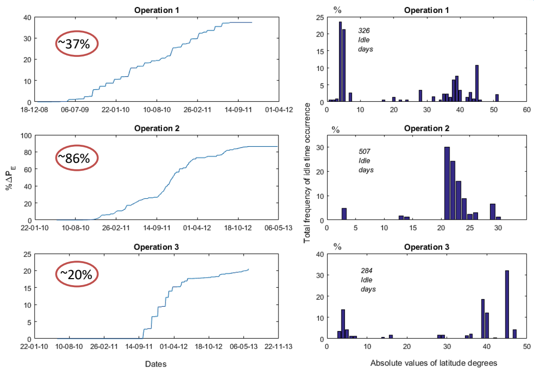


Table II: Ship operation data

Data	*Operation 1*	*Operation 2*	*Operation 3*
Idle days including port stays in 3 years (day)	326	507	284
Average speed (knot)	14	14	14
Sailing day in 3 years	769	588	811
Operating days in 3 years	1095	1095	1095

Case Studies



In 3 years

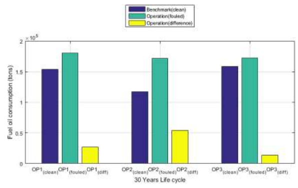
Case Studies

Compared to smooth case

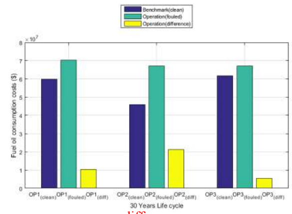
OP 1 +26600 tons

OP 2 +54300 tons

OP 3 +13700 tons



In 3 years



differences

$10.4 million | $21.2 million | $5.3 million

Conclusions

- It is not as simple as it looks!
- Holistic Approach is needed = Multidisciplinary research is needed
- Ship operating profile and ship route are significant parameters that need consideration before selecting a coating.
- The real impact of a coating can only be assessed through LCA of the coating systems in question.
- This approach may be used to decide the best maintenance and/or hull cleaning activities and/or intervals.
- More input means more accurate results. Let's work together!

Q&A

Thank you for your attention

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yigit.demirel@strath.ac.uk

University of Strathclyde Glasgow

RALITSA MIHAYLOVA
Head of Special Projects
Safinah Group, United Kingdom

Ral Mihaylova's background is in shipping business and operations with experience in data analysis and machine learning techniques. She is currently Head of Special Projects at Safinah Group, an independent coating consultancy. Ral has a keen interest in biofouling related matters and is a part of industry-led initiatives on the topic as well as a member of the RINA IMO Committee

Managing the Underwater Hull – Challenges and Opportunities

The management of the underwater hull of ships has relied on four key factors:

- Regular dry-docking and refurbishment of the underwater hull
- Effective fouling prevention coatings with predictable performance
- Relatively high levels of vessel activity with few prolonged static periods
- Underwater hull and propeller cleaning/polishing.

The established regime has been challenged in recent years as fewer and fewer ports have allowed underwater hull cleaning to take place, vessel activity has generally reduced, and slow steaming and prolonged static periods have become more common.
The TBT ban resulted in the need to develop/adopt alternative technology solutions for fouling prevention. In recent years, newer solutions have faced increasing challenges due to H&SE regulations, such as restrictions in relation to the use of biocides, that in some cases have led to a reduction in the perceived performance predictability of fouling prevention systems; challenges to formulations; increasing reliance and interest in UW hull cleaning and/or Grooming concepts.

The above, combined with two real environmental concerns, namely greenhouse gas emissions from ships and the risk of hull-borne invasive species, with emphasis on niche areas on the underwater hull, will challenge the accepted current practice of dry-dock work interspersed with some form of hull cleaning/grooming.

The marine industry is facing a considerable double threat that requires a re-assessment of the management of the Underwater Hull. This paper aims to review the current status/best practice and to identify key challenges and opportunities the industry must face or take advantage of to ensure effective and efficient transportation against an ever-increasing demand for seaborne trade.

Managing the Underwater Hull:

Challenges and Opportunities

Author: **R Kattan** (Principal Consultant , Safinah Group)
Presenter: **R Mihaylova** (Head of Special Projects, Safinah Group)
Contributor: **M Haroutunian** (Newcastle University, UK)

www.Safinah-Group.com

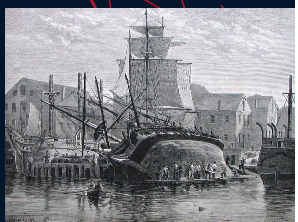
Overview

- Managing the underwater hull: some highlights
- Regulatory drivers
- Current status and challenges
- Room for optimisation
- Conclusions

Managing the Underwater (UW) Hull:

Some highlights

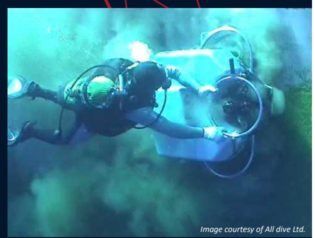
- The need for managing the underwater hull has been understood for many years
  - Portuguese ships in the spice trade took 1 year to Sail to India, by which time the wooden hulls were riddled by fouling damage.
  - Admiral Collingwood at the battle of Trafalgar broke the enemy lines ahead of the rest of the fleet because he had a recently cleaned and re-furbished underwater hull.



Careening of a ship - An Old Whaler Hove Down For Repairs, Near New Bedford, a wood engraving drawn by F. S. Cozzens and published in Harper's Weekly, December 1882.

Regulatory Drivers and Other Factors

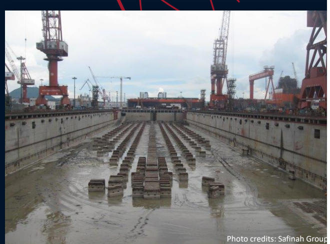
- Regulatory:
  - Biosecurity
  - Emissions
  - Water Quality
- Other:
  - Slow steaming, port congestion
  - Sea water temperature increase
  - Predictability of anti-fouling performance
  - Fuel prices
  - Waste management



Managing the UW hull:

Dry-Dock Process

- Dry-docking is the significant event for the UW hull coating restoration
- Application: time constraints can lead to less than perfect application
- Support blocks effect



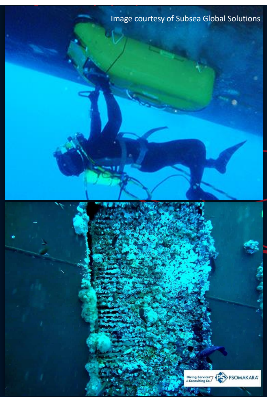
Managing the UW hull:

In-water Hull Cleaning

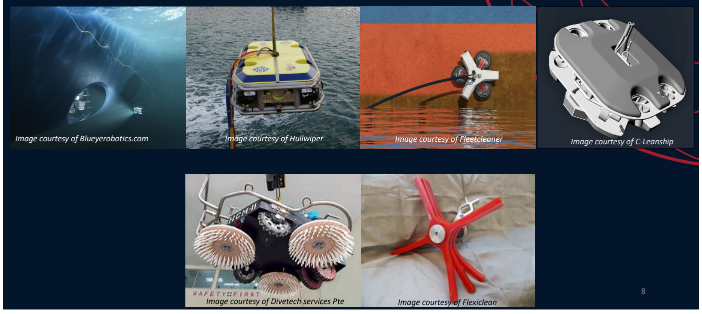
- Increase in frequency
- Key activities:
  - Vertical sides
  - Flat bottom
- Key areas (biosecurity):
  - Niche areas

Managing the UW hull:
In-water Hull Cleaning Process

- To date largely a manual process
- The result of diver intervention pre-defines:
  - the cleaning pattern
  - the associated time required
- Diver systems at mercy of the weather/current and vessel schedule
- Inconsistency of final clean achieved
- Standards are largely subjective

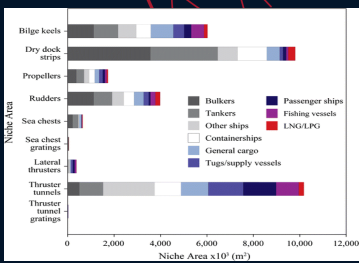


Technology solutions: Examples



Managing the UW hull:
Challenges

- Coatings
  - Compatibility/Suitability
  - Damage to coatings
  - Roughening of hull
- Ship design
  - Appendages and niche areas
- Other
  - Speed/extent of cleaning
  - Port operations optimisation



Extent and contributions of niche areas
Source: Moser et al, 2017

Proactive Hull Management Approach:
An Example

- Speed & extent of cleaning:
  - Divers - decompression
  - ROV – umbilical, barge positions
  - Time
  - Weather
- Logistics: port operations

Is there room for process optimization?

Hull Management Timeline for a Commercial Vessel (Period: 9 months)		
Area	Intervention	Time
PS 25% (AFT)	1	Start
ST 25% (AFT)	2	20 days
PS & ST 50% (FW)	3	Month 6
PS 50%	4	Month 6
ST 75%	5	Month 6
PS 80%	6	Month 9

Some areas of the vessel have been treated 3 times in 9 months, whereas others only 1.

Optimising UW Hull Cleaning:
Emissions/Vessel Performance Perspective

- Research on the effect of hull roughness indicates that the priority area would be the forward part of the hull followed by the stern[1]
- Preliminary research on the impact of fouling supports this and adds some interesting opportunities for improving the impact of limited intervention by hull cleaning when time is restricted and the whole hull cannot be treated[2]

Optimizing UW Hull Cleaning
Emissions/Vessel Performance Perspective

- Orientation of fouling may be more important than extent[2]*:
  - 5% vertical fouling can add up to 20% resistance
- Prioritising hull areas:
  - Fouling at the bow has the greatest impact on added resistance
  - Aft end next most important area
- Treating both sides of the hull while the vessel is alongside?

****Preliminary results from research in progress carried out at Newcastle University (UK) – academic lead Dr Maryam Haroutunian***

Conclusions

- In order to produce effective best practice recommendations in relation to UW hull management from vessel performance/emissions perspective more research is needed:
  - Hull cleaning patterns
  - Impact on coatings (functional specifications; long-term effect of cleaning equipment)
- Niche areas:
  - Review of potential design solutions to minimise biofouling accumulation
  - Technology solutions tailored to niche areas
- Optimal vessel performance and biosecurity: best practice recommendations going forward should serve/address both objectives.

Thank you

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References

- Moser, C. S., Wier, T. P., First, M. R., Grant, J. F., Riley, S. C., Robbins-Wamsley, S. H., Drake, L. A.(2017). Quantifying the extent of niche areas in the global fleet of commercial ships: The potential for “super hot spots” of biofouling. Biological Invasions, 19, 1745–1759. https://doi.org/10.1007/s10530-017-1386-4
- Kauczynski & Walderhaug (1987) Effects of distributed roughness on the skin friction resistance of ships; International Shipbuilding Progress Vol 34 Jan 1987
- Kontrafouris.P (2019) An investigation into the effects of fouling location and orientation on added resistance. Newcastle University (UK).

Jason Monty
Head, Department of Mechanical Engineering
The University of Melbourne, Australia

In-situ measurements of the ship hull drag penalty due to biofouling

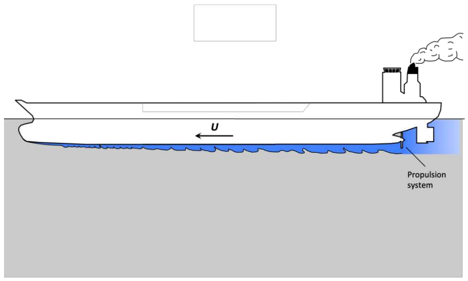
In-situ measurements of the ship hull drag penalty due to hull roughness

Jason P. Monty
Nick Hutchins and Bagus Nugroho
Department of Mechanical Engineering
THE UNIVERSITY OF MELBOURNE

Background

Mechanical Engineers; fluid mechanics experimentalists

Known for studying fundamentals of turbulent boundary layers



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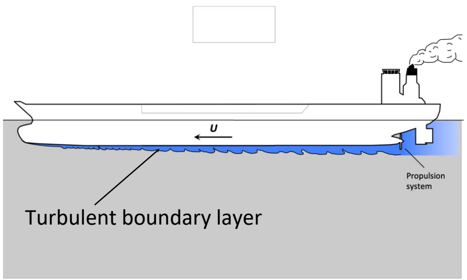


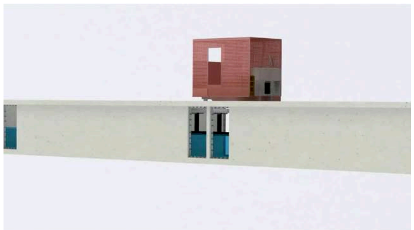
Background

Mechanical Engineers; fluid mechanics experimentalists

Known for studying fundamentals of turbulent boundary layers

Specialising in:

- high-fidelity data acquisition using novel experimental methods
- novel data analysis methods



Tubeworm fouling

In 2010, N. Hutchins began working with A. Scardino (DSTG)

Initially simply scanning fouled coupons

Photograph of fouled coupon

Tubeworm fouling

A. Scardino deployed 300 x 150 x 3mm coupon in Hobsons Bay

Immersed for 2 months then air dried for 7 days

Photograph of fouled coupon

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A. Scardino deployed 300 x 150 x 3mm coupon in Hobsons Bay

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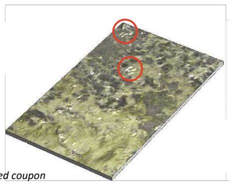
Coupon fouled with predominantly serpulid tubeworms (*Hydroides* sp., *Galeolaria* sp. and *Spirorbid* Sp.)



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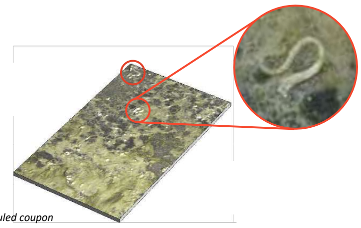

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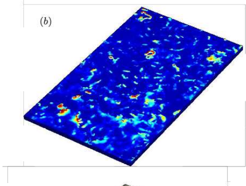
Light slime (FR 10-20) between tubeworms (FR 40)

Light slime was allowed to dry - not reproduced in surface scan

Photograph of fouled coupon

Tubeworm fouling

We scan this surface using a 3D laser scanner



Photograph of fouled coupon

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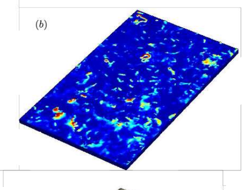
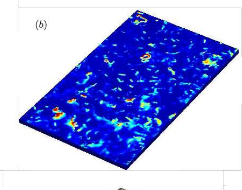


Photograph of fouled coupon

Tubeworm fouling

So we have all the surface data we need.

What do we want to do with this?



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Tubeworm fouling

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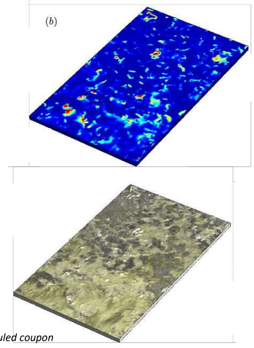
What do we want to do with this?

Predict the hull drag penalty due to the ‘roughness’ if this were on a ship



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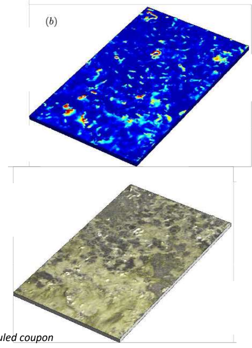
No recognised way of using geometry to accurately determine ship drag penalty



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Tubeworm fouling

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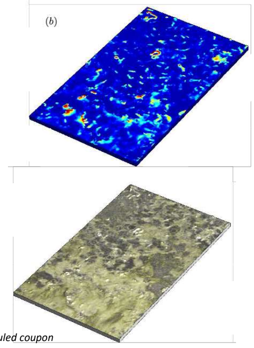
Wind-tunnel tests to measure the drag needed

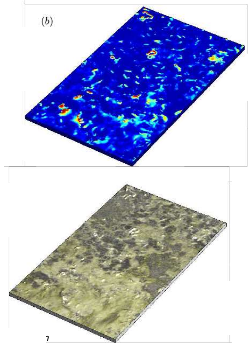


Photograph of fouled coupon

Tubeworm fouling

600 x 300 mm tiles were cast from an initially CNC machined surface

24 tiles to cover wind-tunnel floor



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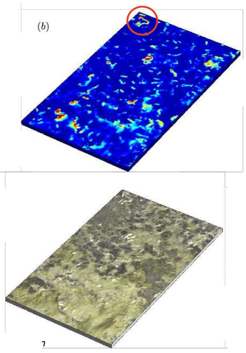

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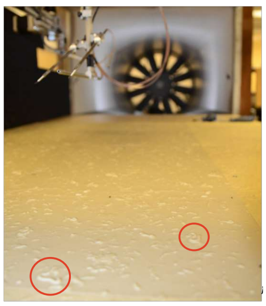

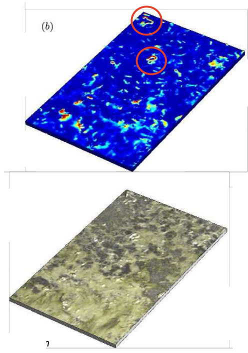

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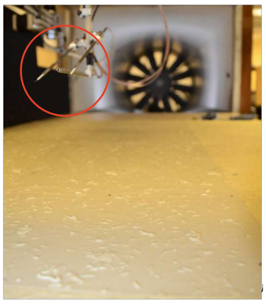
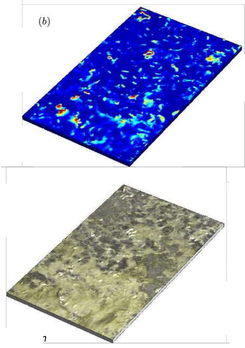
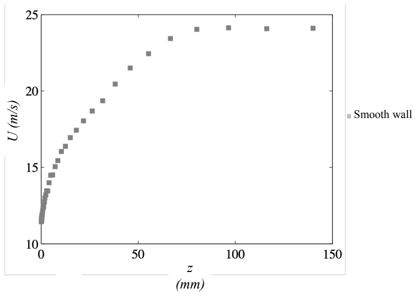




Results

Velocity, U, plotted against distance from the wall, z



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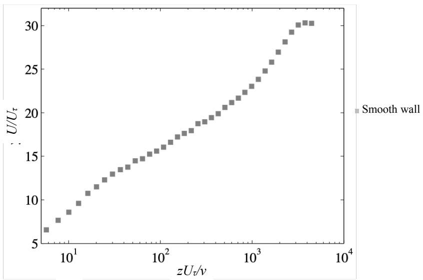
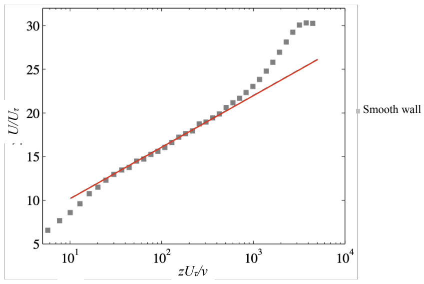
AIM: Estimate drag from FLOW MEASUREMENTS



Results

Friction velocity, U_τ , determined from fitting velocity profiles to

$$\frac{U}{U_\tau} = \frac{1}{0.384}\log\left(\frac{zU_\tau}{\nu}\right) + 4.2 - \Delta U^+$$



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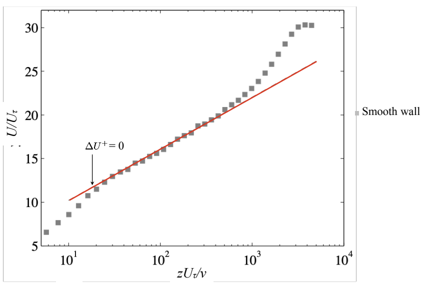

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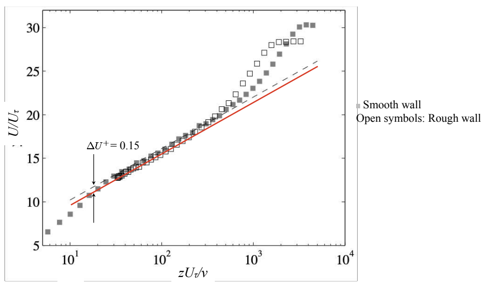

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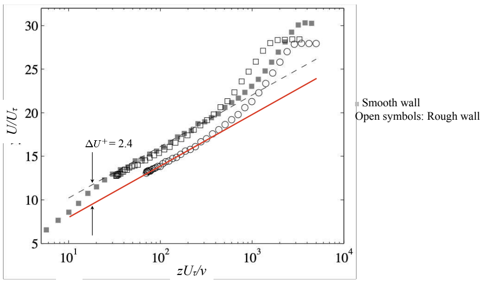

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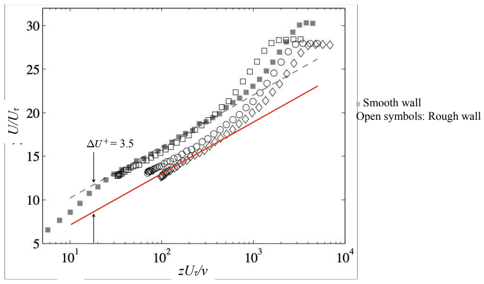

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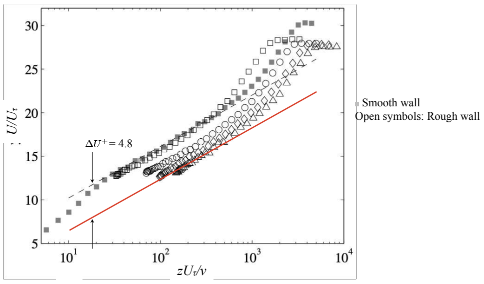

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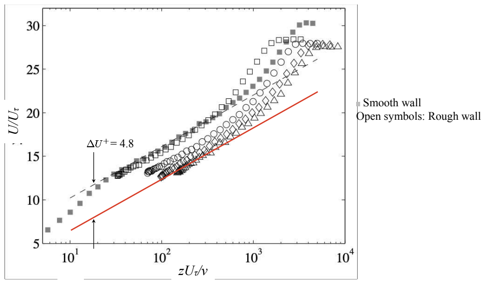
Once we have ΔU^+ for each velocity, we can find k_s ...



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Once we have ΔU^+ for each velocity, we can find k_s ...

... by forcing the highest velocity (most rough) data onto

$$\Delta U^+ = \frac{1}{0.384}\log\left(\frac{k_s U_\tau}{\nu}\right) + 4.2 - 8.5$$

Correlation developed for drag for a sandpaper surface

Results

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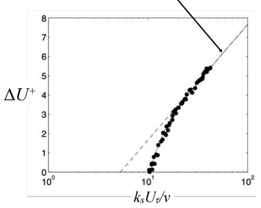

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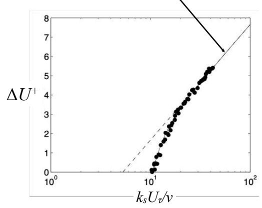

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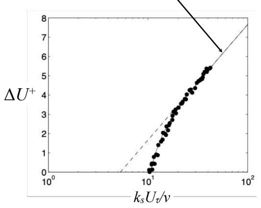

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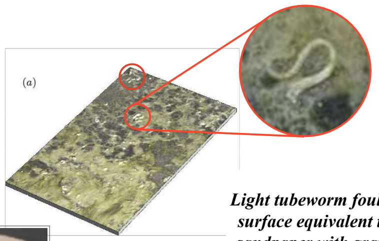

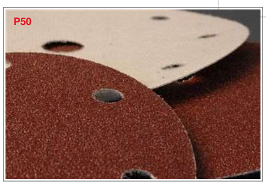

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P50 grit

Estimate of ship-scale drag

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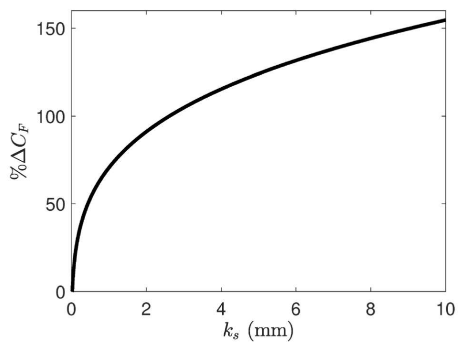
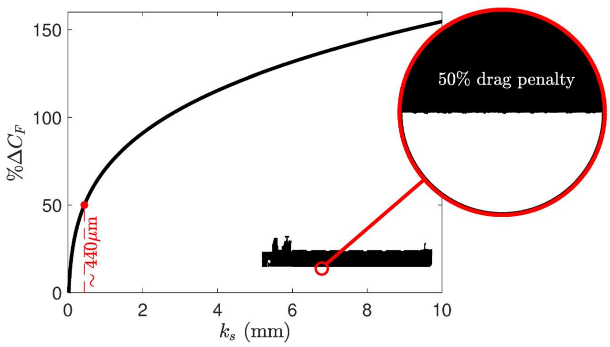
Some subtleties with hull roughness

Equivalent sandgrain roughness height k_s vs percentage skin friction drag penalty $\%\Delta C_F$ for a ship at typical operating conditions



Some subtleties with hull roughness

Beyond the smooth limit, the first few 10s of microns of roughness are disproportionately expensive in terms of drag penalty



Summary

Given a surface condition (surface scan or fouled coupon) we can reproduce in the wind-tunnel and test to find k_s

Can be used to predict drag on a full-scale ship with the ONLY assumption being a **universal mean velocity profile**

This work can be found in

Monty, Dogan, Hanson, Scardino, Ganapathisubramani & Hutchins (*Biofouling*, 2016)

In-situ ship experiments

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In collaboration with ITS (Surabaya) and University of Southampton (UK)…

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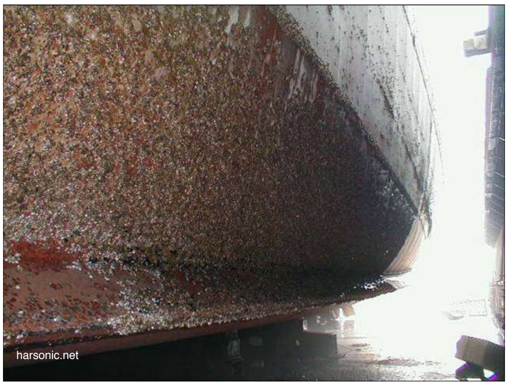

In-situ ship experiments

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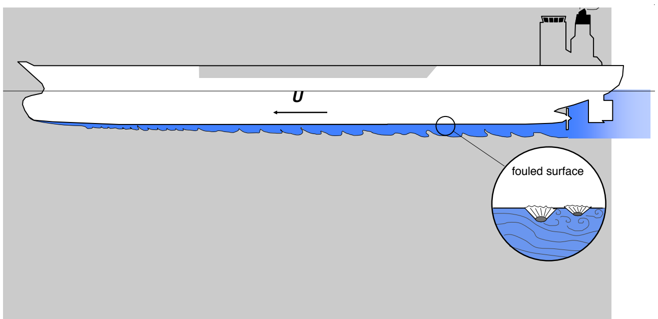

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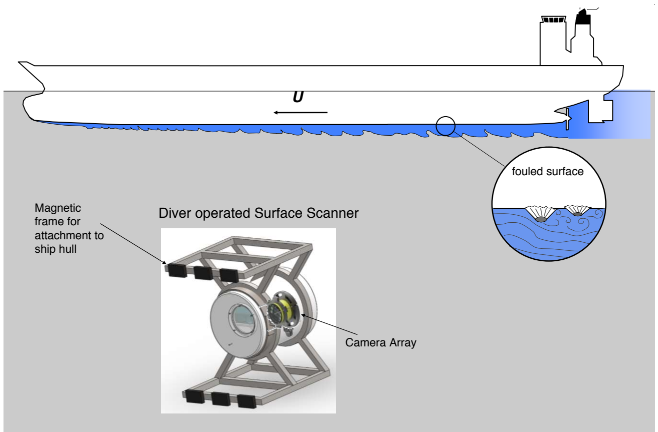

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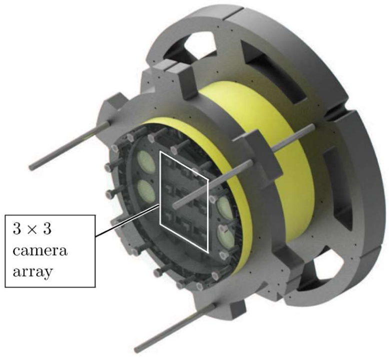

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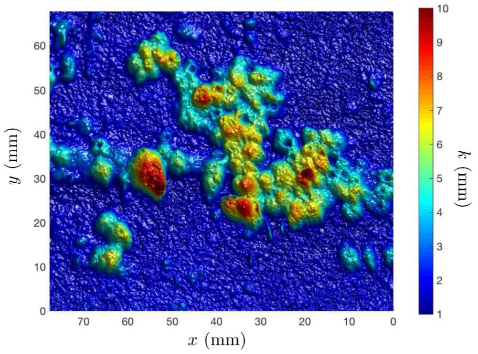

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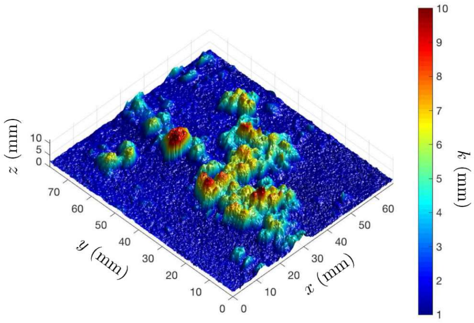

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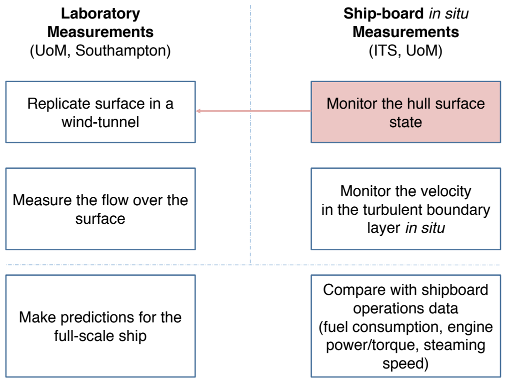

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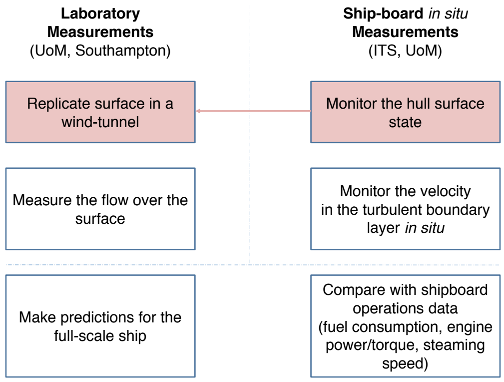

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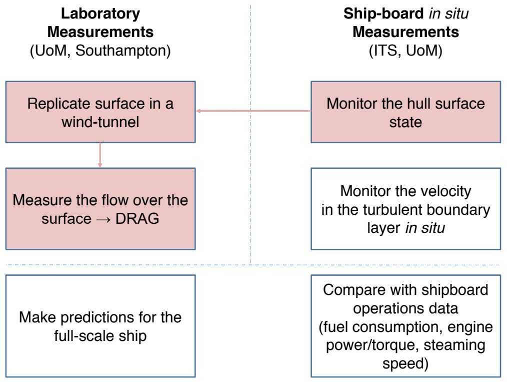

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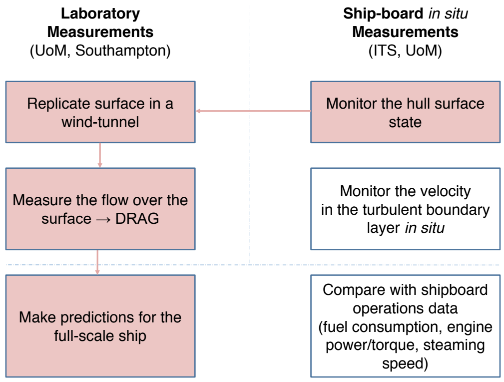

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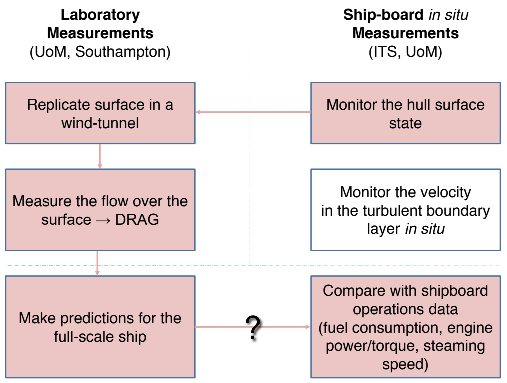

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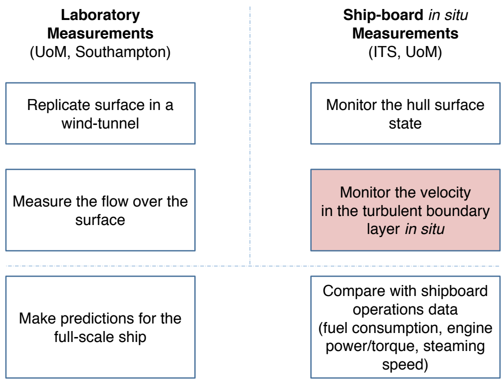

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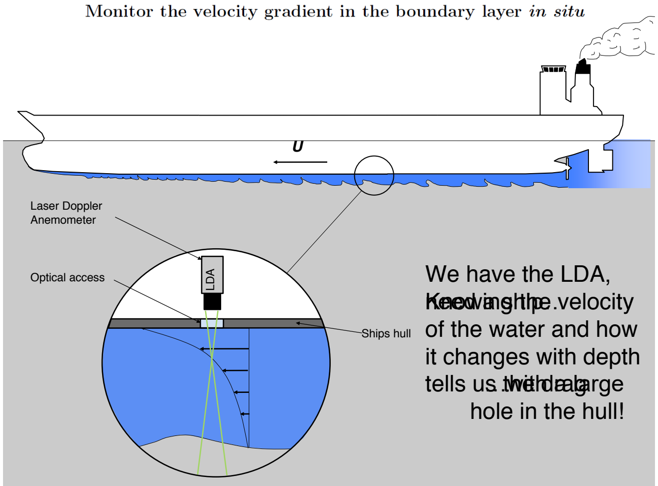

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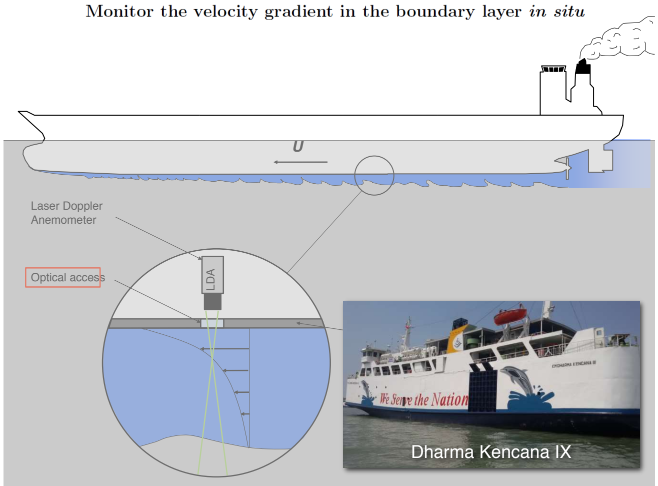

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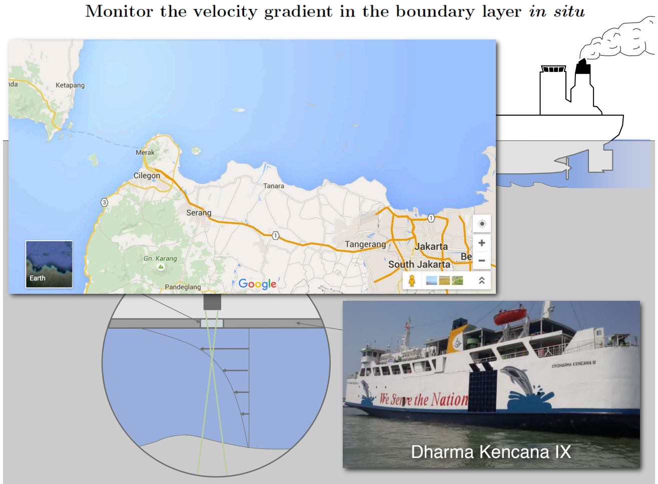

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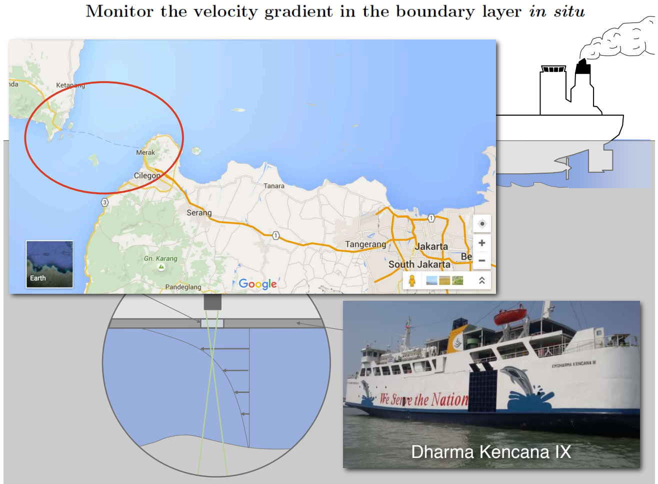

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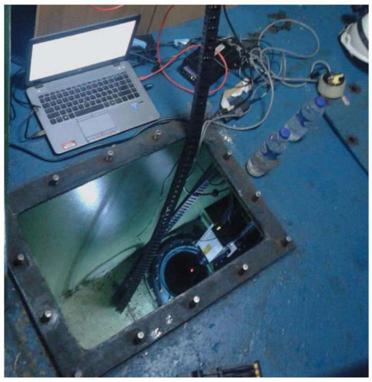

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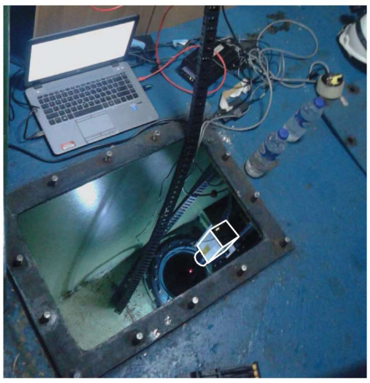
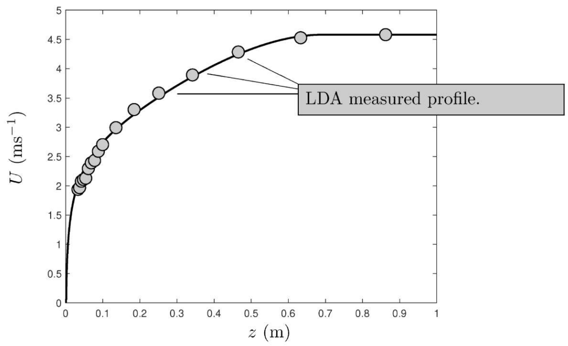


A preliminary *in-situ* TBL measurement

Compare measured mean profile with that from the evolution prediction at $x = 25.5$ m for $k_s = 30$ mm.



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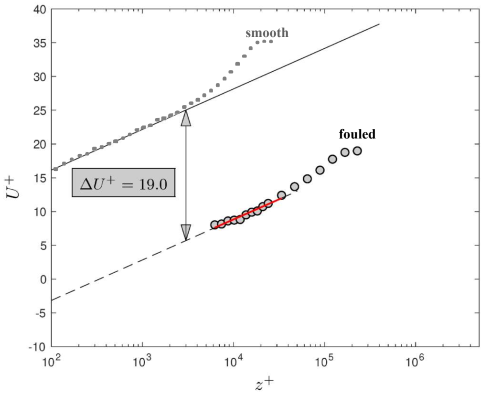

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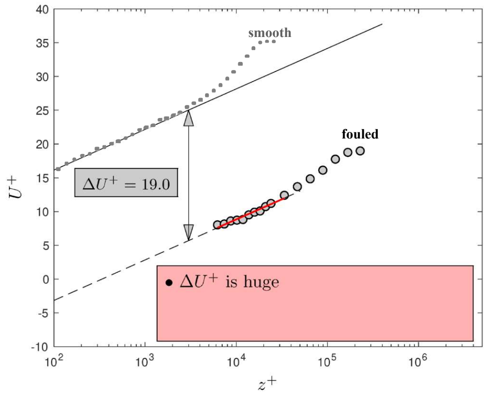

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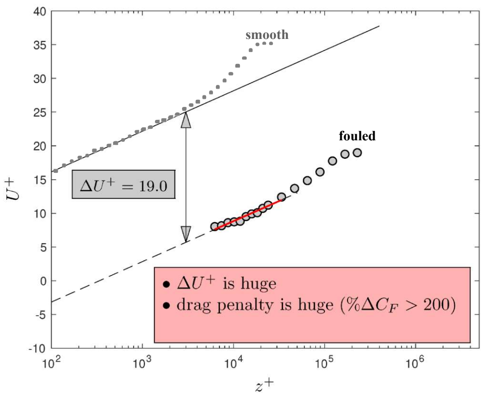

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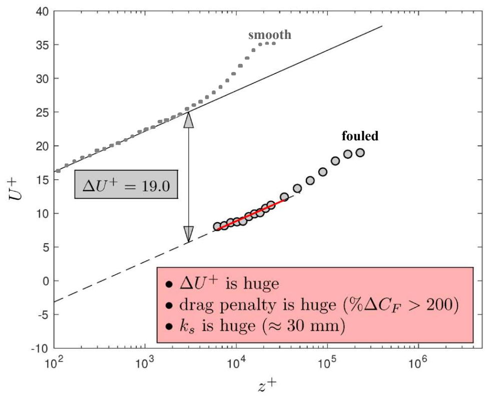

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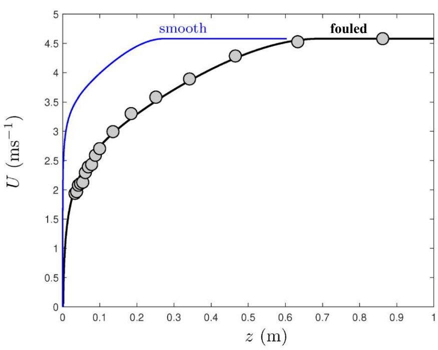

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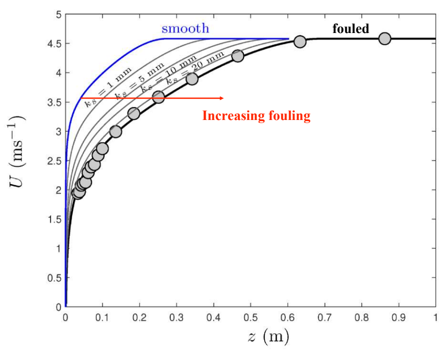
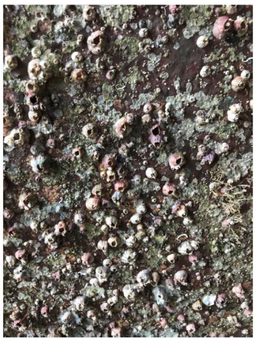


$k_s = 30$ mm: A very dirty ship

Images taken during dry-docking reveal fouling that is consistent with the LDA measured k_s



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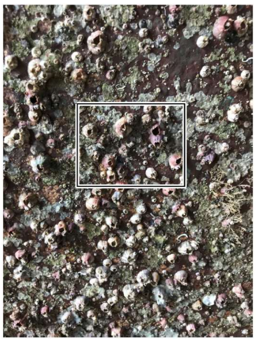

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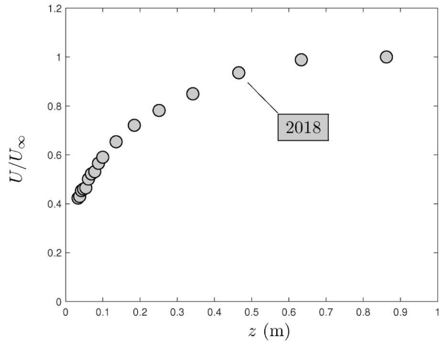

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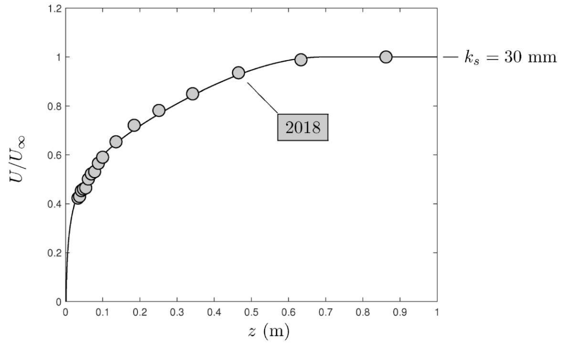

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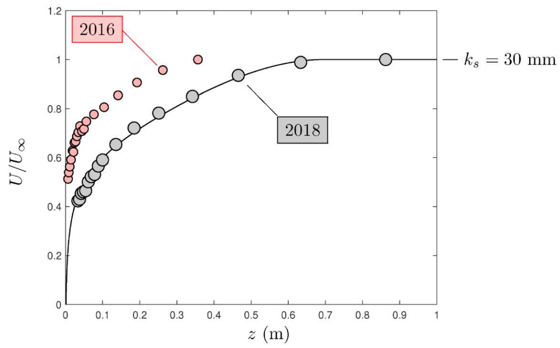

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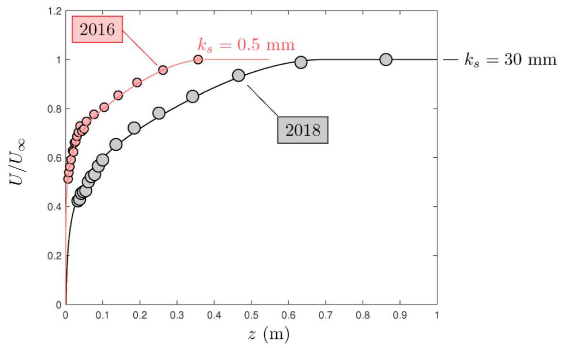

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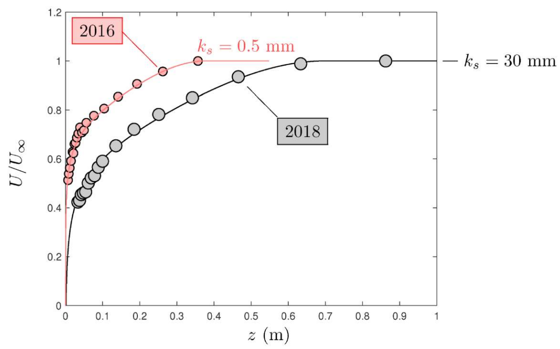

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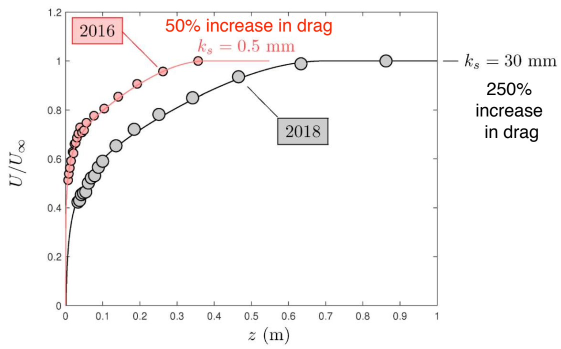

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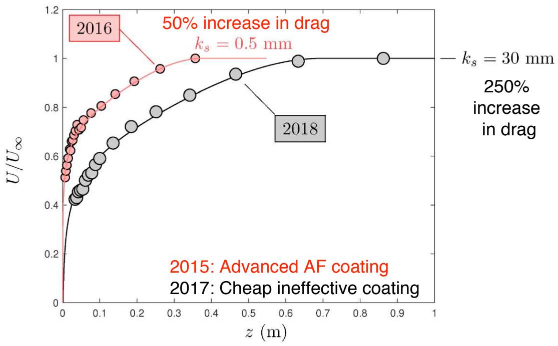
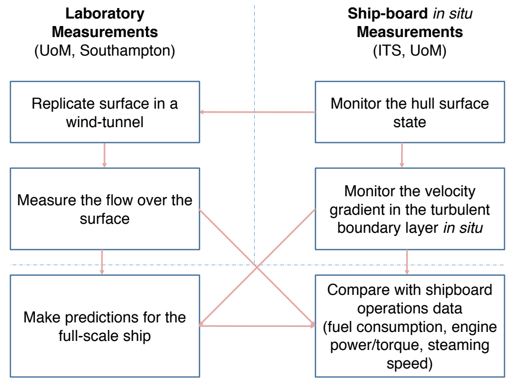


In-situ + Lab experiments



Conclusions

Inability to ascribe equivalent sand-grain roughness k_s is a major bottleneck in efforts to quantify the roughness penalty

BAGUS NUGROHO
Associate Lecturer, Department of Mechanical Engineering
University of Melbourne, Australia

International collaborative research in ship drag penalty due to hull roughness

International collaborative research in ship drag penalty due to hull roughness

Bagus Nugroho[1,2], Rio Baidya[1], Muhammad Nizar Nurrohman[3], Adi Yusim[4], Fredhi Agung Prasetyo[5], Mohammad Yusuf[6], I Ketut Suastika[3], I Ketut Aria Pria Utama[3], Cheng Chin[7], Jason Monty[1], Nicholas Hutchins[1], Bharathram Ganapathisubramani[2]

1. The University of Melbourne
2. University of Southampton
3. Institut Teknologi Sepuluh Nopember
4. Universitas Jember
5. PT Biro Klasifikasi Indonesia
6. PT Dharma Lautan Utama
7. The University of Adelaide

4th ANZPAC, Melbourne, 30 September – 4 October 2019

Outline

- Background
- Research team and Funding
- Activities and Results so far
- Future work

Background

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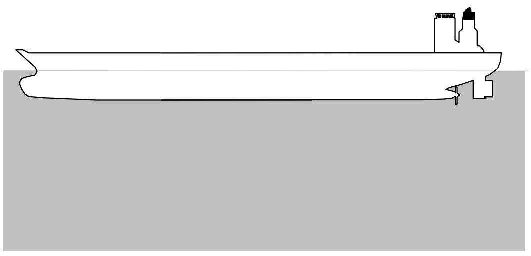

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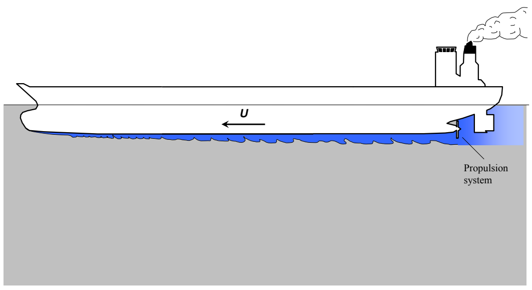

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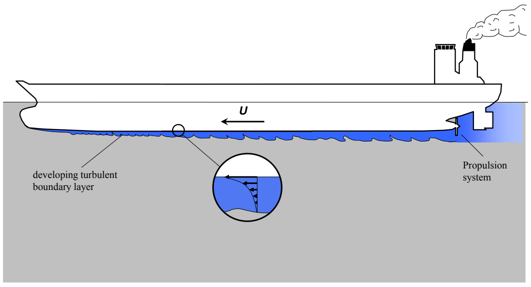
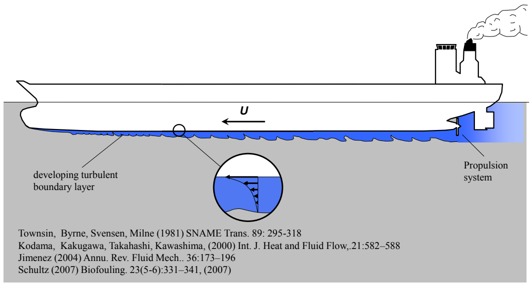


Background

- Up to 80%–90% of the total drag experienced by a large bulk carrier could be due to turbulent skin-friction drag.



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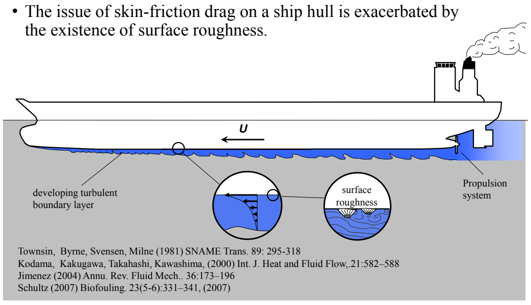
- Up to 80%–90% of the total drag experienced by a large bulk carrier could be due to turbulent skin-friction drag.
- The issue of skin-friction drag on a ship hull is exacerbated by the existence of surface roughness.



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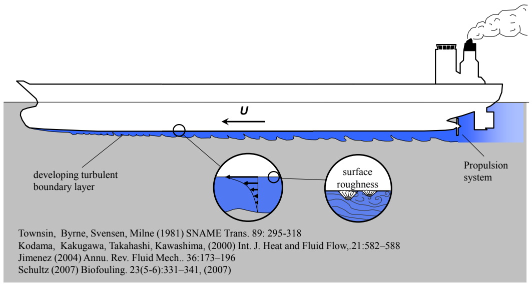

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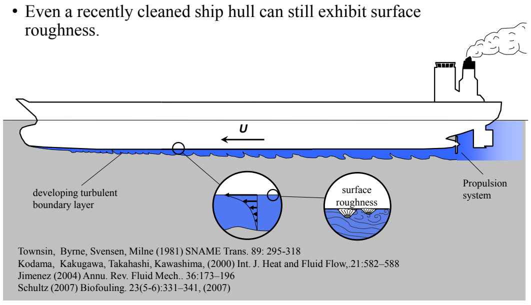
- Even a recently cleaned ship hull can still exhibit surface roughness.



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Difficult to do all simultaneously

Need plenty of human resources

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Classification Bureau:
- PT Biro Klasifikasi Indonesia (PT BKI) - Indonesia

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Laboratory Measurements

Replicate surface in a laboratory facility

Measure the flow over the surface

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Monitor the hull surface state

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Compare with shipboard operations data (fuel consumption, engine power/torque, steaming speed)

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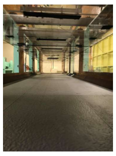

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Activities and results

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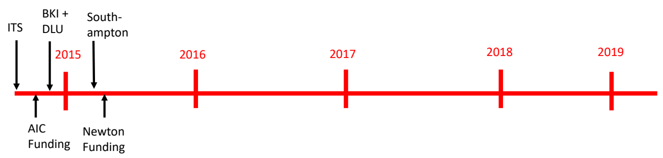

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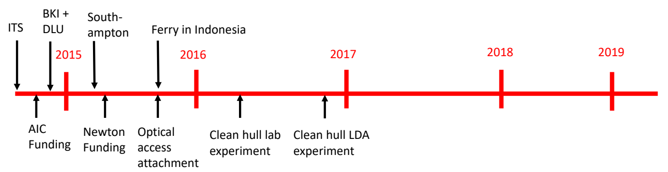

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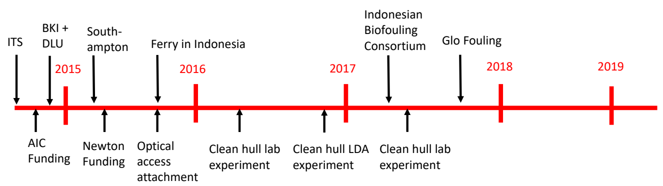

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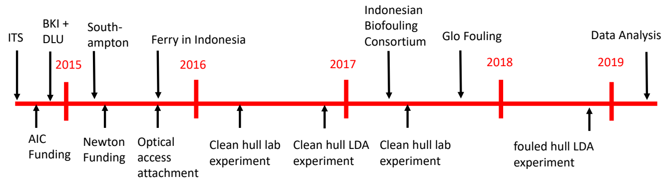

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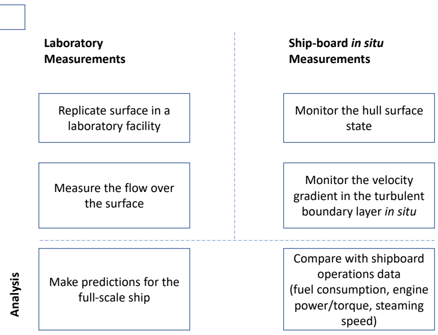

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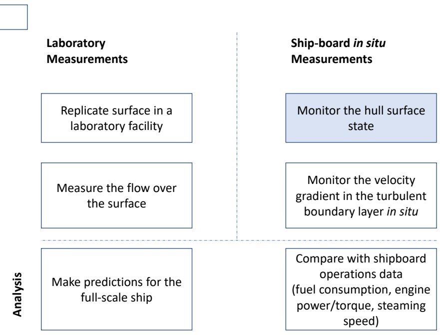

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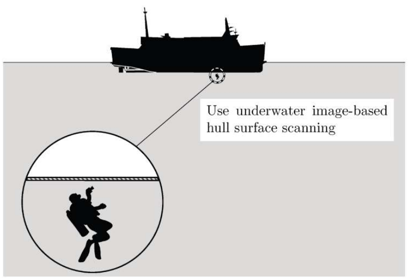

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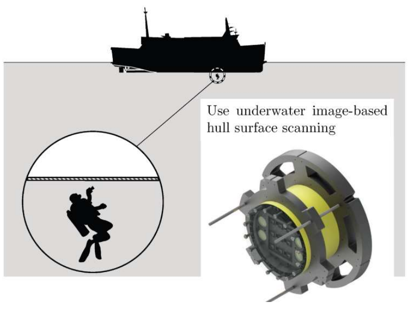
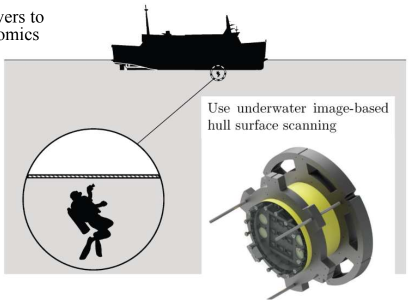


Activities and results

2015-2018

Working with divers to design the ergonomics



Activities and results

2015-2018

Regular monitoring of the hull state

Using standard stereo photogrammetry / tomography techniques, multiple images are reconstructed into 3D surface scan data

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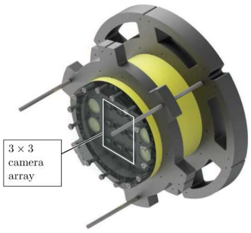
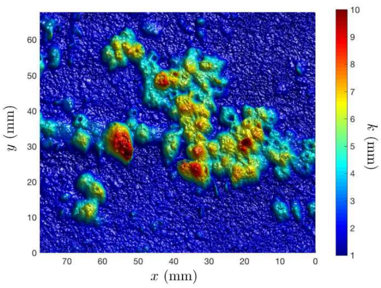


Activities and results

2015-2018

Activities and results

2015-2018



Activities and results

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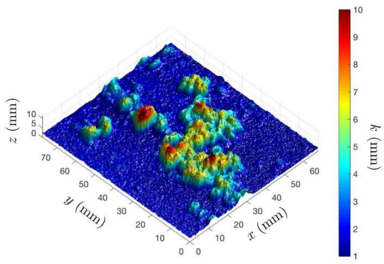

Activities and results

2015-2018

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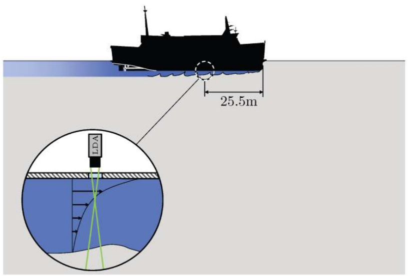
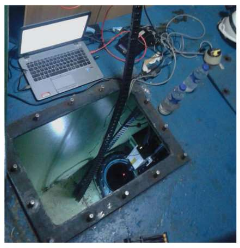


Activities and results

2015-2018



Activities and results

2015-2018

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2015-2018

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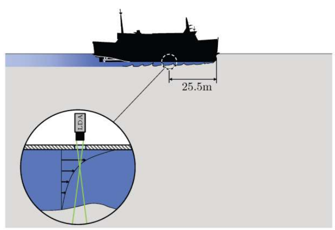


Activities and results

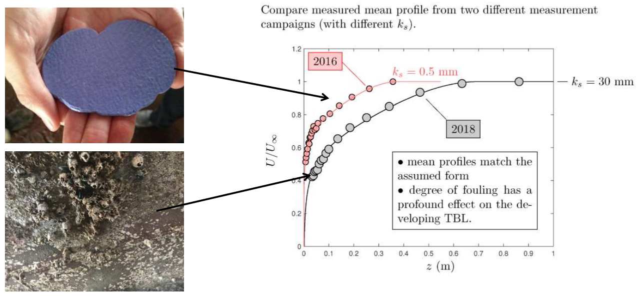
2015-2018

Activities and results

2015-2018

Same ship - different years

Compare measured mean profile from two different measurement campaigns (with different k_s).



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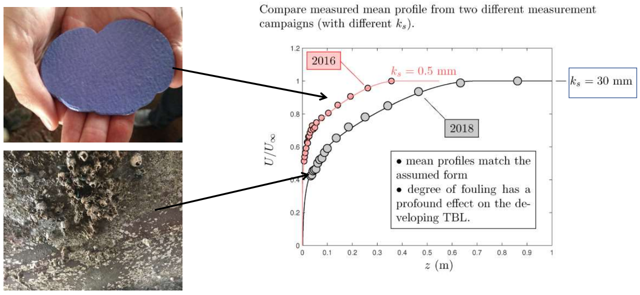

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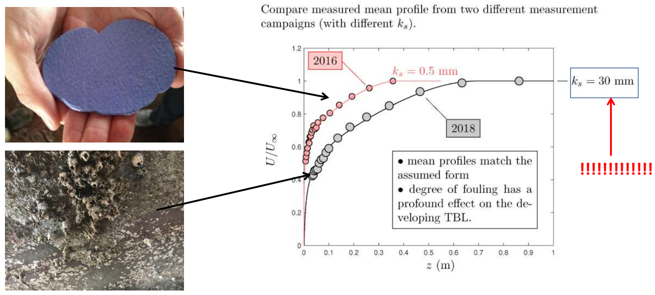

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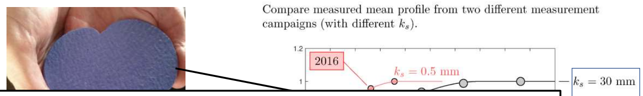

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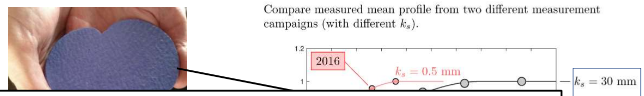

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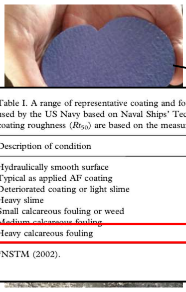

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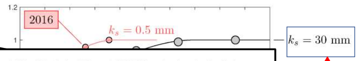

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Activities and results

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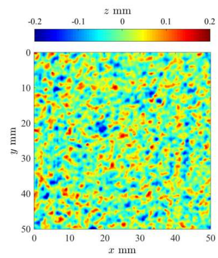

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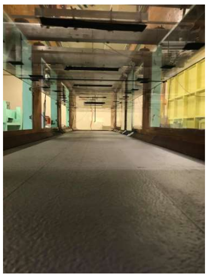
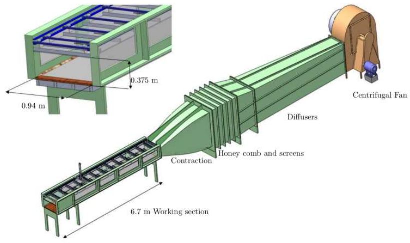




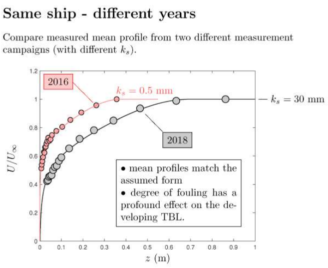
Activities and results

2015-2018

Sand grain equivalent roughness height = 0.1232 mm

Activities and results

2015-2018



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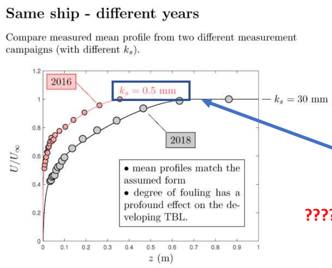

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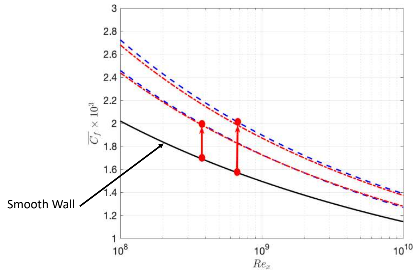

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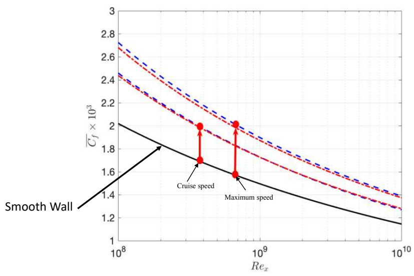

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Activities and results

2015-2018

Empirical estimation

$$\Delta U^+ = \frac{1}{\kappa} \ln k_a^+ + \beta \log ES_x + \gamma$$

L. Chan, M. MacDonald, D. Chung, N. Hutchins, A. Ooi. (2015) J. Fluid Mech, 771:743–777

Activities and results

2015-2018

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$$\Delta U^+ = \frac{1}{\kappa} \ln k_a^+ + \beta \log ES_x + \gamma$$

Only need average height k_a and effective slope ES_x.

Where κ is log law constant 0.4, β and γ is roughness empirical constant 1.47 and 1.12 respectively.

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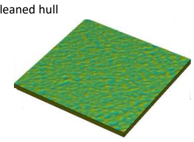
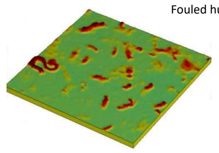
Activities and results

2015-2018

Recently cleaned hull



Fouled hull



Activities and results

2015-2018

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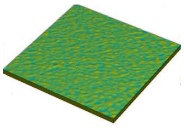

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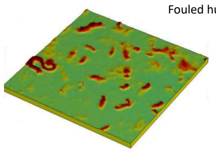

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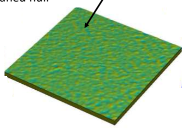

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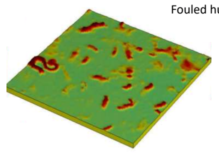

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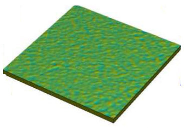

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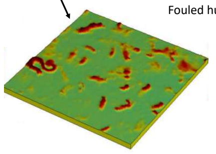

Activities and results

2015-2018

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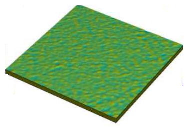

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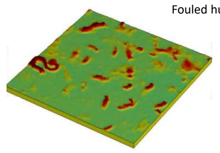

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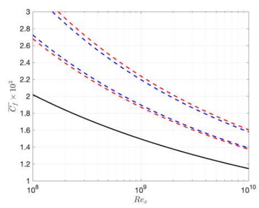

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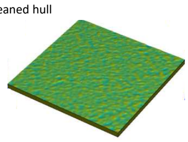

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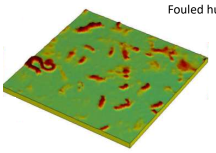
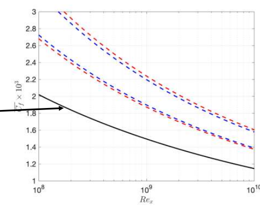


Activities and results

2015-2018

Smooth Wall



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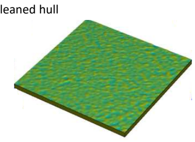

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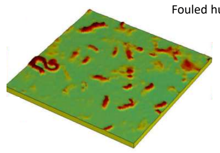

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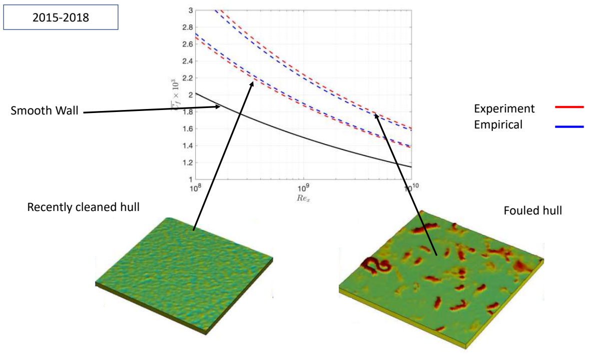

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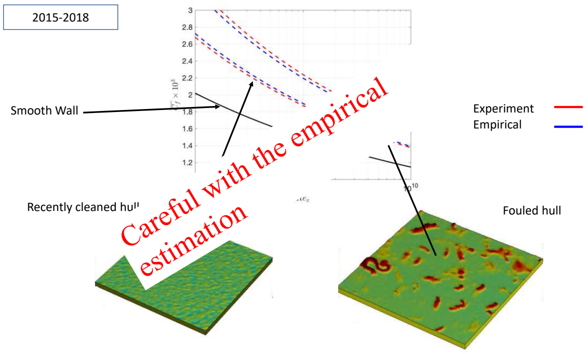
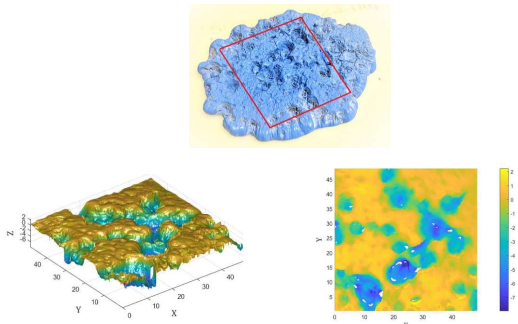


Results so far



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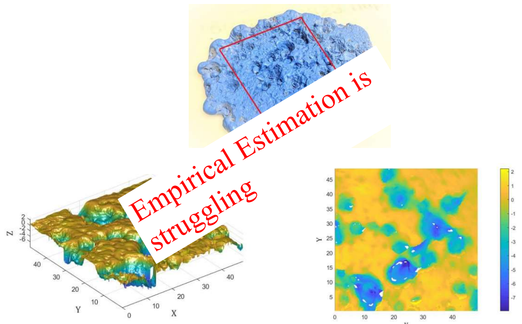

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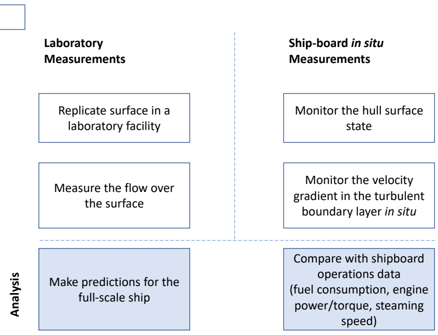


Activities and results

2015-2018

M.L. Hakim, N. Maqbulyani, B. Nugroho, I.K. Suastika, and I.K.A.P. Utama (2019)*Wind tunnel experiments and CFD simulations study to investigate the effects of roughness on ship resistance.* The International Conference on Ocean, Engineering Technology and Environmental Sustainability (I-OCEANS). Kuala Terengganu, Malaysia.

I. K. A. P. Utama, B. Nugroho, R. Baidya, M. N. Nurrohman, A. K. Yusim, F. A. Prasetyo, M. Yusuf, I. K. Suastika, B. Ganapathisubramani, J. P. Monty, N. Hutchins, (2018) *Skin friction drag measurement over a recently cleaned and painted ship hull under steady cruising via in-situ laser-based measurement coupled with empirical estimation*. Royal Institution of Naval Architects (RINA) Conference, *Full Scale Ship Performance. London, United Kingdom.*

B. Nugroho, I. K. A. P. Utama, J. P. Monty, N. Hutchins, B. Ganapathisubramani (2018)*The influence of in-plane roughness wavelength relative to the boundary layer thickness.* 12th International ERCOFTAC Symposium on Engineering Turbulence Modelling and Measurements (ETMM). Montpellier, France.

I. K. A. P. Utama, B. Nugroho, J. P. Monty, N. Hutchins, B. Ganapathisubramani (2018) *Recent progress in estimating ship-hull drag penalty. The* 1st Maritime Safety International Conference (MASTIC). Bali, Indonesia.

M.L. Hakim, B. Nugroho, C. Chin, T. Putranto, I. K. Suastika. I K.A.P. Utama (2018) Assessment of drag penalty resulting from the roughness of freshly cleaned and painted ship hull using Computational Fluid Dynamics. 11th International Conference on Marine Technology (MARTEC). Kuala Lumpur. Malaysia.

M.L. Hakim, I K.A.P. Utama, B. Nugroho, A.K. Yusim, M.S. Baithal, I K. Suastika (2017) *Review of correlation between marine fouling and fuel consumption on ships*. SENTA 2017: 17th Conference on Marine Technology. Surabaya, Indonesia.

B. Nugroho, R. Baidya, M. N. Nurrohman, A. K. Yusim, F. A. Prasetyo, M. Yusuf, I. K. Suastika, I. K. A. P. Utama, J. P. Monty, N. Hutchins, B. Ganapathisubramani (2017) *In-situ turbulent boundary layer measurements over freshly cleaned ship-hull under steady cruising*. Royal Institution of Naval Architects (RINA) Conference, International Conference on Ship and Offshore Technology (ICSOT). Jakarta, Indonesia.

I. K. A. P. Utama, B. Nugroho, C. Chin, M. L. Hakim, F. A. Prasetyo, M. Yusuf, I. K. Suastika, J. P. Monty, N. Hutchins, B. Ganapathisubramani (2017) *A study of skin friction drag from realistic roughness of a freshly cleaned and painted ship hull*. International Symposium on Marine Engineering (ISME). Tokyo, Japan.

N. Hutchins, J. P. Monty, B. Ganapathisubramani, B. Nugroho, I. K. A. P. Utama (2016) *Turbulent boundary layers developing over rough surfaces: from the laboratory to full-scale systems.* Plenery speaker paper. *20*th Australasian Fluid Mechanics Conference (AFMC). Perth, Australia.

I. K. A. P. Utama, B. Ganapathisubramani, N. Hutchins, B. Nugroho, J. P. Monty, F. A. Prasetyo, M. Yusuf, M. Tullberg (2016) *International collaborative work to improve research quality and enhance academic achievement.* Royal Institution of Naval Architects (RINA) Conference, Education & Professional Development of Engineers in the Maritime Industry, Singapore.

Activities and results

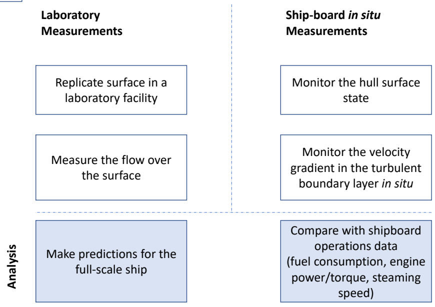
2015-2018

Four Journal papers in the pipeline

1. The influence of roughness wavelength and average height on turbulent boundary layers.
2. In-situ turbulent boundary layer measurements over ship-hull under steady cruising.
3. Revisiting rough hull drag penalty.
4. Empirical estimation technique for ship drag penalty due to roughness.

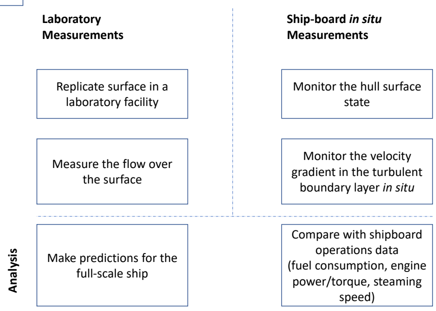
Activities and results

2015-2018



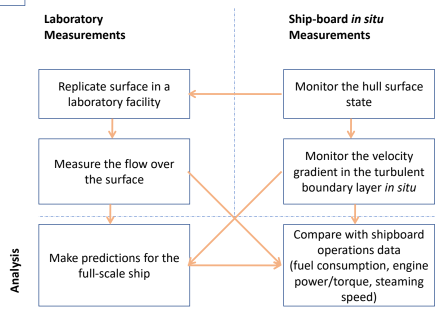
Activities and results

2015-2018



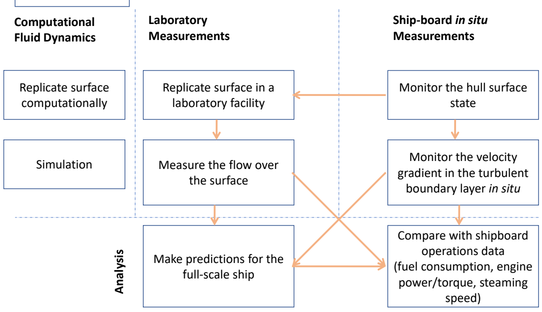
Activities and results

2018-2019



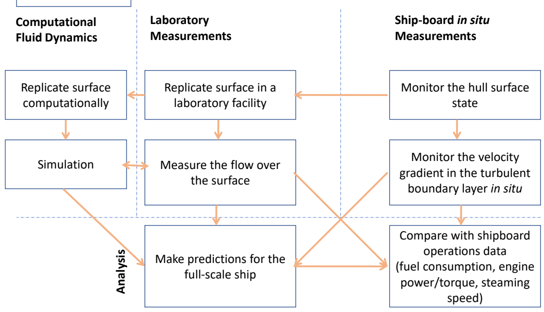
Activities and results

2018-2019



Activities and results

2018-2019



Activities and results

2018-2019

Activities and results

2018-2019

Indonesia Biofouling consortium

- Prof I Ketut Aria Pria Utama (Institut Teknologi Sepuluh Nopember)
  expertise: ship hydrodynamics, ship design.
- Prof Sunaryo (Universitas Indonesia)
  expertise: ship production, ship construction
- Dr Romanus Prabowo (Universitas Jenderal Sudirman)
  expertise: biofoulings, bio diversity
- Dr Fredhi Agung (PT Biro Klasifikasi Indonesia)
  expertise: ship safety

Activities and results

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IMO Glo-Fouling : Advising the Indonesian Government

Activities and results

2018-2019

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Education

2 masters students
1 PhD students

Activities and results

2018-2019

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IMO Glo-Fouling : Advising the Indonesian Government

Education

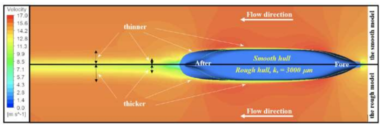
2 masters students
1 PhD students

Joint research with developing nations are very rewarding

Future work

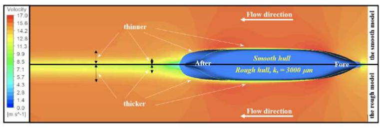
Future work

2019 and beyond



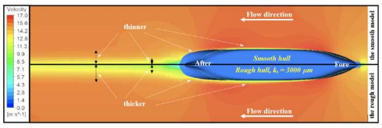
Future work

2019 and beyond



Future work

2019 and beyond



Future work

2019 and beyond

BERNARDO A.P. DA GAMA
Professor, Department of Marine Biology
Universidade Federal Fluminense, Brazil

Bernardo A.P. da Gama is a marine biologist, scientist and university professor, working at the Universidade Federal Fluminense (Niterói, Rio de Janeiro), mainly with benthic marine chemical ecology (in particular, antifouling defence), biofouling, and marine community ecology. He has also collaborated or supervised students in fields as diverse as microplastics pollution and marine bioinvasions. He is also interested in the good/novel use of biostatistics in ecological studies and in everything else concerning biodiversity conservation.

Antifouling solutions from seaweed biomimetics

Bernardo A.P. da Gama, Rodrigo P. de A. Santos, Renato C. Pereira Universidade Federal Fluminense Rio de Janeiro, Brazil

Since ancient times, human entrepreneurship has faced the seas, but biofouling has always imposed severe constraints to all maritime activities. The usual way to deal with the undesired growth of marine benthic organisms on man-made structures has been to employ the “biocide approach”, such as the recently banned tributyltin (TBT), effective but harmful to marine life. Substitute biocides comprise a Pandora’s box of different synthetic compounds, mostly with unknown environmental fate and toxicity. A paradigm shift is therefore urgent in order to deal with biofouling efficiently, but in an environmentally friendly way. The emerging field of biomimetics comprises the imitation of the models, systems, and elements of nature to solve complex human problems. A biomimetic approach to deal with biofouling is based on the fact that seaweeds, as benthic, sessile organisms living in the euphotic zone, where fouling pressure is maximal, had billions of years to evolve antifouling defense, and different seaweeds are known to dedicate energy and resources in the production, storage and release of natural antifouling compounds. However, natural defense mechanisms are often multifaceted, and emerging evidence has accumulated concerning other macroalgal mechanisms to keep thalli devoid of undesired growth, such as oxidative bursts, epithallus sloughing, bacterial quorum sensing modulation and microtopography. Bioinspired antifouling approaches to some of these mechanisms already exist - such as microencapsulation, ablative, and low-adhesion paints – or are under investigation, such as engineered antifouling microtopographies and quorum sensing modulation. It seems likely that, in order to develop new solutions to this old problem, we need to learn from nature and develop bioinspired antifouling solutions that combine several mechanisms. A combined biotechnological approach joining chemical and physical antifouling defense is expected to start soon. Understanding global patterns and mechanisms underlying the production of algal antifoulants is a fundamental step toward this goal.

1st GEF-UNDP-IMO GloFouling R&D Forum and Exhibition on Biofouling Management

4th ANZPAC Workshop on Biofouling Management for Sustainable Shipping

Antifouling solutions from seaweed biomimetics

Prof. Dr. Bernardo A.P. da Gama

Universidade Federal Fluminense

Niteroi - Rio de Janeiro

Melbourne, 2 October 2019

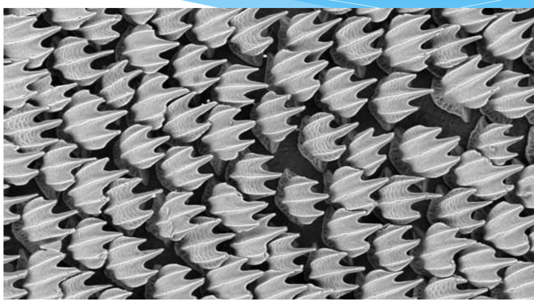
The biocide approach to antifouling

- Problem: marine biofouling
- Affects not only navigation but all human-made affairs in the sea – including clean energy generation
- Fouled ships transport exotic species to new sites where they may turn into bioinvaders
- Past and present solutions involve a "biocide approach", using toxic compounds with adverse effects on marine life
- TBTs, copper and a plethora of other 'booster biocides'

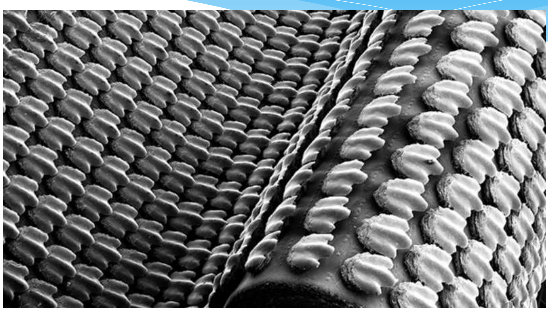
Biomimetics

- Imitation of the models, systems, and elements of nature
- Purpose: solving complex human problems
- Marine life has *always* been a source of inspiration!

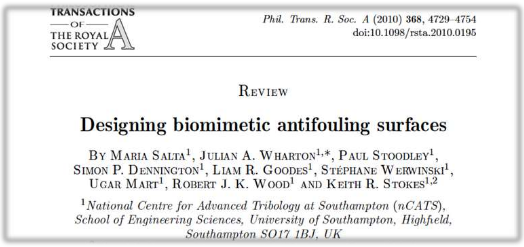
Biomimetics



Biomimetics



Biomimetics & Antifouling



TRANSACTIONS OF THE ROYAL SOCIETY A

Phil. Trans. R. Soc. A (2010) 368, 4729–4754
doi:10.1098/rsta.2010.0195

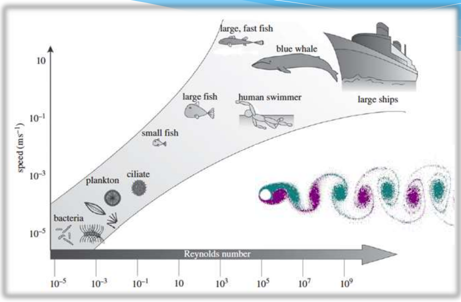
Review

Designing biomimetic antifouling surfaces

By Maria Salta[1], Julian A. Wharton[1,*], Paul Stoodley[1], Simon P. Dennington[1], Liam R. Goodes[1], Stéphane Werwinski[1], Ugar Mart[1], Robert J. K. Wood[1] and Keith R. Stokes[1,2]

[1]*National Centre for Advanced Tribology at Southampton (nCATS), School of Engineering Sciences, University of Southampton, Highfield, Southampton SO17 1BJ, UK*

Why seaweeds?



Hydrodynamic interactions - Reynolds number variation for biological systems with respect to speed.
Source: Salta *et al.* (2010) *Phil. Trans. R. Soc. A.*

Why seaweeds?

- Sessile and restricted to the euphotic zone
- Face the same problems due to biofouling / epibiosis
- Best chemists in the sea
- Emerged 2.8 billion years ago*
- Selected for AF defenses over a long evolutionary timescale!

Image: Fraser Shiers

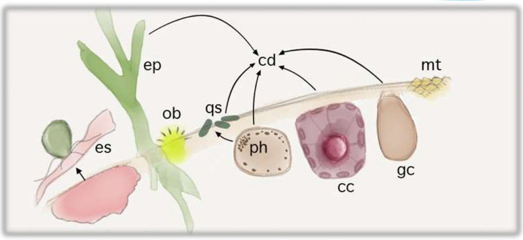
* Des Marais (2001) On the origins of photosynthesis. *Science 19*: 436.

Algae became fouled

NOAA/SiMON

Algae became fouling

Seaweed strategies to deal with biofouling



Da Gama *et al.* (2014) *Advances in Botanical Research*

Natural product-based seaweed antifoulants

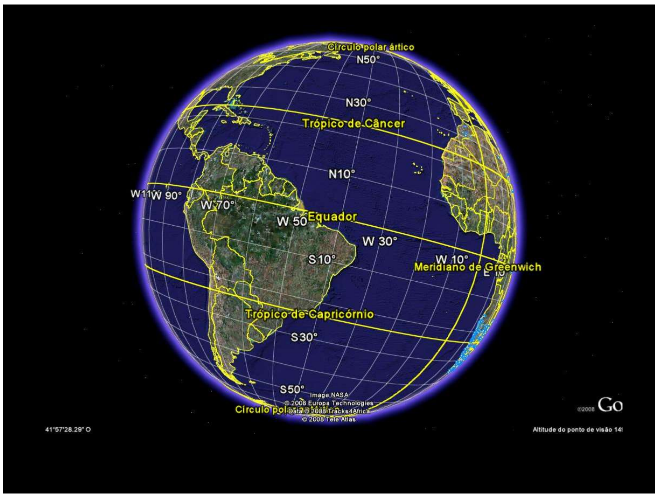
- Laboratory

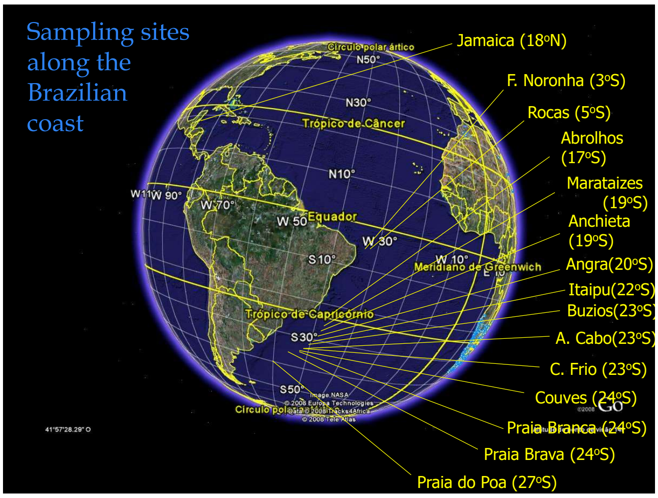
12

Da Gama *et al.* (2003) *Biofouling*


Natural product antifoulants
Field
R2P6


Image NASA
© 2008 Europa Technologies
Data © 2008 Tracks4Africa


Círculo polar ártico
N50°
N30°
Trópico de Câncer
N10°
W 90°
W 70°
W 50
Equador
W 30°
S 10°
W 10°
Meridiano de Greenwich
Trópico de Capricórnio
S30°
S50°
Círculo polar
Image NASA
© 2008 Europa Technologies
41°57'28.29" O


Sampling sites along the Brazilian coast
Jamaica (18°N)
F. Noronha (3°S)
Rocas (5°S)
Abrolhos (17°S)
Marataizes (19°S)
Anchieta (19°S)
Angra(20°S)
Itaipu(22°S)
Buzios(23°S)
A. Cabo(23°S)
C. Frio (23°S)
Couves (24°S)
Praia Branca (24°S)
Praia Brava (24°S)
Praia do Poa (27°S)
Círculo polar ártico
N50°
N30°
Trópico de Câncer
N10°
W 90°
W 70°
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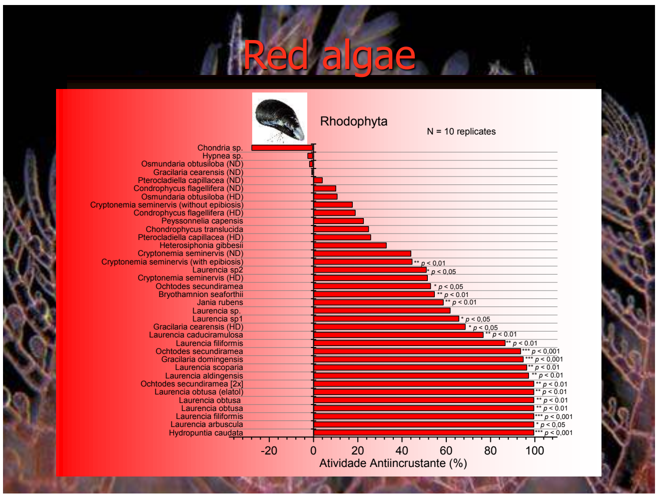
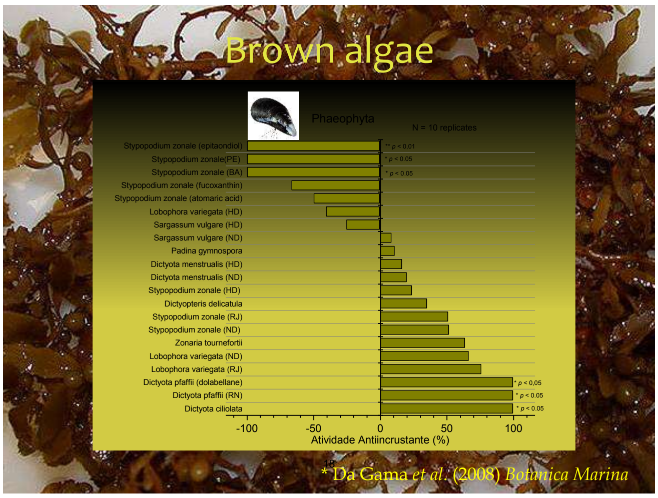
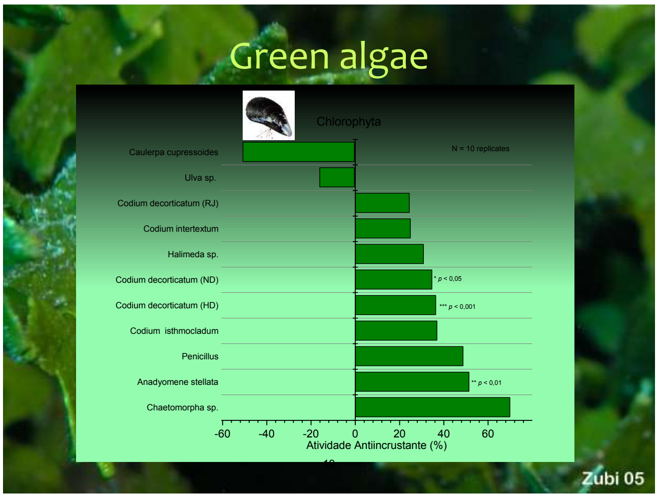
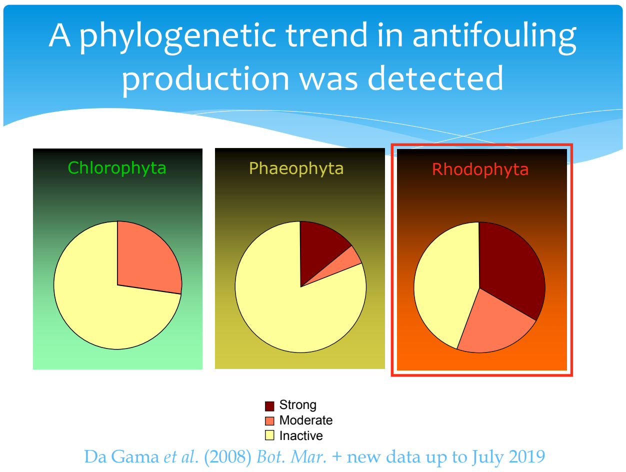
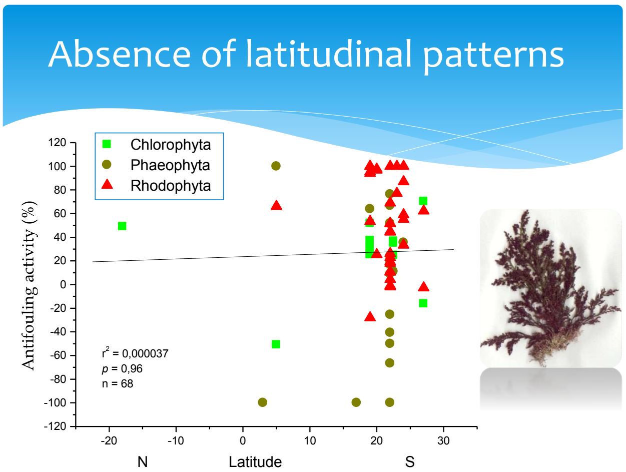
S 10°
W 10°
Meridiano de Greenwich
Trópico de Capricórnio
S30°
41°57'28.29" O

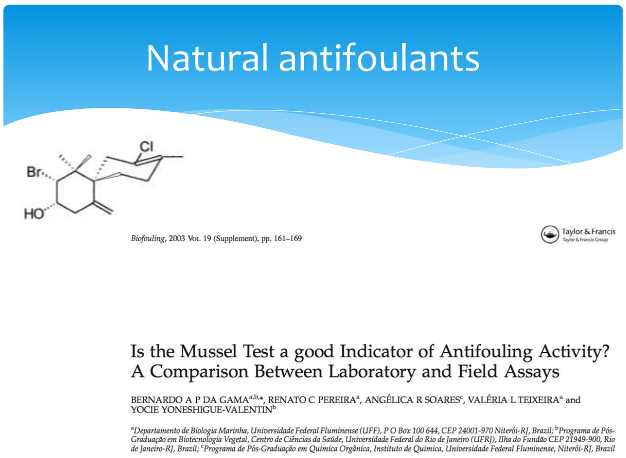

Red algae
Rhodophyta
N = 10 replicates
-20
0
20
40
60
80
100
Atividade Antiincrustante (%)

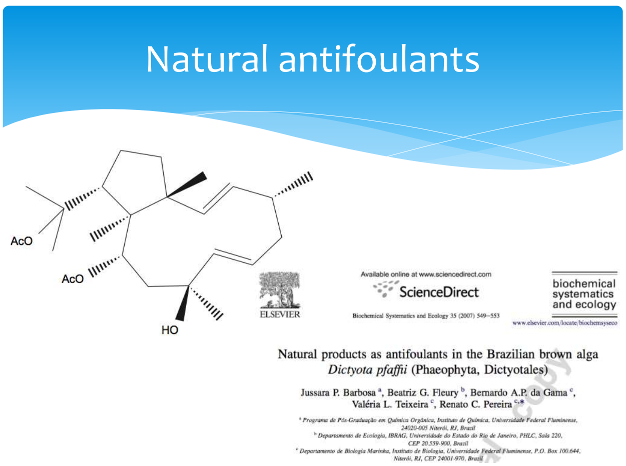

Brown algae
Phaeophyta
N = 10 replicates
-100
-50
0
50
100
Atividade Antiincrustante (%)
* Da Gama et al. (2008) Botanica Marina

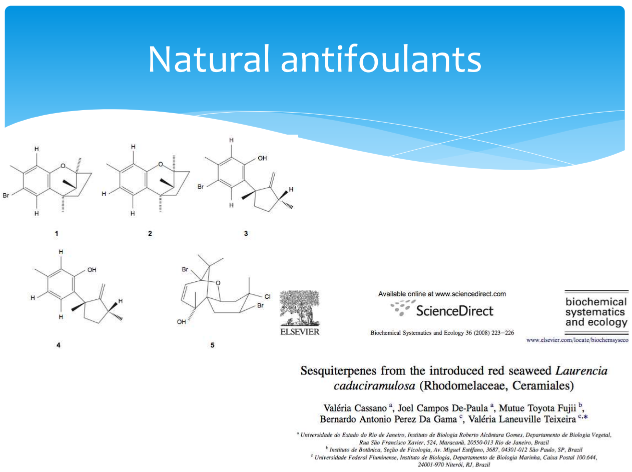

Green algae
Chlorophyta
N = 10 replicates
Caulerpa cupressoides
Ulva sp.
Codium decorticatum (RJ)
Codium intertextum
Halimeda sp.
Codium decorticatum (ND)
Codium decorticatum (HD)
Codium isthmocladum
Penicillus
Anadyomene stellata
Chaetomorpha sp.
* p < 0,05
*** p < 0,001
** p < 0,01
-60 -40 -20 0 20 40 60
Atividade Antiincrustante (%)
Zubi 05


A phylogenetic trend in antifouling production was detected
Chlorophyta
Phaeophyta
Rhodophyta
Strong
Moderate
Inactive
Da Gama et al. (2008) Bot. Mar. + new data up to July 2019


Absence of latitudinal patterns
Chlorophyta
Phaeophyta
Rhodophyta
Antifouling activity (%)
r² = 0,000037
p = 0,96
n = 68
N
Latitude
S


Natural antifoulants
Br
HO
Cl
Biofouling, 2003 Vol. 19 (Supplement), pp. 161–169
Taylor & Francis
Is the Mussel Test a good Indicator of Antifouling Activity? A Comparison Between Laboratory and Field Assays
BERNARDO A P DA GAMA, RENATO C PEREIRA, ANGÉLICA R SOARES, VALÉRIA L TEIXEIRA and YOCIE YONESHIGUE-VALENTIN

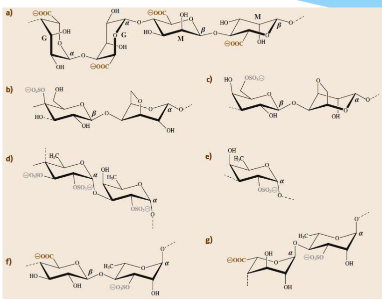

Natural antifoulants
AcO
AcO
HO
ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
biochemical systematics and ecology
Biochemical Systematics and Ecology 35 (2007) 549–553
Natural products as antifoulants in the Brazilian brown alga Dictyota pfaffii (Phaeophyta, Dictyotales)
Jussara P. Barbosa, Beatriz G. Fleury, Bernardo A.P. da Gama, Valéria L. Teixeira, Renato C. Pereira


Natural antifoulants
ELSEVIER
Available online at www.sciencedirect.com
ScienceDirect
biochemical systematics and ecology
Biochemical Systematics and Ecology 36 (2008) 223–226
Sesquiterpenes from the introduced red seaweed Laurencia caduciramulosa (Rhodomelaceae, Ceramiales)
Valéria Cassano, Joel Campos De-Paula, Mutue Toyota Fujii, Bernardo Antonio Perez Da Gama, Valéria Laneuville Teixeira

Coefficient of Friction Hypothesis

- μ = 0,07 (coefficient of friction varies from 0 – 1)
- Rough surfaces have higher values
- Seaweed polysaccharides may reduce μ, thus hindering adhesion

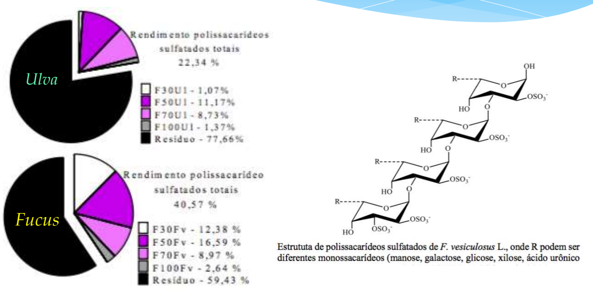
Seaweed polysaccharides



(a) alginate
(b) *k*-carrageenan
(c) agarose-6-sulfate
(d,e) fucoidans
(f,g) ulvans

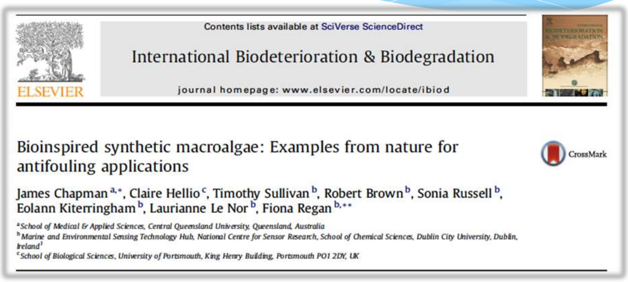
Synytsya *et al*. (2015) *In:* Kim S.E. Springer Handbook of Marine Biotechnology

Seaweed sulphated polysaccharides



Reis, S.E. (2016) Master thesis, UFJF

Other seaweed AF strategies: microtopography



Contents lists available at SciVerse ScienceDirect

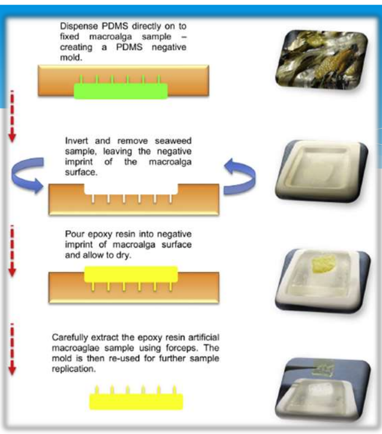
International Biodeterioration & Biodegradation

journal homepage: www.elsevier.com/locate/ibiod

Bioinspired synthetic macroalgae: Examples from nature for antifouling applications

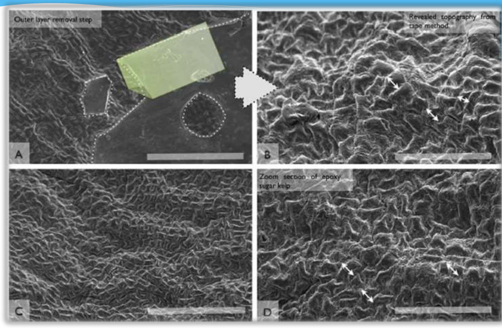
James Chapman [a,*], Claire Hellio [c], Timothy Sullivan [b], Robert Brown [b], Sonia Russell [b], Eolann Kiterringham [b], Laurianne Le Nor [b], Fiona Regan [b,**]

[a] School of Medical & Applied Sciences, Central Queensland University, Queensland, Australia
[b] Marine and Environmental Sensing Technology Hub, National Centre for Sensor Research, School of Chemical Sciences, Dublin City University, Dublin, Ireland
[c] School of Biological Sciences, University of Portsmouth, King Henry Building, Portsmouth PO1 2DY, UK



Chapman et al. (2014) *International Biodeterioration & Biodegradation*

Seaweed microtopography



Chapman et al. (2014) *International Biodegradation & Biodeterioration*

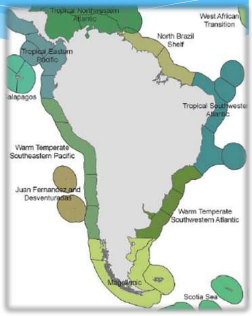
New biomimetic antifoulants

- Combine more than one mechanism (*e.g.*, physical and chemical) – multilevel defense system
- Non-toxic, biodegradable chemicals in coatings with interactive surface properties (ablative / self-polishing coatings, non-adhesive coatings, AF microtopographies)
- Microencapsulation of natural product analogues or even "oxidative burst" emulation
- Quorum-sensing inhibitors or "live paints"
- Glycolipids as AF compounds in brown algae*

* Plouguerné *et al.* (2014) *Frontiers Cell. & Inf. Microbiol.* / Plouguerné *et al.* (2019) in prep.

New biomimetic antifoulants

- Cast light upon the mechanisms underlying AF defence in seaweeds
- Multivariate matrix with satellite-gathered data (SST, chl-*a*, etc.) + AF activity + known natural product composition + known bioactivities
- Provide a basis for new biomimetic antifoulants from macroalgal origin / inspiration
- A combined biotech approach joining chemical & physical AF defence is expected to start in 2020
- Commercially available macroalgal products may lead to fast availability of new biotech AF technologies



Spalding *et al.* (2007) *BioScience*

Thank you! Obrigado!

- CNPq – Research Productivity Grant
- To all our amazing partners: R.C. Pereira, G. Amado-Filho★, R. Coutinho, L. Salgado, W.C. Paradas, D.B. Sudatti, C. Hellio, E. Plouguerné, R.P. Reis & students: R.P.A. Santos, A.G.V. Carvalho★, K. Weidner
- Organizing Committee of the GloFouling Partnerships / 4th ANZPAC, in particular to John Alonso & Violeta Luque

bapgama@gmail.com

John Polglaze
Director
PGM Environment, Australia

John Polglaze served full-time in the Royal Australian Navy (RAN) for 19 years, with sea service in both submarines and surface ships, gaining extensive experience with ship operations and maintenance. He then transferred to the Navy Reserve and began a second career as an environmental consultant. Both as a Naval Officer and civilian consultant, John has around 40 years of maritime experience and has been directly involved with the management of ship biofouling for almost 20 years. He led the RAN biofouling study and formulated the RAN's biofouling management policies and procedures as well as a range of Australia's national biofouling policies and management protocols. This work led to him being invited to author various components of the IMO's international biofouling management guidelines. John works globally, and has conducted more than 500 ship biofouling inspections and risk assessments, including for over 60 warships of 15 different classes. His work spans all elements of the full life spectrum of ships, from concept development and design, through build, trials, operations, maintenance and refit, to decommissioning and disposal. He regularly advises warship design and acquisition programs on environmental compliance matters, including the means to identify and mitigate biofouling risks. John is a Chartered Marine Scientist and a Fellow of IMarEST and is currently studying towards a Diploma in Naval Architecture.

Warships and biofouling: a comparison with commercial ships

As with any ship, warships are prone to biofouling, both of external voids and niches and of internal seawater circulation systems. What is different in comparison with typical merchant ships, however, is the accentuated susceptibilities of warships due to factors such as design, equipment configurations, and typical operating and maintenance profiles. Warships and commercial ships are designed, built, operated and maintained for different purposes and with different operating imperatives, and this is reflected in their differing biofouling risk characteristics. As well as the general biofouling penalties related to fuel efficiency and marine invasive species transfer risks common to all ships, warships also have unique, and mission critical, tactical and operational reasons to better manage biofouling, internally and externally, to ensure that they attain and remain at peak operational efficiency.

This presentation will consider biofouling vulnerabilities of warships - addressing surface combatants, submarines, and naval auxiliaries - and how these differ from those pertaining to archetypal ships in routine commercial service. The presentation will concentrate upon the key and distinct features of the design, equipment fit, and patterns of employment of warships and naval auxiliaries, and how these stand them apart from commercial ships in terms of both their susceptibility to biofouling and the associated challenges of effective management.

Warships and Biofouling

A Comparison with Commercial Ships

John Polglaze

BSc (Hons), MEnvMan&Dev, GradCertMarSci, Cert Auditor (Env), CMarSci, FIMarEST

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PGM 500
Ship Biofouling Inspections / Assessments

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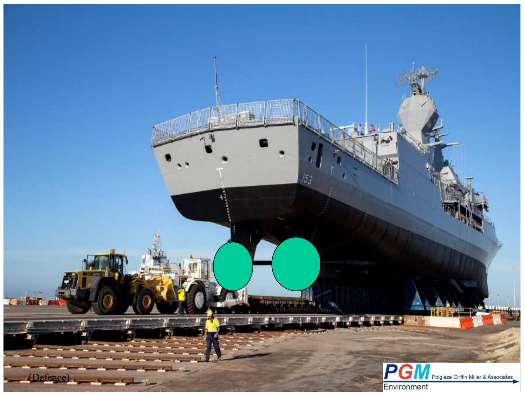
Environment



Fouling Facts: The Fundamentals

- **<u>Every vessel</u>** has some form of fouling (external and/or internal).
- Biofouling is difficult to predict and is an integrator of:
  - vessel design and construction;
  - maintenance, cleaning and anti-fouling coating status; and
  - usage patterns and history of operations.

What are the factors that set warships apart?

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Warship

(USN)

Merchant ship

(Port of Rotterdam)

Merchant ship

(Maritime Hawaii)

Warship

(USN)

Warship

(Defence)

Merchant ship

(BIMCO)

Warship or merchant ship?

Warship or merchant ship?

(Defence)

Warship Biofouling Risk Profiles: Underlying Themes

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- **<u>What</u> are the biofouling characteristics of warships?**
  - **how and why are these different to merchant ships**

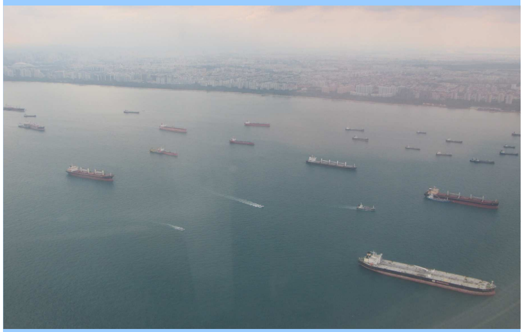
Warship Biofouling Risk Profiles: Underlying Themes

- **<u>What</u> are the biofouling characteristics of warships?**
  - **how and why are these different to merchant ships**
- **<u>Why</u> do warships need to effectively manage biofouling?**
  - **how and why is this different to merchant ships**

Warship Biofouling Risk Profiles: Underlying Themes

- **<u>What</u> are the biofouling characteristics of warships?**
  - **how and why are these different to merchant ships**
- **<u>Why</u> do warships need to effectively manage biofouling?**
  - **how and why is this different to merchant ships**
- **<u>How</u> is it best to manage warship biofouling?**
  - **how and why is this different to merchant ships**

Warship Biofouling Risk Profiles *cf* Merchant Ships



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(USN)

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Ship Biofouling Vulnerability Indicators

- Many and/or complex niches.
- Extended periods of inactivity or low-speed operations, particularly in coastal waters.
- Work in contact with bottom.

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Warship Biofouling Risks

Warships are more prone to hull-fouling than most ships because of their:

- Extensive range and variety of voids and niches (ie. areas of minimal flow)
- Regular, extended periods alongside (>2 weeks)
- Unique (and extensive) seawater intake requirements

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Size Matters?

An estimate of the total wetted surface area (WSA) of ship arrivals into a port or region is essential to determine the potential scope of biofouling and to inform management strategies to reduce the future invasions.

(Moser et al. 2015)

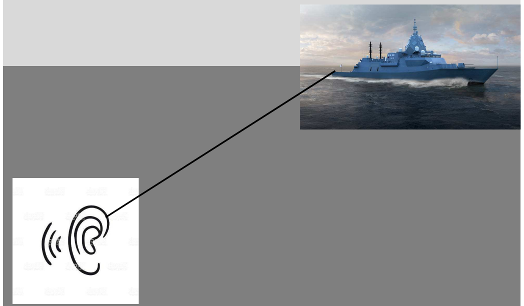
….. and <u>many</u> others.

~ 4000m² wetted surface area

(USN)

Warship Biofouling Management Imperatives *cf* Merchant Ships

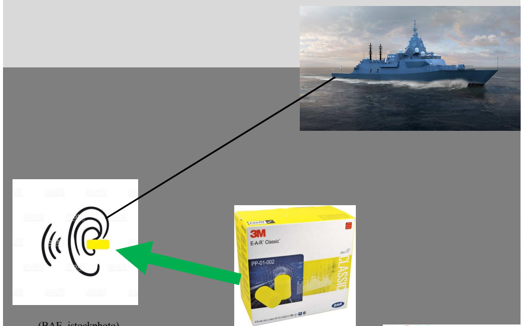
(BAE)



(BAE, istockphoto)

Warship Biofouling: Operational Imperatives

- Self noise:
  - fouling ⬆
  - ship noise ⬆
  - operational effectiveness ⬇
- Underwater sensor performance:
  - fouling ⬆
  - acoustic transfer fidelity ⬇



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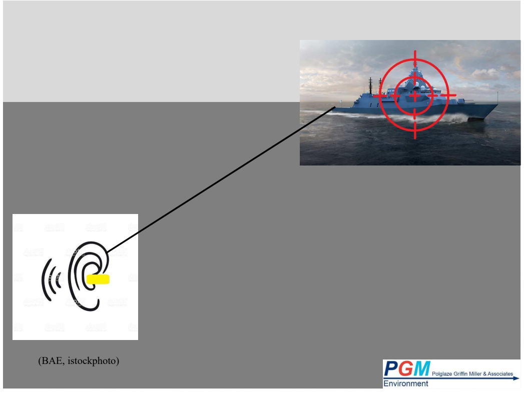

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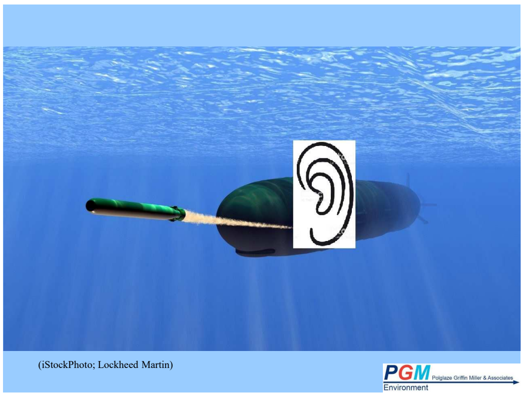


(iStockPhoto; Lockheed Martin)

Warship Biofouling: Operational Imperatives

Conventional SMs:

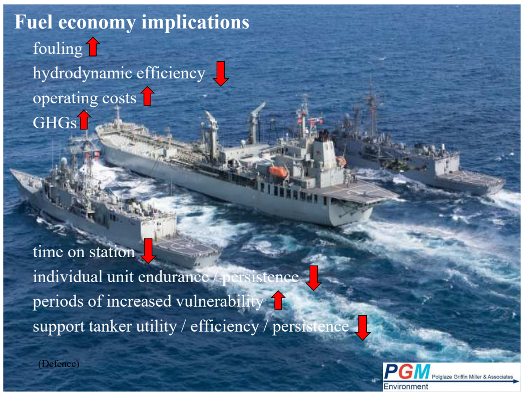
– fouling ⬆
– platform self noise ⬆
– battery endurance ⬇
– snort regularity and duration ⬆
– indiscretion ratio ⬆
– platform effectiveness as low noise listening platform ⬇

- Signature (visual) ?

(Defence)

(Defence)

(USN)



Warship Biofouling: Internal Seawater Systems

- Combat systems
  - fouling ↑
  - system cooling efficiency ↓
  - system availability and reliability ↓
  - ship combat effectiveness ↓
- Habitability
  - fouling ↑
  - system cooling efficiency ↓
  - personnel comfort and efficiency ↓

Environment

Warship Biofouling: Force Protection Considerations

Biosecurity management responses can:

- Result in ship being sent to sub-optimal berth/anchorage.
- Require isolation of seawater intake systems, with implications for:
  - system availability / redundancy
  - firefighting capacity

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Warship Biofouling Risks

In operational terms, biofouling can:

- Reduce hull and propulsion hydrodynamic efficiency, with resultant decease in endurance, requiring more regular refuelling **(external fouling) – merchant ship issue?**
- Reduce hull and propulsion hydrodynamic efficiency, with resultant increase in ship self-noise and lowering of cavitation inception speed **(external fouling) – merchant ship issue?**
- Degrade platform's effectiveness as a low self-noise acoustic sensor platform **(external fouling) – merchant ship issue?**

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Warship Biofouling Risks (cont.)

- Degrade sonar performance, via absorption and scattering of acoustic energy by fouling of sonar transducer windows **(external fouling) – merchant ship issue?**
- Degrade combat capability via degradation of seawater cooling systems servicing propulsion units, auxiliaries, and weapons, sensors and communications systems **(internal fouling) – merchant ship issue?**
- Reduce air conditioner efficiency, with subsequent degradation of ship habitability and crew efficiency **(internal fouling) – merchant ship issue?**

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Warship Biofouling Risks (cont.)

- Block or impede flow in seawater pipes, with resultant implications for ship safety and survivability **(internal fouling) – merchant ship issue?**
- Impose increased maintenance and repair costs **(internal/external fouling) – merchant ship issue?**
- Compromise platform availability and utility due to realised or potential concerns regarding marine pest transfers **(internal/external fouling) – merchant ship issue?**
- Require ship to berth/anchor in designated location and/or isolate internal seawater circulation systems, with implications for Force Protection posture **(internal/external fouling) – merchant ship issue?**

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Submarine Biofouling Risks

In operational terms, SM fouling can also specifically:

- Cause deterioration of indiscretion ratio **(external fouling: conventional boats)**.
- Compromise visual signature **(external fouling)**.

Comparative Biofouling Profiles

MERCHANT SHIPS (typical)	WARSHIPS
Mostly underway at sea	Regular, extended periods alongside
Slab sides and flat bottoms – simplifying protection, inspection and cleaning	Curved hull form, with many projections
Minimal no. of seachests and other voids and appendages	Large number of seachests, and often numerous other voids and appendages
Simple internal seawater circulation systems	Complex, intricate and operationally vital seawater circulation systems
Seek to improve hydrodynamic efficiency and manage biosecurity risks	Need to maximise endurance, minimise self-noise, ensure effective operation of seawater circulation systems and manage biosecurity risks
Not regularly concerned with protecting against terrorist attacks / sabotage	Significant Force Protection imperatives

Biofouling Management Objectives and Drivers

MERCHANT SHIPS (typical)	WARSHIPS
Reduce (fuel) operating costs	Maintain / enhance operational effectiveness
Demonstrate regulatory compliance	Ensure platform availability
	Maintain Force Protection posture
	Reduce maintenance burden and costs
	Reduce (fuel) operating costs
	Demonstrate regulatory compliance

(Some) Warship Biofouling Considerations


22
22
Voids: Sling Tubes
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Environment


Sonar Domes
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Environment


Poorly Protected Internal Seawater Systems
(Defence)
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SM General Hull Areas
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Environment


SM General Hull Areas (above waterline)
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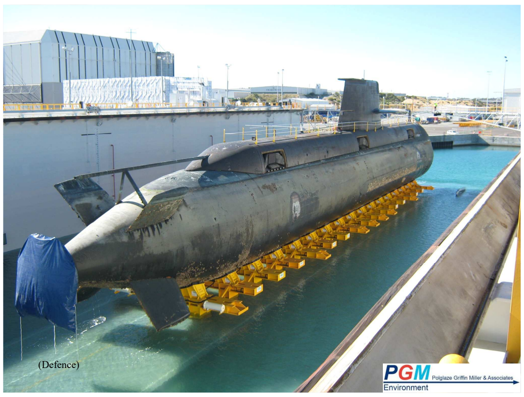
(Defence)
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Environment

Warship Biofouling Management Options and Opportunities *cf* Merchant Ships

Design Options

- Seachests and pipework can be oversized to limit the effects of biofouling:
  - this design response only exacerbates biosecurity risks and compounds their management

Biofouling Controls in Design
(External)

- Elimination of external fouling niches and voids.
- Simplification of voids and niches to facilitate maintenance and inspection.
- Design of grates and other voids (eg. seachests, A/EPU housings) to permit access by divers for in-water inspection and maintenance:
  - consistent with Force Protection imperatives.

Biofouling Controls in Design
(External)

- Tailored application of <u>effective</u> AFCs.
- Application of appropriate AFCs to areas not traditionally coated, such as screws.

Biofouling Controls in Design
(Internal)

- Inclusion of <u>effective</u> marine growth prevention systems (MGPS) in internal seawater systems.
- Design of internal pipework to facilitate maintenance and inspection and decrease biofouling vulnerabilities.
- Using materials considered less vulnerable to fouling, such as cupro-nickel.
- Consideration of alternatives to seawater cooling systems, such as closed circuit freshwater cooling systems with seawater heat exchangers.

Biofouling Controls in Operations

- Comprehensive navy biofouling management policy and technical standards.
- Identification of extended periods where ship/s stationary, and resultant implications for biofouling condition.
- Implementation of appropriate evaluation / inspection program, with tailored 'tools'.
- Periodic, focused in-water cleaning, as warranted:
  - ensuring that cleaning tools and techniques are suitable for the more complex hull shapes and multitude of underwater fittings typical of warships.

Warships *cf* Merchant Ships

- Compared with (typical) merchant ships, warships have far greater proclivity for biofouling, and far greater need and diversity of reasons to manage multiple forms of biofouling.
- Generic merchant ship biofouling control concepts, management and risk reduction measures only have limited application in terms of effective biofouling management for warships.

Thank you.

ERIC HOLM
Research scientist
U.S. Navy's Naval Surface Warfare Center, USA

Eric Holm is a research scientist (ecologist) in the Corrosion and Coatings Technology branch at the U.S. Navy's Naval Surface Warfare Center – Carderock Division. He received his Ph.D. in Zoology from Duke University, where his research examined the ecology and genetics of settlement site choice of barnacles. He has more than 30 years of experience working with invertebrate biofouling organisms, in particular acorn barnacles and serpulid tubeworms. At the Naval Surface Warfare Center, Eric has been active in programs investigating the performance of antifouling and fouling-release hull coatings at both ship- scale and panel-scale including impacts on hydrodynamic drag, and the effects of hull cleaning tools on coating physical condition. His basic research includes investigations of the initial attachment and adhesion of biofouling organisms, and how they are influenced by material surface properties and genetics.

Using CFD and experiments to estimate impacts of biofouling on ship resistance

Eric Holm, Abel Vargas, Scott Gowing, Peter Chang, Christina Dehn, Scott Storms, Hua Shan Naval Surface Warfare Center, Carderock Division, West Bethesda, MD, USA

We have been using computational fluid dynamics (CFD) and experiments to estimate, for a typical US Navy hull, the impact of biofouling on resistance. Biofouling roughness was expressed as equivalent sandgrain roughness (*ks*), and incorporated into the roughness wall model of the NavyFOAM viscous flow solver. Two- phase, unsteady Reynolds-averaged Navier-Stokes (RANS) simulations utilizing the modified wall model were validated against results from experiments. We then used this approach to examine the effects of varying levels of biofouling homogeneously and heterogeneously distributed across the hull. Biofouling roughness values were obtained from existing literature, as well as from models generated by additive manufacturing and evaluated in a flow channel. The ship hull was divided into sections defined by Navy technical documents. Resistance was evaluated for *ks* distributed homogeneously across the hull, and changes in skin friction quantified both for the entire hull and for each section. The divided hull was then used to explore the effects of heterogeneous biofouling by assigning different *ks* values to the various sections. Results from simulations such as these can be used to construct cost-benefit analyses for new biofouling control technologies, or to plan or initiate hull maintenance activities such as cleaning.

Naval Surface Warfare Center, Carderock Division

Using CFD and Experiments to Estimate Impacts of Biofouling on Ship Resistance

This brief is provided for information only and does not constitute a commitment on behalf of the U.S. Government to provide additional information on the program and/or sale of equipment or system. (NAVSEAINST 5230.12A)

Eric Holm, Abel Vargas, Scott Gowing, Peter Chang, Christina Dehn, Scott Storms, and Hua Shan

CAPT Cedric McNeal
Commanding Officer, NSWCCD

4th ANZPAC Workshop on Biofouling Management for Sustainable Shipping

Lawrence Tarasek, SES
Technical Director, NSWCCD

Biofouling Control and the US Navy

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Primary means of control – antifouling coatings

- Commercial-off-the-shelf systems
- Ablative technology, copper and copper-free

Problem: Biofouling-control coatings are formulated to satisfy the needs of commercial operators, and those needs don't always match those of the Navy

- Low operational tempo
- Long dry docking cycles (8-12 years)

Result:

- Regular in-water hull cleaning
- Potential for operations with biofouled hulls/significant fuel wastage
- No easy solutions

What are the economic consequences of our control strategy?

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- The economic consequences appear to be almost completely associated with the impact of biofouling on ship performance
- Exact size (in terms of $$) is difficult to know
  - Measurement of impacts
  - Relative contribution of various practices or technologies to the problem
- Need better understanding of the nature and size of the problem in order to implement cost-effective solutions

Underway Using Speed-Time Profile[1] Time/Quarter (hours) 1,019	Fully Cleaned Quarterly Fuel[2]	Moderate Hull Quarterly Fuel	Substantial Hull Quarterly Fuel	Moderate Propulsors Quarterly Fuel
Underway/Quarter (barrels):	7,912	9,230	13,331	8,142
Increase (barrels):		1,318	5,419	230
Increase (%):		16.7%	68.5%	2.9%
Cost/Quarter (EUR):	€ 1,044,383	€ 1,218,415	€ 1,759,631	€ 1,074,760
Increase (EUR):		€ 174,032	€ 715,248	€ 30,378

[1]Speed-Time Profile based on historical data from USNS Spearhead (T-EPF 1)
[2]Fuel calculation uses combined SFC measured on T-EPF 2 and reported by Austal
[3]Fuel Cost Conversion: 1 US Dollar (USD) = 0.88 Euro (EUR)

Experimental/Computational Approach to Estimating Impacts

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- Develop computational fluid dynamics approach for quantifying the impact of hull biofouling on ship performance
- Transition the modeling approach to a tool or tools that provide a hydrodynamic basis for making maintenance decisions, or evaluating the efficacy of novel biofouling control processes or technologies

Project Structure

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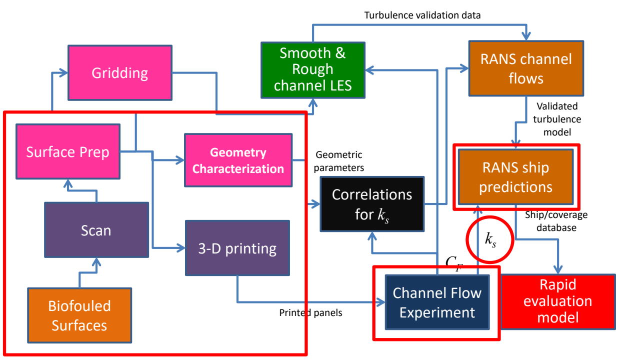

Obtaining k_s Experimentally

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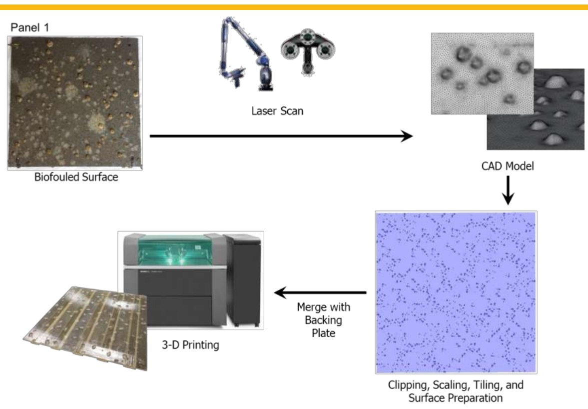

Obtaining k_s Experimentally

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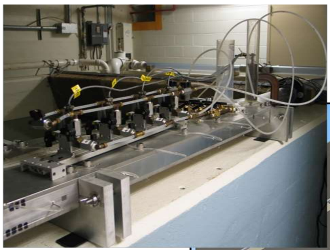
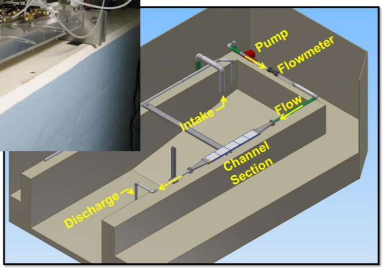


- Provide reliable drag measurements for scaled rough surfaces and correct boundary layer characteristics



- Primary objective was to bound the US Navy biofouling problem in terms of k_s, and not to test hypotheses

k_s at Full Scale

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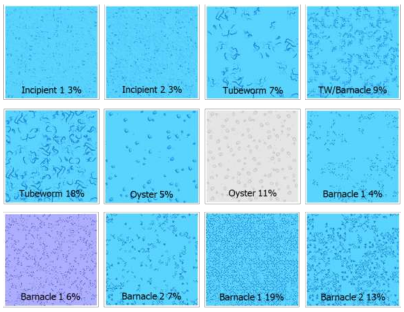

Biofouling Type	k_s (μm)
Deteriorated Coating/Light Slime[1]	100
Incipient Fouling 1 (3%, 0.6 mm)	150
Incipient Fouling 2 (3%, 0.7 mm)	200
Tubeworm (7%, 0.9 mm)	250
Heavy Slime[1]	300
Tubeworm[2]	325
Tubeworm (51%, 0.9 mm)	500
Tubeworm + Juv. Barnacle (9%, 1.8 mm)	517
Tubeworm (18%, 0.9 mm)	560
Oyster (5%, 4.4 mm)	570
Oyster (11%, 4.4 mm)	770
Small Calcareous Fouling/Weed[1]	1000
Barnacle 1 (4%, 6.6 mm)	1090
Barnacle 1 (6%, 6.6 mm)	1710
Barnacle 2 (7%, 8.7 mm)	1800
Medium Calcareous Fouling[1]	3000
Filamentous Algae 2[3] (35%, < 58 mm)	3300
Barnacle 1 (19%, 6.6 mm)	4490
Filamentous Algae 1[3] (50%, < 71 mm)	4600
Barnacle 2 (13%, 8.7 mm)	5080
Heavy Slime/Streamers[4]	8800
Heavy Calcareous Fouling[1]	10000

[1]Values from Schultz (2007) Biofouling 23:331-341
[2]Value from Monty et al. (2016) Biofouling 32:451-464
[3]Values from Schultz (2000) J. Fluids Eng. 122:357-363
[4]Value from Murphy et al. (2018) Biofouling 34:976-988

Computational Fluid Dynamics

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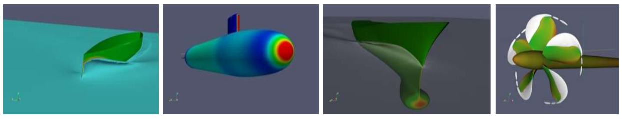
- Utilized NavyFOAM, CFD code developed at NSWC-Carderock from OpenFOAM
- NavyFOAM is routinely used for vessel design, and predicting resistance, maneuvering, seakeeping, and acoustic signatures
- Biofouling roughness was incorporated by modification of wall functions
- Validated against results from flat plate/water tunnel and towed flat plate, differences range from 0.5% - 1.5%



Resistance of a Biofouled Hull

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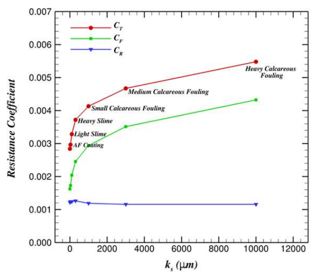
- Ship hull model: DTMB 5415 (DDG 51)
- Length between Perpendiculars: 142.0 m
- Wetted Area: 2976.2 m²
- Froude Number = 0.28
- Fixed sinkage and trim
- No appendages

- Changes in Total Resistance driven by increases in Frictional Resistance associated with biofouling
- Biofilms increase Total Resistance by 10%-25% relative to clean/painted condition
- 'Heavy Calcareous Fouling' increases Total Resistance by 85% relative to clean/painted condition



C_T = Total Resistance C_F = Frictional Resistance C_R = Residuary Resistance

Resistance of a Biofouled Hull

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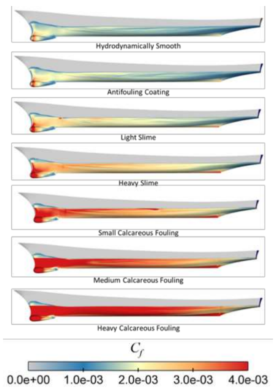
- Local values of frictional resistance are heterogeneously distributed across the hull even when biofouling is homogeneously distributed
- Decrease in frictional resistance from bow to stern
- Regions of high resistance extend further aft as k_s increases
- Frictional resistance varies not only in streamwise direction, but also from waterline to keel
- Effect was suggested previously by hull cleaning studies



Resistance of a Biofouled Hull

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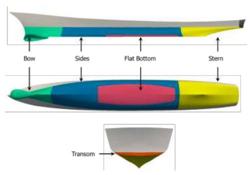
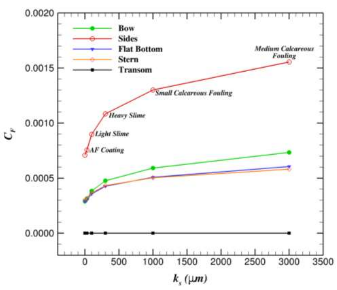
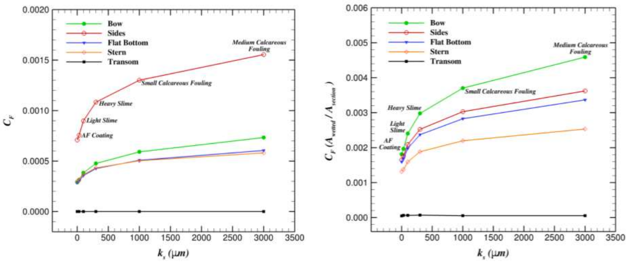
- Hull model divided into sections corresponding to diver inspection plan
- Allows for evaluation of impacts of biofouling on different sections of the hull





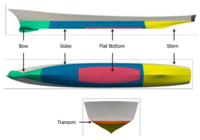
- The majority of the frictional resistance is generated by biofouling on the side of the hull
- The transom makes no contribution to total frictional resistance
- The hull bottom and stern generate similar levels of frictional resistance

Resistance of a Biofouled Hull

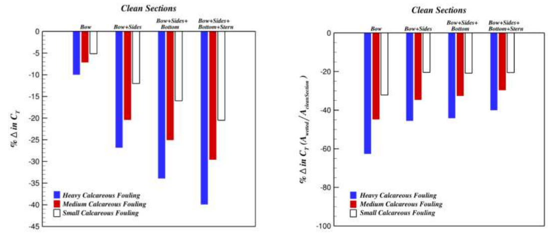


- The bow section generates more frictional resistance than any other section of the hull when normalized by the sectional area

Heterogeneous Biofouling – Hull Cleaning

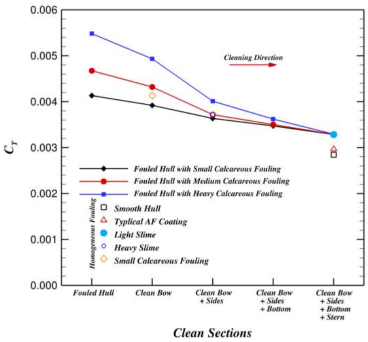


- Biofouling of a given level applied to all sections of the hull
- Once cleaned, hull returned to 'Light Slime' condition
- On a per-unit-area basis, cleaning of the bow has greatest impact



Heterogeneous Biofouling – Hull Cleaning

- Benefit from cleaning multiple hull sections depends on initial biofouling condition
- For 'Small' and 'Medium' calcareous biofouling, cleaning of bow and sides returns ship to resistance level comparable to 'Heavy Slime'
- For 'Heavy' calcareous biofouling, bow, sides, and bottom must be cleaned to attain the same level of resistance



Conclusions

- We now have a CFD method that allows us to simulate the effects of homogeneous and heterogeneous biofouling accumulations on ship resistance and thus, ultimately, ship performance
- We are working on a simpler, less computationally-intensive approach that can be incorporated into a pier-side or desk-top tool

What can we do with it?

Conclusions

- Fleet-wide estimates of fuel penalties due to biofouling – can better associate USN Fouling Rating Scale with k_s, apply that k_s estimate to individual ship inspections, and combine with operational tempo, speed-time profile, and plant alignment data, for all ship classes. Provides baseline/framework for evaluating:
  - Decision-making for hull maintenance
  - Costs and benefits of existing maintenance or control practices or technologies
  - Scope for implementation of improved control technologies

Acknowledgements

- Sponsored by Naval Surface Warfare Center Carderock Division under the Naval Innovative Science and Engineering (NISE) program, managed by the NSWC Carderock Division Director of Research.
- Thanks to our collaborators: Michael Schultz (USNA), Joseph Gorski (NSWC), Elizabeth Haslbeck (NSWC), Matthew Shanks (NSWC), Christian Sarofeen (NSWC), Samantha Kretschmer (NSWC), Patrick Violante (NSWC), Geoff Swain & Kelli Hunsucker (Florida Institute of Technology), Brian Nedved (University of Hawaii)

DOD HPC MODERNIZATION PROGRAM
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Questions?

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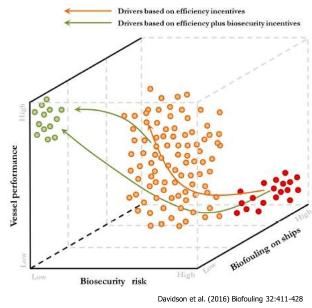
Performance vs. Biosecurity Risk

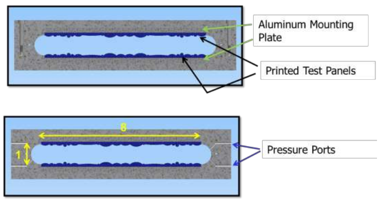
- Davidson et al. (2016) suggested some degree of mismatch between biofouling control objectives related to vessel performance vs. biosecurity risk
- Mismatch attributed to biosecurity risks associated with biofouling in vessel niche areas, which may have little impact on ship performance
- Given new understanding of drag-generation by common macrofoulers, mismatch associated with biofouling on flat hull surfaces may also be important
- To what extent will performance monitoring systems be able to detect presence of low-form macrofouling that may be of biosecurity interest?



Davidson et al. (2016) Biofouling 32:411-428

Channel Flow Facility

Channel Cross Section



- Transition and channel are 3.45 m long (80H)
- 1700 Lpm max flow, Re_τ = 500-2000
- Channel has 8:1 width/height ratio (203.2 mm x 25.4 mm)
- Use change in pressure over length of channel to obtain friction coefficients

k_s at Full Scale

- Effects of organism type, size, and coverage
- Results for incipient fouling are comparable to 'slime'
- Values for tubeworm biofouling are comparable to 'slime' at lowest levels of cover, about double that at higher levels of cover*
- Values for oysters fall between those for tubeworms and barnacles
- Even relatively low levels of barnacle cover can generate large sand grain roughnesses
- Need more data from compliant organisms, mixtures of organisms (size, shape, compliance)
- What are the important aspects of biofouling that generate drag?

Biofouling Type	k_s (μm)
Deteriorated Coating/Light Slime[1]	100
Incipient Fouling 1 (3%, 0.6 mm)	150
Incipient Fouling 2 (3%, 0.7 mm)	200
Tubeworm (7%, 0.9 mm)	250
Heavy Slime[1]	300
Tubeworm[2]	325
Tubeworm (51%, 0.9 mm)	500
Tubeworm + Juv. Barnacle (9%, 1.8 mm)	517
Tubeworm (18%, 0.9 mm)	560
Oyster (5%, 4.4 mm)	570
Oyster (11%, 4.4 mm)	770
Small Calcareous Fouling/Weed[1]	1000
Barnacle 1 (4%, 6.6 mm)	1090
Barnacle 1 (6%, 6.6 mm)	1710
Barnacle 2 (7%, 8.7 mm)	1800
Medium Calcareous Fouling[1]	3000
Filamentous Algae 2[3] (35%, < 58 mm)	3300
Barnacle 1 (19%, 6.6 mm)	4490
Filamentous Algae 1[3] (50%, < 71 mm)	4600
Barnacle 2 (13%, 8.7 mm)	5080
Heavy Slime/Streamers[4]	8800
Heavy Calcareous Fouling[1]	10000

[1]Values from Schultz (2007) Biofouling 23:331-341
[2]Value from Monty et al. (2016) Biofouling 32:451-464
[3]Values from Schultz (2000) J. Fluids Eng. 122:357-363
[4]Value from Murphy et al. (2018) Biofouling 34:976-988

Roughness Wall Function for *k-ω* Model

- Based on Knopp et al. (2009)
- The model modifies ω to account for transitional roughness values
- User inputs equivalent sand grain roughness k_s

Log law for smooth wall: $u^+ = \frac{1}{\kappa} ln(y^+) + C \quad \kappa = 0.41, \quad C = 4.9(\sim 5.1)$

Log law for fully rough wall:

$$\frac{u}{u_\tau} = \frac{1}{\kappa} ln\left(\frac{y}{k_s}\right) + B \qquad \kappa = 0.41, \quad B = 8.5 \quad \text{for fully rough (Nikuradse, 1933)}$$

Let $d_0 = exp(-B\kappa)k_s$ where B depends on the nature of roughness:

$$B = \left[C + \frac{1}{\kappa} ln\left(k_s^+\right)\right](1 - sin(\pi h/2)) + 8.5\, sin(\pi h/2)$$

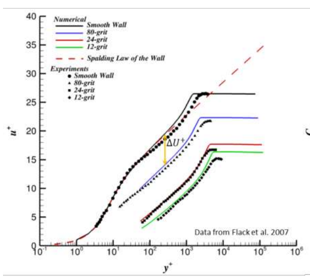
$$h = \begin{cases} \frac{ln\left(k_r^+ / k_{r,S}^+\right)}{ln\left(k_{r,R}^+ / k_{r,S}^+\right)}, & k_{s,S}^+ < k_s^+ < k_{s,R}^+ \quad \text{Transitional regime} \\ 1, & k_s^+ > k_{s,R}^+ \quad \text{Fully rough regime} \\ 0, & k_s^+ < k_{s,S}^+ \quad \text{Hydraulically smooth} \end{cases}$$

If $d_0 << y$ then the Nikuradse's log law can be written as: $\frac{u}{u_\tau} = \frac{1}{\kappa} \ln\left(\frac{y + d_0}{d_0}\right)$

d_o is the hydrodynamic roughness length scale which represents the effective origin

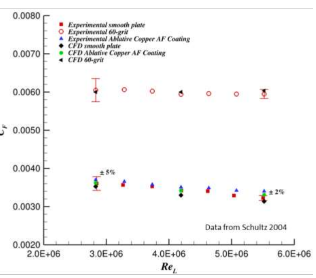
Validation of Roughness Model

Water Tunnel



Wall Surface	ΔU^+ (Exp)	ΔU^+ (CFD)	% Difference
80 Grit	5.24	5.26	0.46%
24 Grit	10.8	10.65	1.42%
12 Grit	13.0	12.85	1.19%

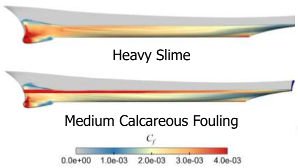
Towed plates

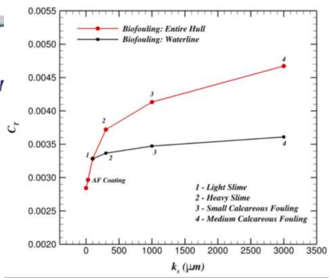


	60-grit Sandpaper			Ablative Cooper Anti-fouling Coating		
Re_L	$C_{F\ Exp}$	$C_{F\ CFD}$	% Difference	$C_{F\ Exp}$	$C_{F\ CFD}$	% Difference
5.5×10^6	0.005949	0.0060325	1.39%	0.003401	0.003308	2.76%
4.2×10^6	0.005941	0.0060253	1.41%	0.003507	0.003416	2.62%
2.8×10^6	0.006048	0.0060074	0.67%	0.003701	0.003616	2.32%

Heterogeneous Biofouling – Waterline

- Biofouling is often heavier on a ship's waterline
- What impact does a fouled waterline have on the total resistance?
- Zone from waterline to 6' deep (23% of total wetted hull area), with a homogeneous distribution of biofouling against a background of 'Light Slime'





- C_T of 'Medium Calcareous Fouling' on waterline is comparable to that for homogeneous biofouling of entire hull by 'Heavy Slime'

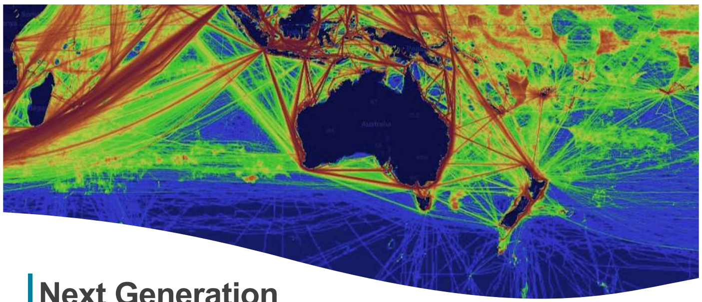
Dave Abdo
Senior scientist, Aquatic Biosecurity team
Department of Primary Industries and Regional Development, Australia

Dr Dave Abdo is a senior scientist within the Aquatic Biosecurity team at the Department of Primary Industries and Regional Development, which is the lead agency for biosecurity in the state of Western Australia. Dr Abdo has a strong background in benthic ecology and invertebrate biology, specialising in aquatic biosecurity. He has worked in both industry and government sectors, covering a range of topics from studying reproductive and growth biology of invertebrates, technical method development using in photogrammetry and hydroacoustic, to identifying and mapping benthic faunal communities. His current work includes designing and conducting surveillance programs through to managing emergency responses and providing strategic aquatic biosecurity advice.

Next generation pro-active biosecurity management to mitigate the transfer of harmful aquatic species through biofouling

Dave Abdo, Con Strydom, K. Shanmugasundaram, Justin McDonald Department of Primary Industries and Regional Development, Hillarys, WA

Biofouling is widely recognised as one of the most significant pathways for the introduction of invasive marine species (IMS) that can cause severe social, environmental and economic impacts. Addressing IMS is not only a matter of ensuring the health and integrity of marine ecosystems, but ultimately about safeguarding ecosystem services that sustain the livelihoods of coastal communities across the globe. We describe a global vessel risk assessment portal "Vessel-Check" to aid the maritime industry and governments in identifying actions that can as low as reasonably practicable mitigate the risk of vessels transferring IMS across the world's oceans. Focusing primarily on a vessel's management practices, the portal rapidly and consistently assesses a vessels biofouling management practices to ensure they are sufficient to mitigate the introduction of IMS. The early detection of vessel mediated biofouling risks through Vessel-Check allows for more effective risk management options by both developing countries that have limited capacity to effectively manage IMS risks, as well as developed counties where it can be used to enhance existing practices. Further, increased consistency between biofouling regulators provides certainty and Increased understanding of biofouling risk factors within the maritime industry. Vessel- Check provides the global solution to IMS risk mitigation via shipping; will make direct contributions to the targets set out in the United Nations Sustainable Development Goals (SDGs)(e.g. SDGs 13, 14 & 15), and will contribute to Convention on Biological Diversity and its Aichi Biodiversity Targets (e.g. Strategic Goal B, and Aichi Target 9).



Next Generation Pro-active Biosecurity Management

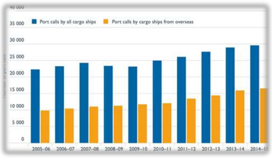
Abdo, D.A., Strydom, C., Shanmugasundaram K., and McDonald, J.I.

Department of Primary Industries and Regional Development, Government of Western Australia

DHI

Why?

- Preaching to the converted @ ANZPAC
  - Vessel biofouling substantial MoI for IMS globally
- Australia facing ever increasing IMS pressure from biofouling with increasing vessel trade/visitation*
  - push to increase usage of 'blue highway'



* Movement by multiple jurisdictions for biofouling management

How? … old way

- WA has employed online questionnaire (1542 returns 2015-17):
  - user fatigue
  - low convenience/efficiency for industry and regulators
  - no historical component
  - Focus of some risk metrics ?
  - Cross-jurisdictional applicability ✗
- 6% useable returns (86 over 3 yrs)
- Limited coverage of vessels visiting WA (<1.5% of ~4000 unique visits assessed
  - Oil and gas sector main users (86% of all useable returns)
  - Av. 25% O&G vessels assess by VC over last 3yrs

Can we do better – YES

Vessel-Check

How? … innovate, protect, grow

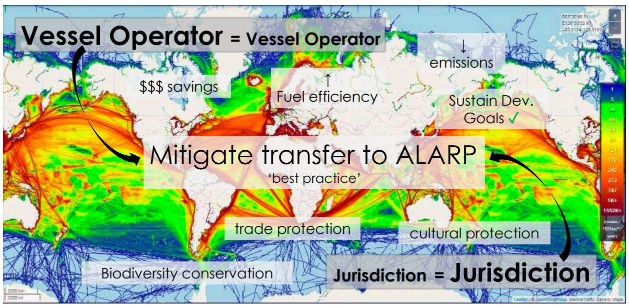
'Vessel-Check' portals goal is three-fold:

1. increase awareness and education on the control and management of ships' biofouling;
2. aids vessels (**importantly pre-border**) to identify vessel management actions/processes which can ALARP mitigate the risk
3. provide a risk-based resource prioritisation for industry and management authorities.

FOCUS BASE – IMO Guidelines

- the chance that the vessels **management practices are not sufficient** to mitigate the transfer of an aquatic pest"

Aid to SHARED RESPONSIBILITY



Vessel-Check - Key Focus Areas

Vessel Owner / Operator

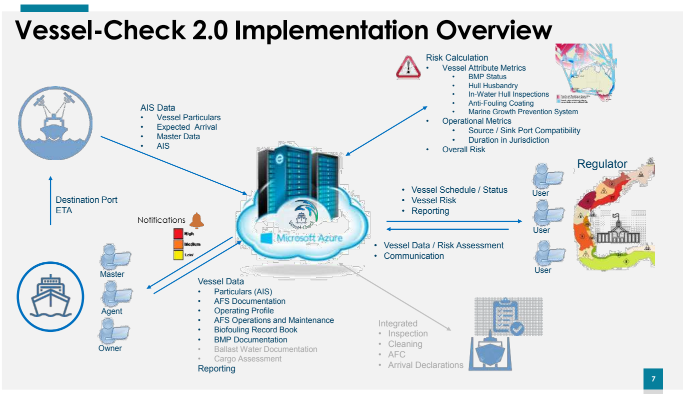
- User friendly online solution to capture biofouling information.
- Avoid duplication between jurisdictions
- Align with IMO guidelines
- Management reporting & notification
- Integrated processes to request and track cleaning & inspections

Biosecurity Risk

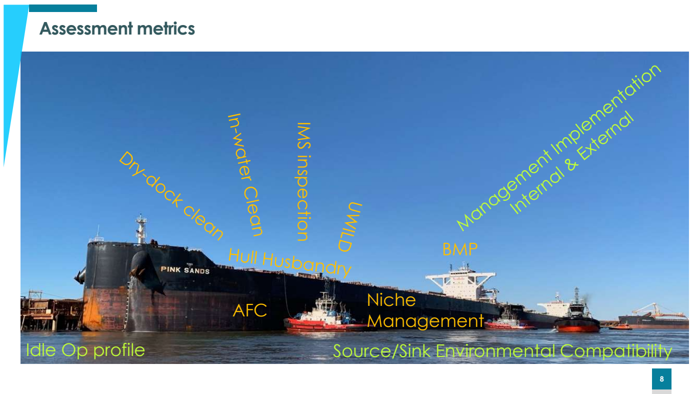
- Consistent and transparent approach to calculate risk
- Flexible risk decision tree
- Focus on hull management practices
- Ability to track risk history.
- Real-Time risk reporting

Regulator

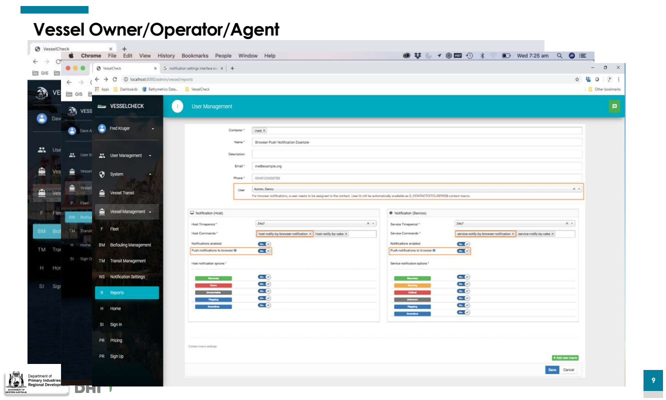
- Integrated with AIS for automated nominations.
- Ability to focus and optimize resources.
- Ability to asses and modify risk assessment / communicate with vessel
- Real-time risk assessment / Reporting
- Account for various marine biosecurity risks (Biofouling, ballast water and concealment in/on cargo).



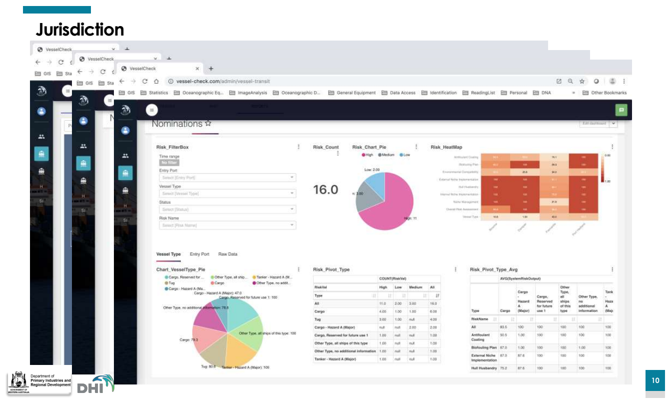
Vessel-Check 2.0 Implementation Overview
Risk Calculation
Vessel Attribute Metrics
BMP Status
Hull Husbandry
In-Water Hull Inspections
Anti-Fouling Coating
Marine Growth Prevention System
Operational Metrics
Source / Sink Port Compatibility
Duration in Jurisdiction
Overall Risk
AIS Data
Vessel Particulars
Expected Arrival
Master Data
AIS
Destination Port
ETA
Notifications
High
Medium
Low
Microsoft Azure
Regulator
Vessel Schedule / Status
Vessel Risk
Reporting
User
User
User
Vessel Data / Risk Assessment
Communication
Master
Agent
Owner
Vessel Data
Particulars (AIS)
AFS Documentation
Operating Profile
AFS Operations and Maintenance
Biofouling Record Book
BMP Documentation
Ballast Water Documentation
Cargo Assessment
Reporting
Integrated
Inspection
Cleaning
AFC
Arrival Declarations
7



Assessment metrics
Dry-dock clean
In-water Clean
IMS inspection
UWILD
Management Implementation
Internal & External
Hull Husbandry
BMP
AFC
Niche
Management
Idle Op profile
Source/Sink Environmental Compatibility
8



Vessel Owner/Operator/Agent
9



Jurisdiction
16.0
10

MPSC
Stakeholder
engagement
CEBRA
review
Testing
Roll-out - NOW
Ongoing Review
Continual improvement
11

COSCO SHIPPING
Vessel-Check - gold at the end of the rainbow

Ralitsa Mihaylova
Head of Special Projects
Safinah Group, United Kingdom

Ral Mihaylova's background is in shipping business and operations with experience in data analysis and machine learning techniques. She is currently Head of Special Projects at Safinah Group, an independent coating consultancy. Ral has a keen interest in biofouling related matters and is a part of industry-led initiatives on the topic as well as a member of the RINA IMO Committee

Digital biofouling risk assessment using big data

R Mihaylova1, R Ramsden2, R Kattan1, M Hindmarsh2, C Fung2 1Safinah Group, Gateshead, UK
2AkzoNobel Marine, Gateshead, UK

Objectives: The objective of the paper is to demonstrate that digital risk assessments can be used for identifying ships that are likely to be carrying hull fouling. The risk assessment will allow relevant authorities to address the potential biosecurity risks in a proactive manner and to allocate resources effectively. This will benefit the environment by reducing the threat of invasive aquatic species while also facilitating efficient planning of port activities.

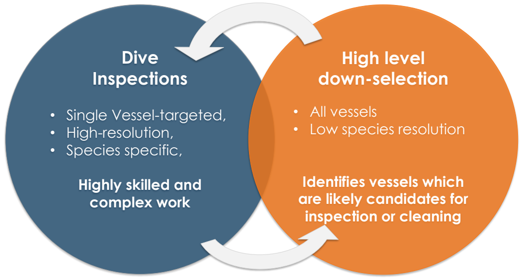
Results: The cumulative fouling challenge is obtained based on the historic activity profile of each vessel and the specific environmental conditions encountered during that period. The vessels can then be further examined in terms of biofouling management history to identify whether the fouling challenge has been adequately managed. The fouling challenge of each individual vessel is combined with the effect of the known biofouling management strategy to provide the relative risk a vessel poses in terms of the transport of hull fouling species. This paper presents a comparison between the output of a digital risk assessment system (PortShield) compared to the underwater hull condition of a range of commercial vessels. The condition of the underwater hull of the vessels was determined by visual inspections.

Conclusions: The case studies carried out to date indicate that risk assessment systems can effectively identify and rank vessels in terms of the risk of transporting hull fouling species. Such systems can be an effective low- cost solution for remotely monitoring and managing biosecurity risks associated with hull-borne species.

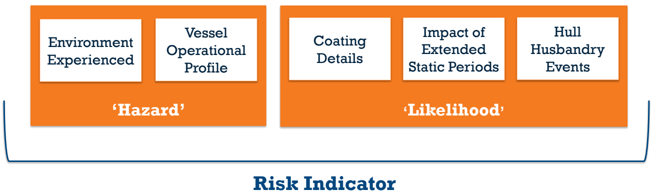
Digital Biofouling Risk Assessment Using Big Data

Ral Mihaylova (Safinah Group)
Richie Ramsden (AkzoNobel)

Two Complementary Approaches to Biofouling Risk Management



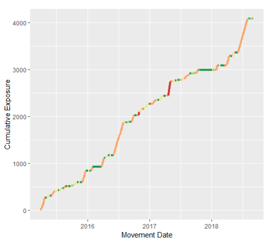
Prioritising vessels for greater scrutiny – down selection

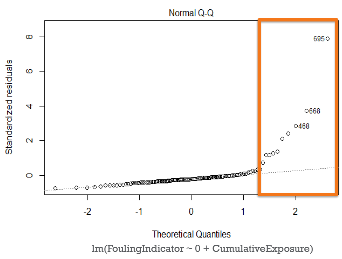


Exposure allows us to compare the relative rating of fouling environment experienced by vessels

- Exposure is a measure reflecting the environment a vessel is exposed to during operation
- Takes into account productivity and environmental conditions
- Activity and speed of a vessel as well as location from AIS data
- Over 1000 vessel fouling inspections extracted
- Distribution of vessel observations analysed

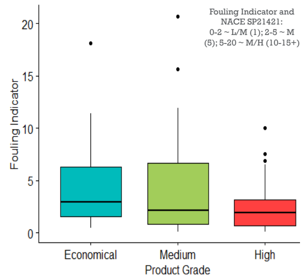
Identifying outliers to expected operation and exposure is vital to prioritising vessels





Main Coating Related Assumptions

- **Types of Coating Technologies**
  - Grouped by long-term expected performance based on type of technology, biocides content and packages (if applicable), etc
  - New technologies/products – conservative view until sufficient in-service track record
  - Long-term in-service performance being analysed to inform coating technologies expected performance assumptions – continuous process.
- **Impact of Extended Static Periods (ESPs)**
  - Assumed that any ESP not followed by a well-executed hull intervention neutralises the fouling mitigating effect of the coating

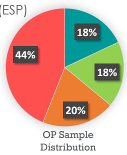


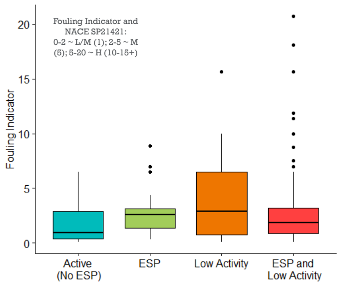
Example of the relationship between coating technology and fouling indicator towards the end of the scheme life based on 174 commercial vessels

Risk Indicator: Preliminary Results

Sample: 174 commercial ships
Inspections: Towards the end of the scheme life
Fouling Indicator: Extent and type of fouling

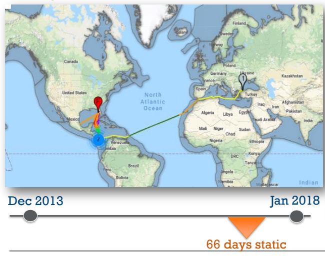
Operational Profile (OP) Categories:
- Active (No ESP)
- Extended static period (ESP)
- Low activity (<60%)
- ESP and Low Activity





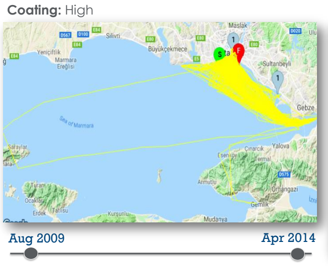
Case study 1 – Extended Static Period

Activity: 51.4%
Coating: Medium
Scheme Life: 60 months



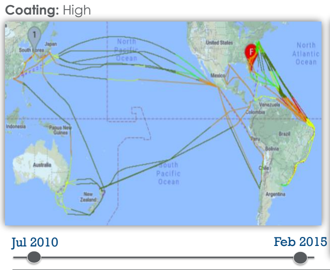
Case study 2 – Low Activity

Activity: 7.5%
Coating: High
Scheme Life: 60 months



Case study 3 – Low Risk

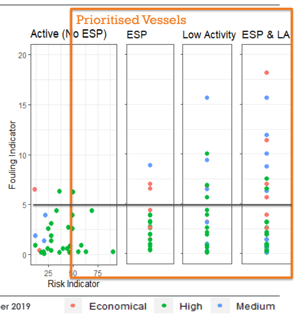
Activity: 72.8%
Coating: High
Scheme Life: 60 months



Conclusions and Future Work

Conclusions:
- Lower activity and extended static periods have a significant impact on fouling
- Coating effect is evident
- Digital risk assessments can be an effective tool for prioritising vessels
- Calibration work: ongoing

Future Work:
- Stratification by operational profiles
- Effect of hull husbandry events
- Niche areas and the impact on risk



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JOHN ALONSO
Project Technical Analyst
International Maritime Organization

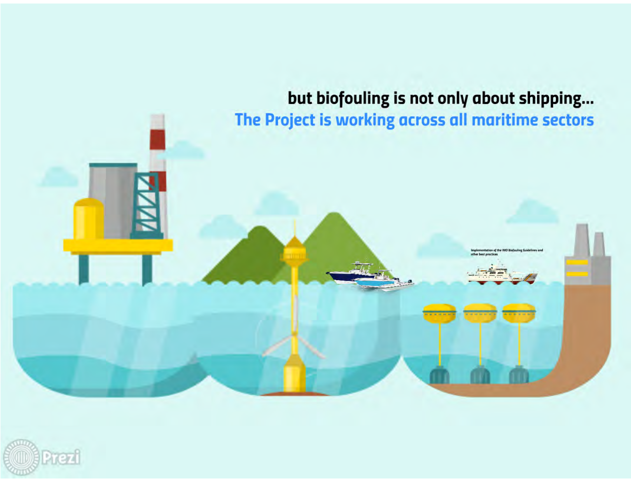
Mr. John Alonso has an academic background in Political Science, Development and Natural Resource Economics. He entered the International Maritime Organization (IMO) in 2011, later joining the GloBallast Partnerships, a capacity-building programme assisting developing countries to reduce the transfer of harmful aquatic organisms in ships' ballast water through the implementation of the Ballast Water Management Convention. During the next two years, John was part of the IMO team that led the design of the GloFouling Partnerships. The GloFouling Partnerships was finally launched in December 2018 and Mr. Alonso is currently the Project Technical Analyst

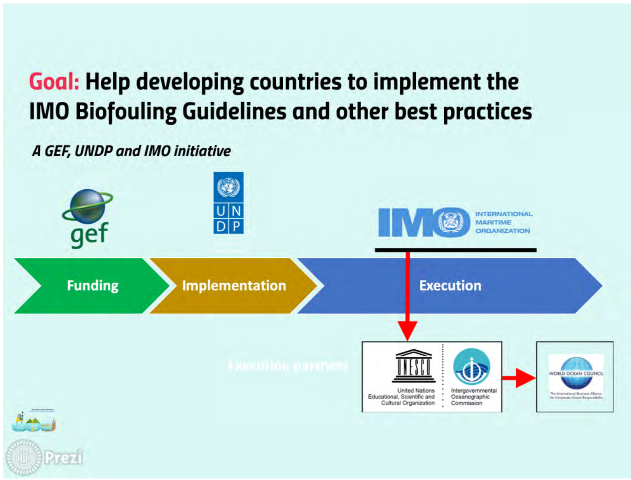
Overview of the GEF-UNDP-IMO GloFouling Partnerships Project

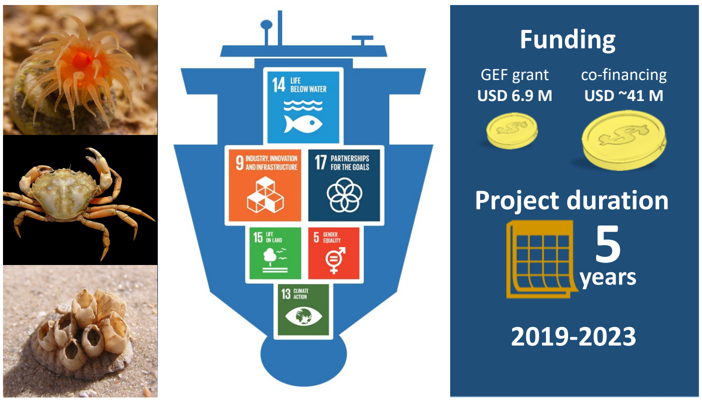
The GloFouling Partnerships project is a new collaboration between the Global Environment Facility (GEF), the United Nations Development Programme (UNDP) and IMO, focused on helping developing countries to prevent the transfer of non-indigenous species which can build up on ships' hulls and other mobile marine structures. Apart from shipping, the GloFouling Partnerships will also address other maritime industries, such as ocean renewable energy, aquaculture, ocean instruments, offshore oil and gas and deep-sea mining. The project includes implementing partners such as the Intergovernmental Oceanographic Commission of UNESCO and the World Ocean Council. During its first eight months of existence, the GloFouling project has already set in motion a number of initiatives at the global, regional and national level, that are expected to help increase the implementation of the IMO Biofouling Guidelines and other relevant best practices for biofouling management.

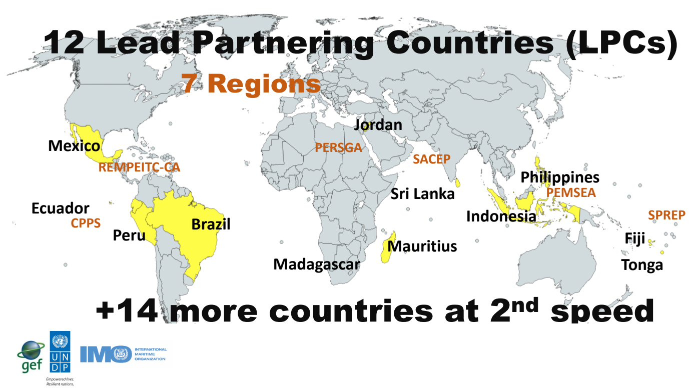

gef
U N D P
IMO
GloFouling Partnerships
1st R&D Forum and 4th ANZPAC Workshop
Melbourne, Australia, 1-4 October 2019
Prezi

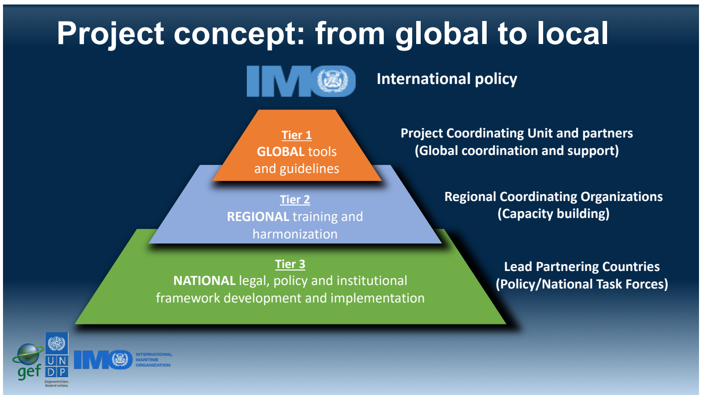

Implementation of the IMO Biofouling Guidelines and other best practices
Prezi

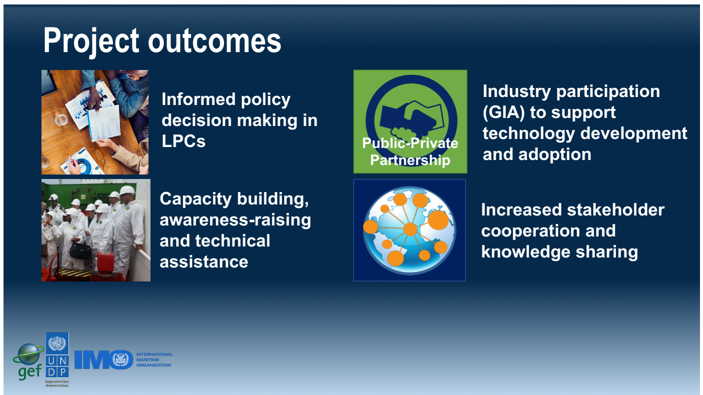

but biofouling is not only about shipping...
The Project is working across all maritime sectors
Prezi


Goal: Help developing countries to implement the IMO Biofouling Guidelines and other best practices
A GEF, UNDP and IMO initiative
gef
U N D P
IMO INTERNATIONAL MARITIME ORGANIZATION
Funding
Implementation
Execution
United Nations Educational, Scientific and Cultural Organization
Intergovernmental Oceanographic Commission
WORLD OCEAN COUNCIL
Prezi

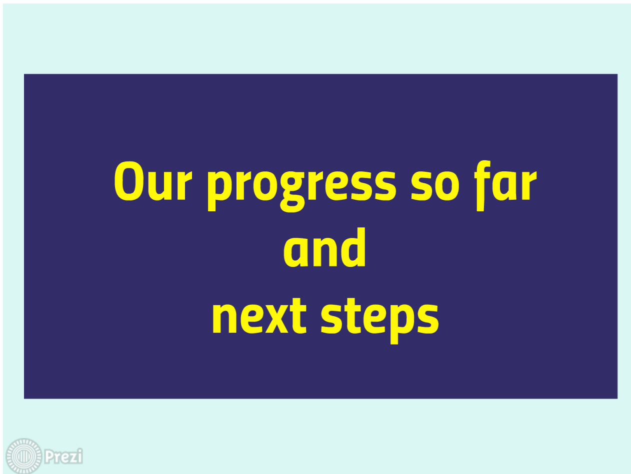

14 LIFE BELOW WATER
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
17 PARTNERSHIPS FOR THE GOALS
15 LIFE ON LAND
5 GENDER EQUALITY
13 CLIMATE ACTION
Funding
GEF grant
USD 6.9 M
co-financing
USD ~41 M
Project duration
5 years
2019-2023


12 Lead Partnering Countries (LPCs)
7 Regions
Mexico
REMPEITC-CA
Ecuador
CPPS
Peru
Brazil
Jordan
PERSGA
SACEP
Sri Lanka
Madagascar
Mauritius
Philippines
PEMSEA
Indonesia
SPREP
Fiji
Tonga
+14 more countries at 2nd speed
gef
U N D P
IMO

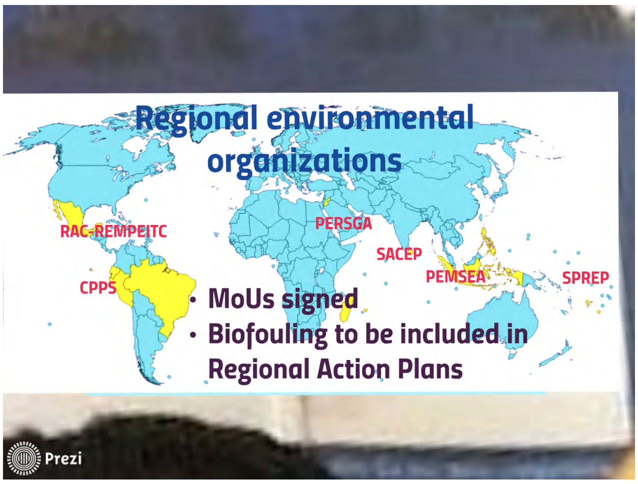

Project concept: from global to local
International policy
Tier 1
GLOBAL tools and guidelines
Project Coordinating Unit and partners
(Global coordination and support)
Tier 2
REGIONAL training and harmonization
Regional Coordinating Organizations
(Capacity building)
Tier 3
NATIONAL legal, policy and institutional framework development and implementation
Lead Partnering Countries
(Policy/National Task Forces)

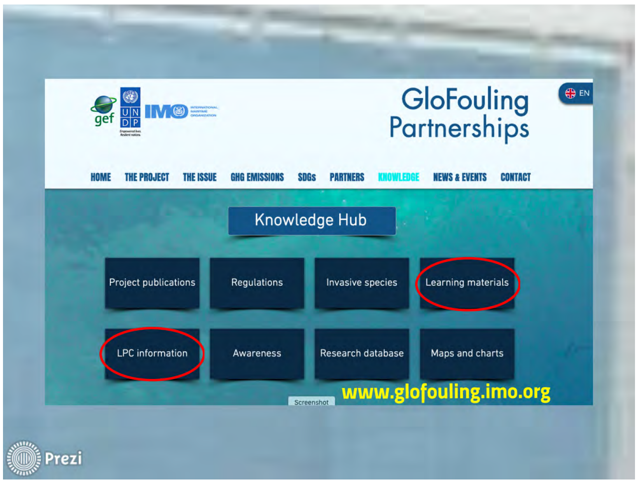

Project outcomes
Informed policy decision making in LPCs
Public-Private Partnership
Industry participation (GIA) to support technology development and adoption
Capacity building, awareness-raising and technical assistance
Increased stakeholder cooperation and knowledge sharing

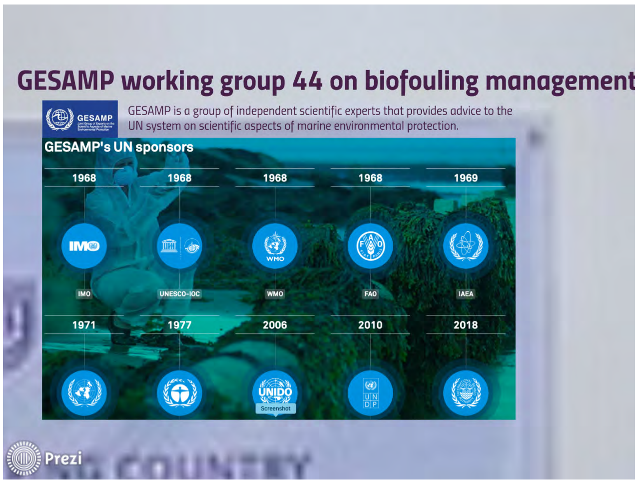

over 400 planned activities
12
Technical publications
12
Demonstration sites
6
Global conferences
2
Audiovisual productions
60
Training workshops
1
Global knowledge hub


Our progress so far and next steps
Prezi

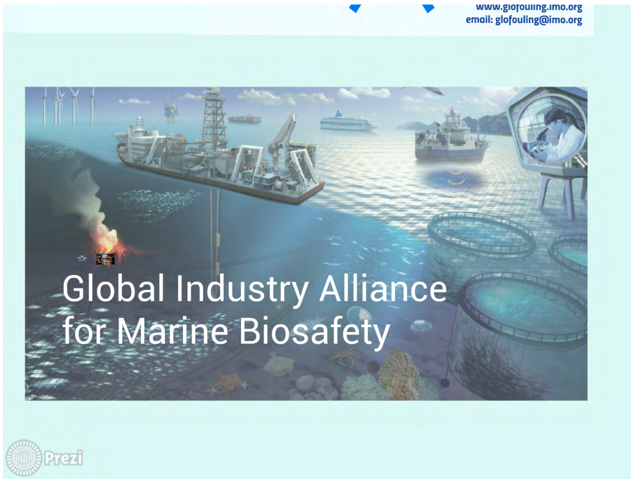

Setting up national task forces
Prezi


Regional environmental organizations
RAC-REMPEITC
PERSGA
SACEP
PEMSEA
SPREP
CPPS
• MoUs signed
• Biofouling to be included in Regional Action Plans
Prezi


GloFouling Partnerships
HOME
THE PROJECT
THE ISSUE
GHG EMISSIONS
SDGs
PARTNERS
KNOWLEDGE
NEWS & EVENTS
CONTACT
Knowledge Hub
Project publications
Regulations
Invasive species
Learning materials
LPC information
Awareness
Research database
Maps and charts
www.glofouling.imo.org
Prezi


GESAMP working group 44 on biofouling management
GESAMP is a group of independent scientific experts that provides advice to the UN system on scientific aspects of marine environmental protection.
GESAMP's UN sponsors
1968
1968
1968
1968
1969
IMO
UNESCO-IOC
WMO
FAO
IAEA
1971
1977
2006
2010
2018
UNIDO
Prezi


Best practices for recreational craft and marinas
IUCN
World Sailing
ICOMIA
GloFouling Partnerships
Prezi


email: glofouling@imo.org
Global Industry Alliance for Marine Biosafety
Prezi


Global Industry Alliance for Marine Biosafety
• IMO-Private sector partnership
• Opportunity for industry environmental stewardship
Prezi


Industry: Performance
Science & regulators: Biosafety
Crossing the bridge
More information: glofouling@imo.org
Prezi

Further Opportunities for collaboration

- Guidance templates for drafting national baseline status reports
- Expert group on impact of biofouling on GHG emissions
- Awareness raising materials

Prezi

Prezi

Thank you!

gef UNDP IMO

GloFouling Partnerships

www.glofouling.imo.org
email: glofouling@imo.org

Prezi

JAGATH GUNASEKARA
Deputy General Manager (Operations)
Marine Environment Protection Authority, Sri Lanka

Mr. A J M Gunasekara is presently working as Deputy General Manager (Operations) of Marine Environment Protection Authority of Sri Lanka with over fifteen years of experience in the marine environment protection. A J M Gunasekara received his bachelor's degree in Science at the university of Ruhuna, Sri Lanka and he holds two Master degrees in Natural Resources Management and Maritime affairs (marine environment and ocean management) from university of Peradeniya, Sri Lanka in 2003 and World Maritime University of Malmo, Sweden in 2011 respectively.
He has involved in ship based pollution management activities in last fifteen years. He has been involved in several projects related to the marine invasive species through ballast water and ship hull fouling He has carried out several researches in the field of marine pollution and marine invasive species and control mechanism and published several papers in the same fields.

Threat of the Invasive Alien Species (IAS) introduced through biofouling in Sri Lankan Waters

Biofouling on vessels is considered as an important mechanism for the inadvertent transfer of non-indigenous marine species around the world. The risk of invasive species introduced through the vessel fouling has a significant impact on developing island nation such as Sri Lanka which import and export mainly rely on shipping and economy vastly rely on the marine environment and maritime industries. However, the impact of invasive alien species and control measures so far has not studied well and understood in developing countries. This paper describes presently available introduced fouling species in commercial ports in Sri Lanka and control measures adopted to prevent this nature invasion. The biological port baseline surveys were carried out in four commercial ports in Sri Lanka namely Colombo, Hambantota, Galle and Trincomalee to identify introduced fouling species. Eight known invasive biofouling species namely Musculista senhousia, Balanus amphitrite, Elminius modestus, Mytilus galloprovicialis, Perna viridis, Crassostrea gigas, Ostrea edulis, and Carcinus maena recorded from the Colombo port. The second-highest number, six species of biofouling invasive species recorded from Trincomalee Galle port. Five known invasive species were recorded from the Hambantota port. However, further studies are being carried out to evaluate the invasiveness of the above species. So far, the impact of marine invasive species is not well studied and well understood. Any of the high- level policies or strategies have not adopted to control the introduction and dispersion of biofouling related invasive species, add-hock measures such as the prohibition of underwater hull cleaning. More comprehensive and stringent policies and strategies should be adopted in line with the regulatory regime and best management practices to prevent the spreading of these silent invaders of the sea to protect Biosecurity and to ensure the sustainability of the marine environment-related industries.

Threat of the Invasive Alien Species (IAS) introduced through biofouling in Sri Lankan waters

, A.J.M. Gunasekara, Thalatha Ranasinghe
Marine Environment Protection Authority
Sri Lanka

Outlines

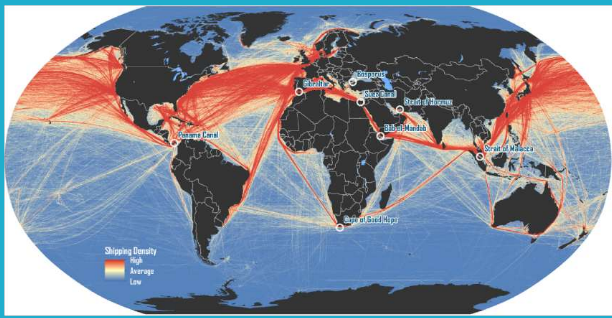
- Background
- Port baseline survey project and result
- Control measures and way forward

Background

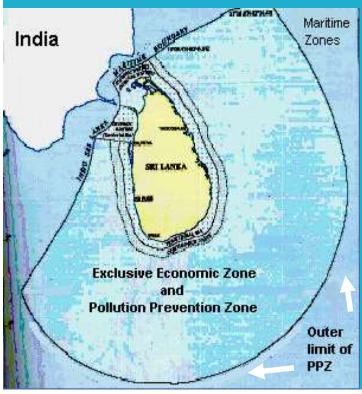
GEOGRAPHICAL IMPORTANCE FOR SHIPPING

- Sri Lanka Located at Strategic location in the Indian ocean- central point of the east and west.
- One of the busiest international shipping lanes pass through the Southern coast of Sri Lanka just 5 nm from land

Close to major shipping routes



Maritimes Zones of Sri Lanka



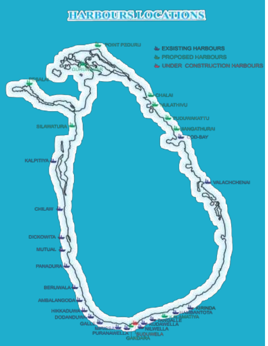
Maritime Zone	from Baseline (Nm)	Area (Sq.Km)
Territorial Sea	12	21700
Contiguous Zone	24	22600
EEZ/PPZ	200	465800

- *Coastal belt- 1760 Km*

Port sector development

Fishing Activities

- More than 2000 Multiday boats and these boats are fishing international waters
- Heavy threat of fouling organism introduction through hull fouling



Shipping activities development and threat marine environment

- Development shipping activities pose a high risk on bio security
- This matter has not considered as priority issue.
- Terrestrial invasive species are well known, impacts are visible
- Legislations and other mechanisms are available
- Marine Invasive species are not studied well, impact not visible and no legislation and control mechanism.
- The country is lacking information regarding not only IAS but also highly needed baseline data in the marine environment.

Port Biological baseline survey project

- conduct biological surveys to review the existing marine biological characteristics of the selected ports.
- evaluate the taxonomic composition of the biota to identify native species and species that may have been introduced.
- investigate for globally known marine invasive species in the study areas

Plankton sampling and analysis

Phyto Plankton

- Horizontal phytoplankton samples were collected using a 20 µm mesh size plankton net.

Zoo Plankton

- Horizontal phytoplankton samples were collected using a 100 µm mesh size plankton net.

Mobile and Sessile fauna

Mobile and sessile fauna

- Visual observations were conducted in the shallow areas with the naked eye and from photographs.
- Qualitative data were collected by underwater visual senses through snorkeling and SCUBA diving using underwater photographs
- At selected sub sites, 25m of Video transect method was conducted to record sessile benthic characteristics
- Additional Sampling techniques –Fishery net s and baited traps

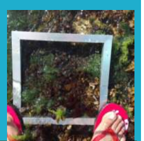
Hard Substrate (Fouling) fauna and flora & Benthic fauna

Hard Substrate (Fouling) Fauna & Flora

- Hard substrate fauna and flora were collected from coral reefs piles, banks, submerged structures, breakwaters and rock-wall facings, other rocky surfaces, floating devices and boat hulls using a locally fabricated scraper with a long arm. Also deployed settlement plates
- High depth samples were collected with the assistance of SCUBA divers.
- Still photographs were taken using an underwater camera before the scraping of samples.
- Samples were collected in to plastic bottles and plastic zip bags and preserved in 70% alcohol for further analysis and identification.

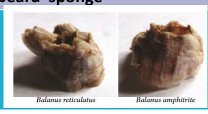
Benthic fauna

- Sediment samples were collected using bottom dredges and grab sampler.
- Collected samples were placed in a plastic sealer bags and preserved with 4% formalin and stored in a refrigerated at 4 ^{0}C until further analysis.



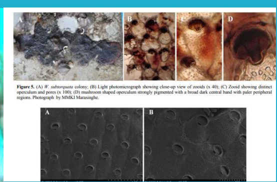
Invasive species found in surveys

Port	No of invasive species (fouling)	species (fouling)
Colombo	7	*Musculista senhousia –Asian date mussel* *Balanus Amphitrite- Stripped Barnacles* *Elminius modestus - Australia acorn barnacle* *Mytilus galloprovicialis – Mediterranean mussel* *Perna viridis - Asian Green Mussel* *Crassostrea gigas - pacific Oyster* *Ostrea edulis -European flat oyster*
Galle	4	**Perna viridis- Asian green mussel** **Crassostrea gigas- Pacific Oyster** **Balanus Amphitrite -Stripped Barnacles** **Clathria prolifera – Red beard sponge**



Port	invasive species (fouling)	Species -Fouling
Trinco	5	*Perna viridis- Asian Green Mussel* *Crassostrea gigas- Pacific Oyster* *Ostrea edulis -European Flat Oyster* *Balanus Amphitrite*- Stripped Barnacles *Clathria prolifera*- Red beard sponge
Hambanota	8	*Rapana venosa -Asian Rapa whelk* *Phallusia nigra –Black sea Squirt* *Perna perna - Brown Mussel* *Brachidontes pharaonis - mussel* *Balanus Amphitrite*- Stripped Barnacles *Balanus reticulates – Reticulated striped barnacl* *Balanus trigonus –Tringle barnacle* *Schizoporella errata- Encrusting bryozoan*

Settlement of non-native *Watersipora subtorquata* (d'Orbigny, 1852) in artificial collectors deployed in Colombo Port, Sri Lanka- Red rust bryozoan (Ranathugha, K and Marasingh, K)



Membranipora membranacea (Bryozoan)

Control Measures

Port level control measures

- Prohibited underwater hull cleaning Colombo port

Ship repair yards

- Waste management plan
- Waste collection and treatment and disposal procedure

Way forward

Lead Partner country to the Glofouling Project

Technical	Research and Development	Permuting requirement and operational procedure
• National Taskforce • Government • Industry	• Universities and Research Agencies • Scientific studies Distribution, abundance • impact • Control and removal technologies	• National strategy • Procedure inline with IMO Biofouling guidelines • permitting vessel • underwater hull clearing procedure

THANK YOU !

RICARDO COUTINHO
Senior research scientist
Instituto de Estudos do Mar Almirante Paulo Moreira, Brazil

Ricardo has a PhD in Biology (Ecology) from the University of South Carolina, USA. Pos-Doc from Duke University and the Woods Hole Oceanographic Institute, USA. Senior Researcher at the Instituto de Estudos do Mar Almirante Paulo Moreira (IEAPM), where he is Head of the Department of Marine Biotechnology and Director of the Laboratory of Marine Resources (LAREMAR). Coordinates the Graduate Program, Masters and PhD in Marine Biotechnology from IEAPM/UFF. Specialist in Biofouling and Bioinvasion with more than 30 years of experience in the area having published more than 115 articles in scientific journals. Advisor of 40 master, and 25 PhD degree. Supervised 13 pos-doc fellowships. He is currently the National Coordinator of the IMO / GEF / UNDP GloFouling Program in Brazil.

Assessment of national publications on Biofouling/Bioinvasion in Brazil

A survey of bibliography of Brazil using key words and Impact factor was done on biofouling/bioinvasion. No studies addressing economic and social aspects related to the biofouling were observed. Bioinvasion studies were concentrated in descriptive works, with lack of environmental and economic impact assessment.

Assessment of national publication on Biofouling/Bioinvasion in Brazil

Ricardo Coutinho
Instituto de Estudos do Mar Almirante Paulo Moreira (IEAPM)

1st GEF-UNDP-IMO GloFouling R&D Forum and Exhibition on Biofouling Management, 1-4 October, Melbourne, Australia

Main questions

How to define which research should be developed in biofouling and bioinvasion in Brazil?

What is the state of the art of biofouling and bioinvasion research in Brazil?

Which areas should be prioritized?

How to convince the Brazilian government to support these areas of research?

Objective

Make a survey of scientific publication of Brazil on biofouling/bioinvasion in order to establish priority on the development of this area

Methodology :

- Bibliographical survey by keyword.
- Quality analysis by classification of Impact Index or Journal Citation Research

Biofouling Brazilian Navy

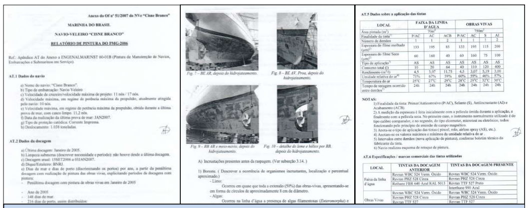
Historical of fouling control : Brazilian Navy

Biofouling research carried out by the Institute of Marine Studies Admiral Paulo Moreira (IEAPM) included :

- a manual for fouling species identification
- a database to store all the information about fouling presence in the ship hull
- Development of a tool for an evaluation of the performance of commercial antifouling systems (AFS).

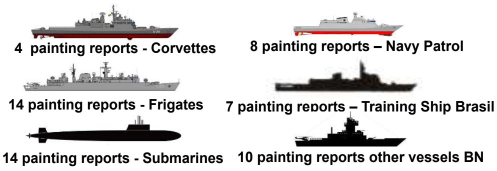
IEAPM

- From 1983 to 2007, we analyzed 320 Painting Reports of ships and submarines of the Brazilian Navy
- Over the years, several aspects were integrated for best practices, such as the evaluations the operational profile of the vessels and the environmental parameters of the anchoring areas of navy vessels.



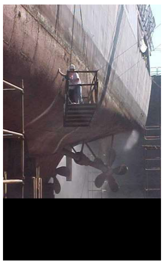
Painting Reports of Ships and Submarines of the Brazilian Navy

- From 1997 to 2008, we report the fouling occurring in 57 vessels of the Brazilian Navy (BN)
- including mainly Patrol Ships, Corvettes, Frigates and Submarines,
- In specific reports for each vessel, the antifouling effectiveness of the paints applied to the hulls was evaluated.



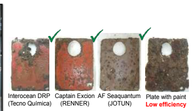
In addition to the results obtained in the paint reports, several ship hulls were sampled during the docking period and we did the survey of fouling species





Between 2003 and 2004, the IEAPM tested 10 new paints from 6 companies, with the aim of replacing the Tributil Tin (TBT) biocide, which was banned because it is highly toxic to the environment.

Experimental structure with plates with 10 TBT inks tested in Guanabara Bay, RJ



Plates with efficient formulations anti-fouling performance after 2 years of testing in Guanabara Bay

Since 2007, the IEAPM has been testing new anti-fouling paints without TBT manufactured by different companies, aiming to homologate the most efficient formulations to be used by the ships and submarines of the Brazilian Navy

Paints tested in Guanabara Bay and in the IEAPM experiment site at Arraial do Cabo City, (better anti-fouling performances)



Biofouling results

KEY Words

Taxonomy
- Flora; Flora.
- Fauna; Fauna.

Biotic Factors
- Fatores Bióticos; Biotic Factors.
- Predação; Predation;
- Competição; Competition

Abiotic Interactions
- Interações Abióticas; Abiotic Interactions.
- Temperature.
- Salinity.
- Luminosity

Ecology Sucession
- Ecological Sucession

Data base :

Google Scholar · ScienceDirect · SciELO · periodicos CAPES · SpringerLink

Base de dados	Palavra Chave	Português	Inglês
Google Scholar	Several	269	1130

Exclusion Criteria

- Non-marine biofouling
- Natural products
- Aspects not related to the theme of Biofouling

Total number of studies : 67

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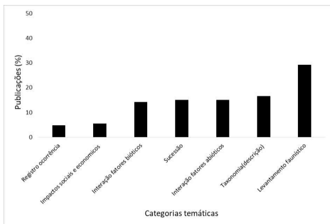
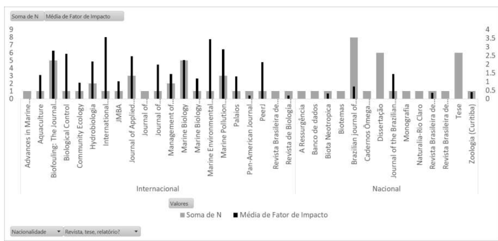
Subject



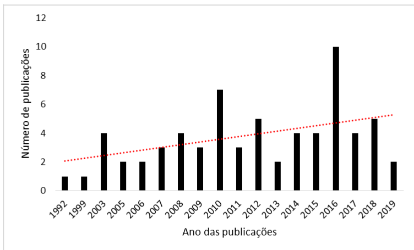
Assessment of economic and social impacts of biofouling

Just 5 articles addressed economic and social aspects related to the biofouling were identified

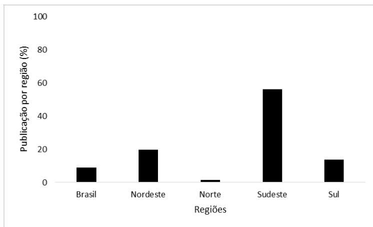
Number of publication /impact factor of journal



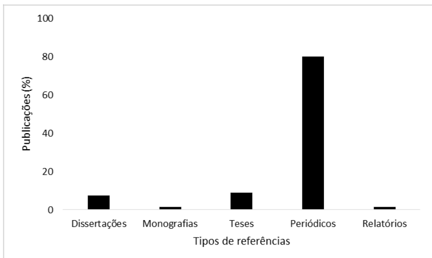
Publication per year



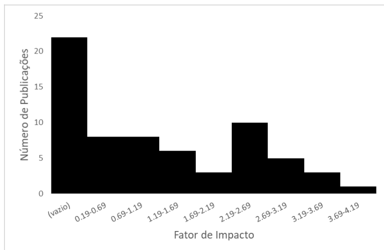
Publication per region



Type of publication



Impactor Factor



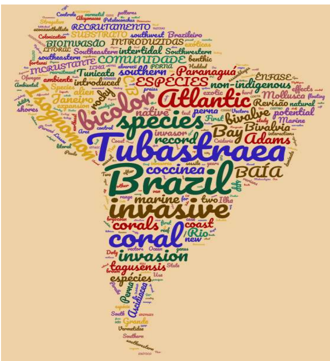
Bioinvasion Results

Bioinvasion Survey

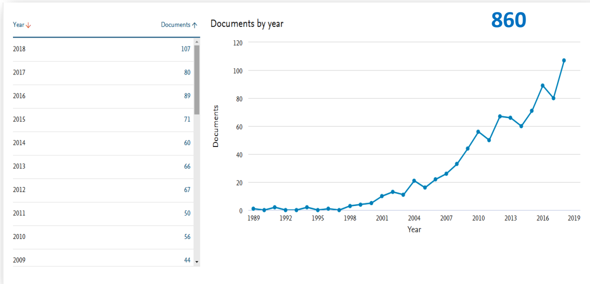
Key Words :

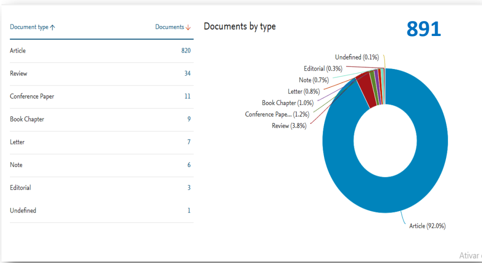
"introduced species" and "Brazil" or "Exotic species" and "Brazil" or "non-indigenous species" and "Brazil" or "marine bioinvasion" and "Brazil" or "non-indigenous species" and "climate change" and "Brazil" or "Impacts of marine bioinvasion" and "Brazil"

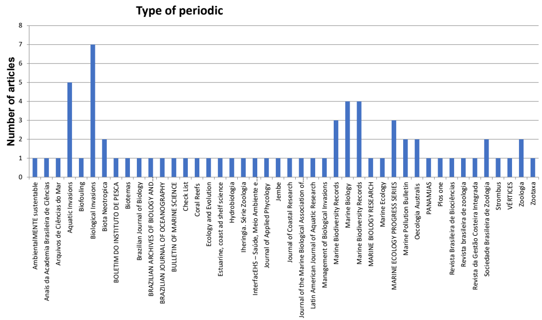
Key Word

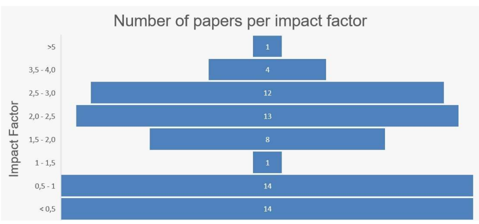


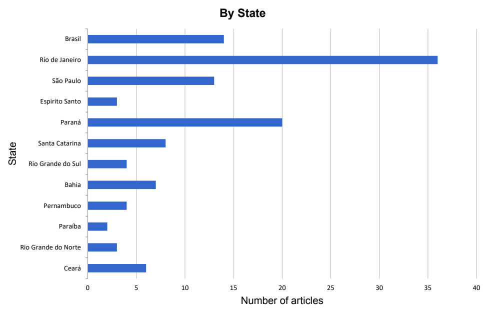
Documents per year

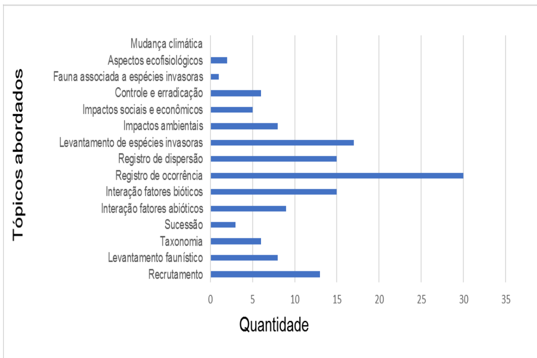


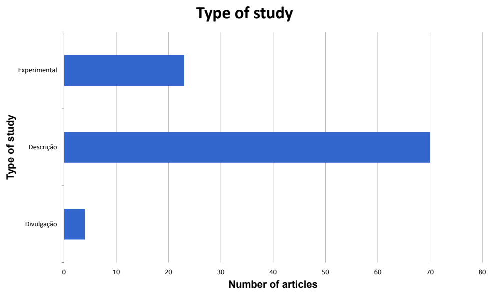












Some conclusions

We need to improve the studies about economic and environment impact assessment in both : biofouling and Bioinvasion

Marine bioinvasion is a recent science in Brazil - (first work of our survey is from 2004)

Most Biofouling studies are concentrated in the Brazilian Navy (IEAPM)

Higher number of papers concentrated in the Southeast and South regions of the country

Tubastrea coccínea and Isognomon bicolor are the main species studied, but other species should also be studied

Most descriptive works, however, the number of experimental works has been growing in recent years (since 2006)

No studies evaluating invasive species in scenarios of climate change in Brazil and environmental DNA - delay in relation to other countries

GloFouling Program may help Increase Biofouling and Bioinvasion studies

IEAPM

Universidade Federal Fluminense

Marine Biotecnology Program- IEAPM/UFF

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Obrigado!

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Patricia Carbajal
Researcher
Instituto del Mar del Peru (Imarpe), Peru

Patricia Carbajal Enzian works at the Biodiversity Research Department of Instituto del Mar del Peru (Imarpe) and has more than ten years working experience in topics related to marine biodiversity and conservation. She is a biologist with post graduate studies in aquatic ecosystem and resources, taxonomy and marine ecology. Her primary research is focused on studying the status and variability of diversity of marine benthic communities in the face of multiple natural and anthropogenic stressors, including fisheries impact, El Niño Event and lately non-indigenous species, especially in ecologically important systems such as kelp forests and seaweeds beds. She also has interest on deepening the knowledge of the richness and diversity of invertebrates and seaweeds in different marine benthic habitats along the Peruvian coast through inventorying studies and curatorial management of Imarpe National Scientific Collections of these groups. Other activities carried out by her include to disseminate the species richness of Peruvian sea through the online institutional platform and elaboration of several identification guides. She is also member of several National Commissions and Technical Groups on biodiversity topics as invasive and non-indigenous species.

State of knowledge of non-indigenous marine species along Peruvian waters

The introduction of invasive and non-indigenous species (NIS) species by vessel hull fouling constitutes a threat to ecosystems and economic activities in coastal areas. This paper presents a diagnosis of the current status of knowledge on NIS along the Peruvian coast and provides information about national regulations. With respect to other latitudes, the finding of NIS in the Peruvian sea is still scarce, which could be explained by the regional oceanographic conditions, as well as the lack of studies in this topic. There has been deliberate introductions of three marine species for cultivation purposes (“turbot” *Scophthalmus maximus*, “Pacific oyster” *Crassostrea gigas*, and “red abalone” *Haliotis rufescens*), and also an accidental introduction of the green seaweed *Caulerpa filiformis* during bivalve aquaculture activities, leading to an expansion of the distribution range of this algae and adverse effects in this industry. Other NIS observed so far, include barnacles, ascidians, polychaetes, bryozoans and macroalgae, among other taxa reported in publications, and recently observed during different research projects. IMO Biofouling Guidelines have not yet been implemented and National regulations are in early stage, based on a National Strategy on Biological Diversity and a List of Invasive Alien Species. We conclude that it is urgent to establish scientific guidelines and strengthen the national regulatory framework to avoid the possible impact of NIS introductions by biofouling in the Peruvian marine ecosystem.

GloFouling Partnerships

1st IMO-GloFouling Research & Development Forum on Biofouling Management

State of knowledge of non-indigenous marine species along Peruvian waters

Patricia Carbajal[1], Rita Orozco[1], Sara Clemente[1], Frederick Orlandini[2]
1. **Instituto del Mar del Perú**
2. Dirección de Medio Ambiente, Dirección de Capitanía y Guardacostas.

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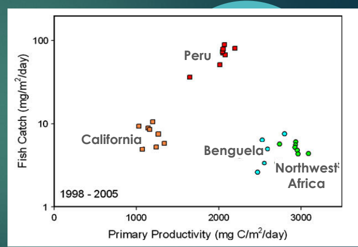
2019

Content

Background

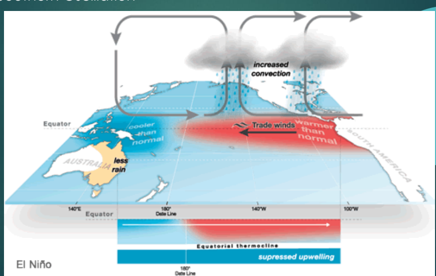
Peruvian marine ecosystem

- Current Humboldt System
- Intensive upwelling



Chavez et al. 2008

- El Niño Southern Oscillation

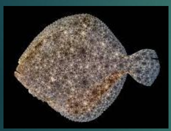


Non-indigenous species

Intentional introductions

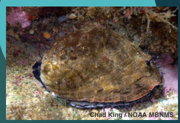
Marine species introduced for aquaculture

- Marine species intentionally transported for aquaculture



"Turbot"
Scophthalmus maximus
(Linnaeus, 1758)

"Pacific oyster"
Crassostrea gigas (Thunberg, 1793)



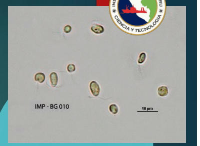
"Red abalone"
Haliotis rufescens
Swainson, 1822

Canepa et al. 2009

Marine species introduced for aquaculture

- Phytoplanktonic marine/brackish species

Species	Place of origin
Nannocloropsis sp.	
Dunaliella tertiolecta	Oslofjord, Norway
Tetraselmis chuii	Millport, Scotland
Chaetoceros calcitrans	Europa
Isochrysis galbana	Port Erin, Isle of Man
Isochrysis sp.	Tahití
Diacronema lutheri (*Monochrysis lutheri*)	Britain
Thalassiosira pseudonana	Germany
Conticribra weissflogii (T. weissflogii)	Europa
Dicrateria inornata	England



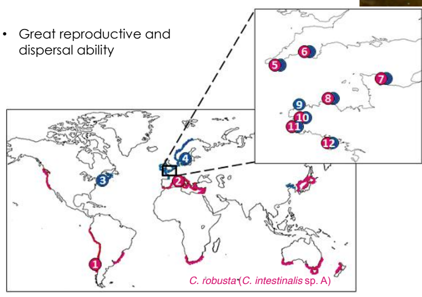
Canepa et al. 2009

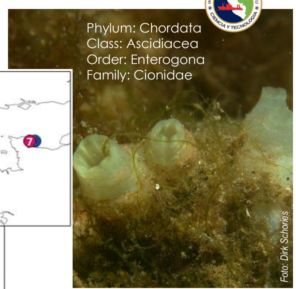
Non-indigenous invasive species

Unintentional introductions

Ciona robusta Hoshino & Tokioka, 1967

- Great reproductive and dispersal ability

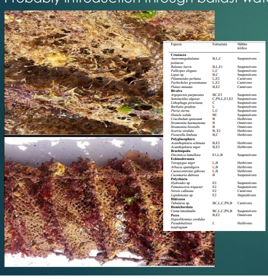


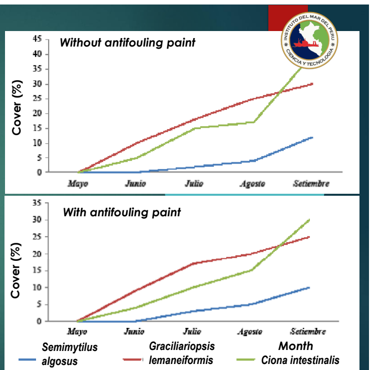


Bochemousse S. 2015

Ciona robusta Hoshino & Tokioka, 1967

- Major component of fouling communities
- Provokes significant losses in scallop aquaculture (*Argopecten purpuratus*).
- Probably introduction through ballast water

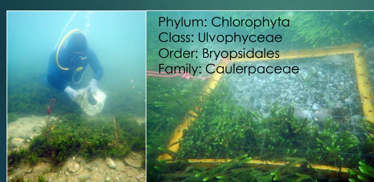




Pacheco & Garate. 2005; Loayza R. 2011; Romulo et al. 2014; Coluncke et al. 2016.

Caulerpa filiformis (Suhr) Hering 1841

- Original from Africa, first time reported in Peru in 1914 by Howe.
- It modifies the infaunal and epifaunal community in shallow sandy bottoms (Carbajal et al. 2018. Aguilar 2019)



Anemonia alicemartinae Häussermann & Försterra, 2001

Phylum: Cnidaria
Class: Anthoza
Order: Actiniaria
Family: Actiniidae

First record in 1979 in Chile as *Actinia* sp.
Dispersal mechanisms:

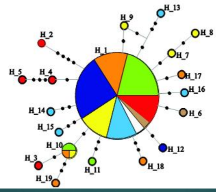
- Short distance dispersal: selection of local conditions for settlement
- Long-distance: among habitats that could facilitate the colonization of new sites.

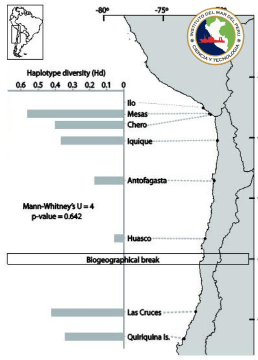
López et al. 2013. Rev. Chil. Hist. Nat 86(3):369–372

Journal of Sea Research
Volume 102, August 2015, Pages 1-9

Population genetics of the invasive cryptogenic anemone, *Anemonia alicemartinae*, along the southeastern Pacific coast

C.B. Canales-Aguirre, A. Quiñones, C.E. Hernández, P.E. Neill, A. Brante





Major genetic diversity in peruvian localities (-18° LS)

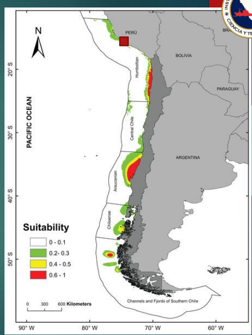
PeerJ

Spread of the non-native anemone *Anemonia alicemartinae* Häussermann & Försterra, 2001 along the Humboldt-current large marine ecosystem: an ecological niche model approach

Javier Pinochet, Reinaldo Rivera, Paula E. Neill, Antonio Brante and Cristián E. Hernández

2019

Along with the characteristics of the life history of *A. alicemartinae*, oceanographic conditions and maritime transport as vector contribute to the southern range expansion of this invasive cryptogenic species in the Humboldt-current large marine ecosystem.

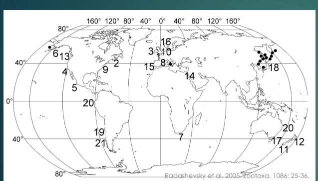


Potential distribution of *A. alicemartinae* predicted by the best Ecological Niche Model.

Non-indigenous species

Unintentional introductions

Dipolydora giardi (Mesnil, 1893)



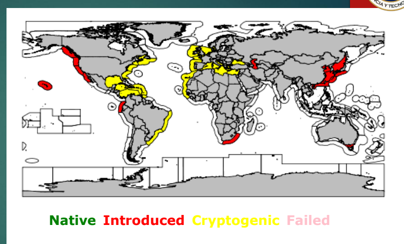
World-wide reports of *D. giardi*

Polydora websteri Hartman in Loosanoff & Engle, 1943

Phylum: Annelida
Class: Polychaeta
Order: Spionida
Family: Spionidae

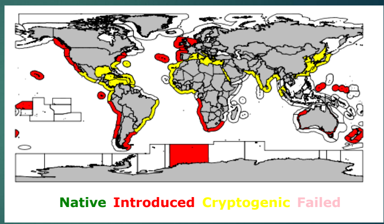
Alitta succinea Leuckart, 1847

Native of Atlantic coast (Global Invasive Species Data)



Tolerant to changes in salinity, temperature and dissolved oxygen. Epitoch phase is found several months of the year, feeds on sediment, algae and microorganisms. These biological characteristics allow it to be established in different environments.

Bugula neritina (Linnaeus, 1758)

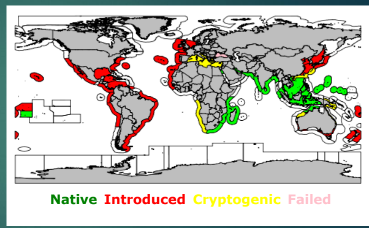


Phylum: Bryozoa
Class: Gymnolaemata
Order: Cheilostomatida
Family: Bugulidae

Tasso et al. 2018. Biodiversity Data Journal 6: e28937

Amphibalanus amphitrite (Darwin, 1854)

Phylum: Arthropoda
Class: Hexanauplia
Order: Sesilia
Family: Balanidae



https://invasions.si.edu/nemesis/calnemo/SpeciesSummary.jsp?TSN=89616

***Ancinus brasiliensis* Lemos de Castro, 1959**

***Elasmopus rapax* Costa, 1853**

***Caprella scaura* Templeton, 1836**

***Monocorophium insidiosum* (Crawford, 1937)**

***Monocorophium acherusicum* (Costa, 1853)**

Tasso et al. 2018. Biodiversity Data Journal 6: e28937

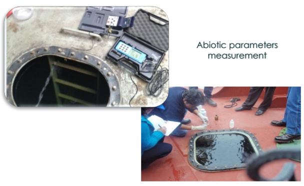
National Legislation

DS N° 018-2016

Ratification of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM), 2004

1. FLAG SHIPS WILL BE CERTIFIED WITH THE BALLAST WATER MANAGEMENT INTERNATIONAL CERTIFICATE, IN ACCORDANCE WITH THE SUPERVISION OF THE MANAGEMENT PLAN THAT IS ON BOARD.
2. MEASUREMENTS WILL BE OPTIMIZED IN VESSELS ARRIVING TO PORT TERMINALS TO DETECT INVASIVE SPECIES.
NATIONAL MANAGEMENT STRATEGIES OF BALLAST WATER IS IN FORMULATION.
3. PROMOTES TECHNOLOGIES FOR BALLAST WATER TREATMENT.

Zooplankton sampling



Abiotic parameters measurement

Proposal Document

Invasive Exotic Species National Action Plan

Prevention, control and impacts mitigation
2019-2024

This document is the result of 4 years of contributions of the Working Group on Invasive Exotic Species (GT-EEI) of the National Commission of Biological Diversity (CONADIB), composed of experts, academics, representatives of civil society and various sectors.

Objectives:

- Prevent the entry of Invasive Exotic Species (IES) into the national territory.
- Control the dispersion of the IES identified in the country (including native species that are introduced to regions outside their natural range) and mitigate the negative impacts on biological diversity, ecosystem services, health and economy.
- Increase awareness of key actors about the risks and impacts of IES for biodiversity, health and the economy, encouraging informed decisions to their management.

Concluding remarks

Some necessities:

- There is a lack of national species inventories in ports and bays
- Scarcity of national taxonomists difficult the task of detecting non-indigenous species

Critical issues:

- Records of non-indigenous species have increased in the last years.
- This introductions events are most likely to be human-mediated through maritime activities.
- The ecological and economical impact of the establishment of non-indigenous species has not been quantified.
- Growing marine related economic activities at national scale could accelarete the introductions of these species.
- The probability of establishment and invasion of non-indigenous species could increase under the climate change scenario.

- IMO Biofouling Guidelines have not yet been implemented increasing the probability of new species introductions.
- It is urgent to establish scientific guidelines and strengthen the national regulatory framework to avoid the possible impact of non-indigenous introductions by biofouling in the Peruvian marine ecosystem.

gef UNDP IMO INTERNATIONAL MARITIME ORGANIZATION **GloFouling Partnerships**

1st IMO-GloFouling Research & Development Forum on Biofouling Management

Patricia Carbajal[1], Rita Orozco[1], Sara Clemente[1], Frederick Orlandini[2]

1. **Instituto del Mar del Perú - Imarpe**
2. Dirección de Medio Ambiente, Dirección de Capitanía y Guardacostas – DICAPI

pcarbajal@imarpe.gob.pe

Thank you

2019

ANTHONY TALOULI
Pollution Adviser
Secretariat of the Pacific Environment Programme (SPREP)

Anthony Talouli (Tony) is currently employed by the Secretariat of the Pacific Environment Programme (SPREP) as the Pollution Adviser for the last 11years.

The Pollution Adviser role involves strategic programme and project coordination, implementation and management. Particularly with respect to the management of terrestrial and marine pollution under the overarching framework of the Integrated Waste and Pollution Management Strategy 2016- 2025 (Cleaner Pacific 2025) *and* Pacific Oceans Pollution Prevention Programme (PACPOL) Strategy 2015-2020 *in the Waste Management and Pollution Control Programme at SPREP.*

Part of this role is managing the marine environment protection aspect of the International Maritime Organization Technical Cooperation Programme in the region as well as being the custodian of the Pacific Regional Marine Spill Contingency Plan (PACPLAN). Both of these roles assist countries in responding to marine oil spills. Another large part of the role is implementing the Pacific Marine Litter Strategy and Action Plan (in draft) *as part of the UN Environment* Regional Seas *and* Global Partnership on Marine Litter *addressing marine plastics both from marine as well as terrestrial sources. The other part of the role involves implementing the* regional strategy to address shipping related invasive marine pests in the Pacific islands (SRIMP-Pac) *in collaboration with the IMO. On a day to day basis the role involves providing technical advice, support and assistance to member countries particularly with regards to funding and resourcing that addresses oil, hazardous chemicals, marine debris and plastics, as well as ship sourced pollution.*

Anthony has an engineering background. He has been at SPREP for the last 10 years and previous to that, 10 years in the oil industry with Shell company.

Working towards a strategic regional strategy for addressing invasive aquatic species

In a region with 98% covered by ocean, with over 12Million people, 21 Pacific island countries and territories, 30million square kilometres the ocean is more important to the Pacific islanders than the global average. As such the health of the marine environment is fundamental to the health of all aspects of the entire Pacific island region. Invasive aquatic species (IAS) is a major concern for Pacific islands. There are 2 vectors in which IAS are brought into the Pacific region through aquaculture and through shipping by ballast water and hull bio- fouling with hull bio-fouling being the greatest threat. The Pacific is a net exporter of ballast water.

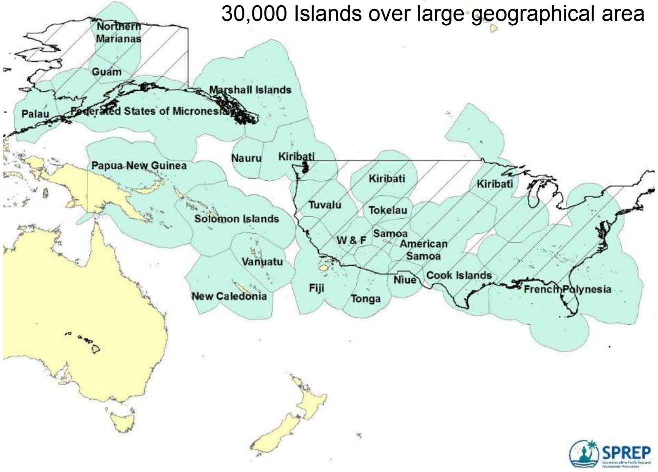
SPREP has a regional strategy to address shipping related invasive marine pests in the Pacific region (SRIMP- Pac) that was adopted by the SPREP Meeting in 2006. Although the strategy is dated the strategy identifies several priorities for the region that are still valid. These priorities will be addressed in the GloFouling project through SPREP as a regional coordinating organisation (RCO) and Fiji and Tonga as pilot lead countries.

4th ANZPAC Workshop on Biofouling Management for Sustainable Shipping
1st GEF-UNDP-IMO GloFouling R&D Forum and Exhibition on Biofouling Management

Working Towards a Strategic Regional Strategy for Addressing Invasive Aquatic Species

Anthony Talouli, Pollution Adviser, WMPC, SPREP

Large Ocean States
30,000 Islands over large geographical area



About SPREP

Strategic Plan 2017 - 2026

- Region's primary intergovernmental environmental organisation
- Promotes cooperation and provides assistance in environmental protection and improvement in the Pacific islands region
- 26 Member governments - 21 Pacific island countries and territories; 5 metropolitan countries (Australia, France, NZ, UK, USA)

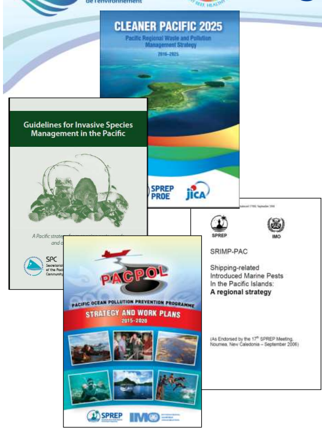
Pacific Leader's Decisions

- **Climate Change** is the single biggest critical issue facing the Pacific
- Recognise importance of **waste and Pollution management for the Blue Pacific**

Current Work

- Invasive Species is a key component of SPREPs work
- Leadership of invasives shared by SPC/SPREP
- Planning & Strategies – GISMP, SRIMP-Pac
- Operations – PILN, PRISMSS
- Funding – GEF6, GloFouling
- Other Projects - Pacific MTCC, EDF11 PacWaste Plus/PEUMP, POLP, AFD, JPRISM2, INFORM, GEF7 ISLANDS

Current Work



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- Pacific MTCC, EDF11 PacWaste Plus/PEUMP, POLP, AFD, JPRISM2, INFORM, GEF7 ISLANDS

Integrated Management System

Invasive Species Focal Area SPREP Strategy 2017-2026

Strategy Vision

Significantly reduce the socioeconomic and ecological impact of invasive species on land and water ecosystems and control or eradicate priority species.

IAS Regional Strategy

Pacific Thematic Priorities

- Institutional Arrangements
- Legislation and Regulation
- Communication and Awareness
- Risk Assessment
- Surveys and Monitoring
- Port State Control
- Ballast Sediment Management
- Training and Capacity Building
- Incursion Response and Control
- Transit Shipping
- Information Management

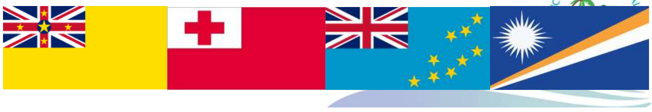
IAS Leadership

SPREP	Pacific Community
Terrestrial	**Biosecurity**
Vessel Hull Bio Fouling	**Aquaculture**
Ship Ballast Water	**Aquarium**

Operations

GEF6 IS Project

- Covering 4 Pacific states for USD 6.0 M
- Niue, RMI, Tuvalu, Tonga
- Marine Invasives priority for Tuvalu to address new BWM Strategy (USD 1.0M)
- 4 Components strengthening institutional frameworks and capacities for IAS management



GloFouling Partnerships

- SPREP RCO
- Fiji & Tonga LPC
- Regional Workshop – June 2019
- BWM, AFS, GloFouling
- National inception workshops – June 2019

GMN | The Global MTCC Network — MTCC PACIFIC Maritime Technology Cooperation Centre

- Low Carbon Transportation
- GMN – 5 Centre's
- Collecting Data from 7 PICs
- Centers in 2 PICs - Fiji & Samoa
- Energy Efficiency – Ship Operations, Solar, propeller fin cap
- Reduction 40% by 2030, work towards 100% by 2050

EUROPEAN UNION

Other Projects

- EDF11 PacWaste Plus — USD 19 M
- Aust. POLP — AUD 16 M
- France AFD — EURO 3 M
- Japan JPRISM2 — USD 10 M
- GEF7 ISLANDS — USD 20 M

Summary

- Invasive Species is a key component of SPREPs work in the region
- Leadership of invasives shared by SPREP & SPC
- Planning & Strategies – GISMP, SRIMP-Pac
- Operations – PILN, PRISMSS
- Funding – GEF6, GloFouling, EDF11 PacWaste Plus, POLP, AFD, JPRISM2, GEF7 ISLANDS, MTCC, INFORM
- Hull Fouling, GHG, AFS
- Integrated Holistic Approach – Review of regional strategies

EMILY JONES
Senior consultant
Ramboll New Zealand Limited, New Zealand

Emily is a Senior Consultant with nearly 15 years of experience in marine biosecurity. At Ramboll, Emily specialises not only in biosecurity but also in the assessment and management of environmental impacts on marine environments. She has carried out numerous vessel biosecurity inspections (internal and external systems) and port/natural area surveys for marine pests. She has worked throughout the Australasian region conducting both nearshore and offshore/deepwater environmental and biosecurity baseline & monitoring programmes. Emily also has training in environmental planning, which provides an ideal background for the conduct of consultation and public awareness programmes.

ROVing Around Marinas: Utility of Mini ROVs in Biofouling Management

Recognising the potential threat of non-indigenous marine species to the region's economy and natural systems, Auckland Council has instituted a programme of regular hull surveys of biofouling on recreational and small commercial vessels. The main aim of this surveillance programme is to capture the current state of hull biofouling across the region's marinas and mooring areas to inform ongoing management. Surveillance was conducted on behalf of the Council by Ramboll in the southern summer of 2019 and will be repeated during the summer of 2019/2020. Over 600 vessels were examined from March to May 2019 using a combination of diver and remote-operated vehicle (ROV) surveys. The dive team, highly experienced in biofouling assessments with several thousand spot surveys conducted over the last few years, focussed on operations at mooring areas and anchorages, while Ramboll's biosecurity scientists used a BlueROV2 to survey vessels in marinas. In this presentation we discuss and compare the usefulness and limitations of using this ROV and diver inspections for biosecurity hull surveillance in New Zealand marinas.

01 The mini ROV

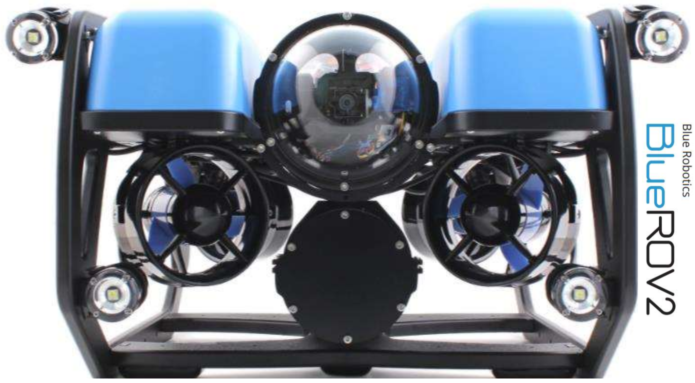
02 The project – vessel hull surveillance in Auckland

03 The utility of the mini ROV

04 The efficiency of the ROV vs divers

05 Final thoughts

RAMBOLL



6 Thrusters
Capable lighting
Live HD video feed
Up to 100m depth
Open Source ArduSub software
Pixhawk autopilot
Weight < 10kg
4-6h battery life

Blue Robotics
BlueROV2

RAMBOLL

The current state of hull biofouling across the region

2018 / 2019 season

Biofouling on recreational and small commercial vessels

Marinas, moorings, anchorages

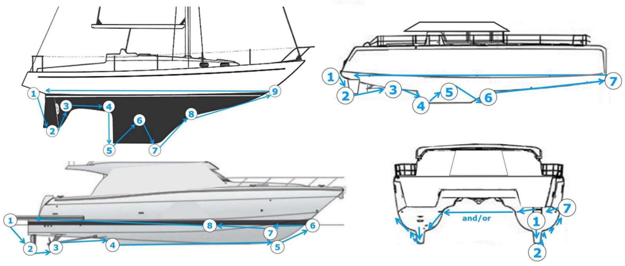
ROV and diver inspections

Level of Fouling (LoF) on vessel hulls

609 vessel inspections

Auckland Council

RAMBOLL



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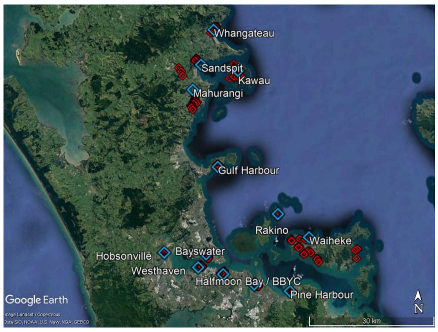

Auckland Council
Te Kaunihera o Tāmaki Makaurau

RAMBOLL

Auckland Council
Te Kaunihera o Tāmaki Makaurau

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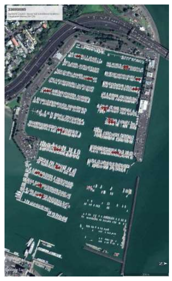

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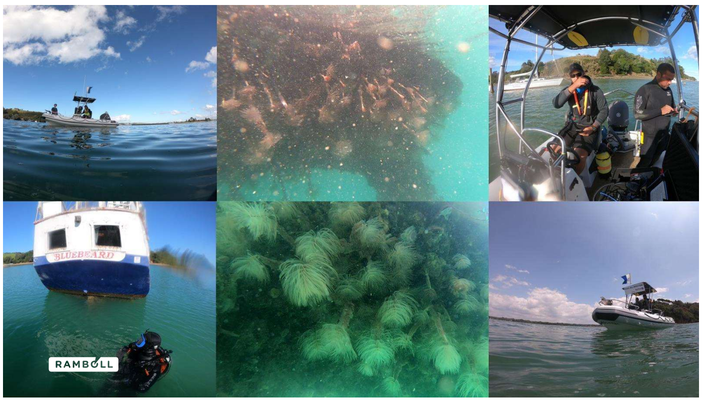
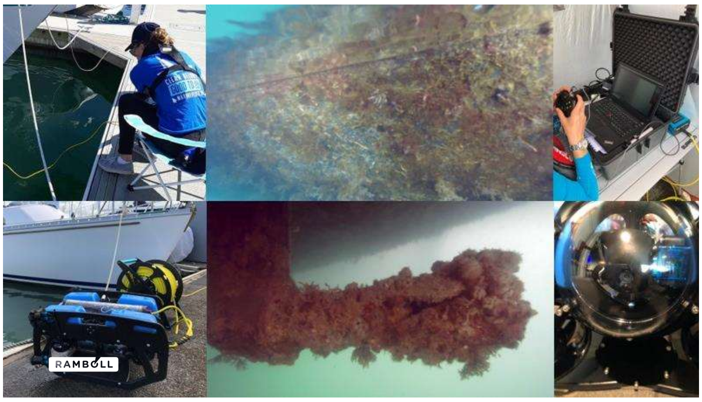


RAMBOLL

DIVER SURVEY IN MOORING AREA

RAMBOLL



01 Small size and low weight
Easy to learn and use

02 Portable, rapid mobilisation
Video/still records

03 Needs only 2 people for operation
Easy to move between sites

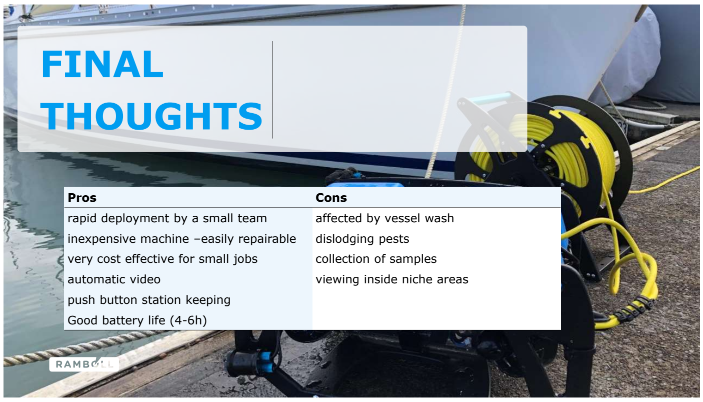
04 Good resolution on flat hulls
and some niche areas BUT

05 Unlikely to see inside some
types of niche areas

06 Influenced by currents and
passing vessels

07 Potential to dislodge biofouling
Unable to take samples

08 Not yet tested in open water
or on vessels larger than 25 m



Pros	Cons
rapid deployment by a small team	affected by vessel wash
inexpensive machine –easily repairable	dislodging pests
very cost effective for small jobs	collection of samples
automatic video	viewing inside niche areas
push button station keeping	
Good battery life (4-6h)	

Michael Sierp
Managing Director
Aquatic Biosecurity Pty Ltd, Australia

Michael is currently the Managing Director of the private consulting company Aquatic Biosecurity Pty Ltd. He is National Secretary for the Australasian Institute of Marine Surveyors AIMS, a RecFishSA Board Director and S.A. State Manager for OzFish Fisheries Habitat development programs. Previously Michael was employed as Marine Biosecurity Manager for the South Australian Government with a focus on fisheries, maritime and the environment where he was elected Chair of the national Marine Pest Sectoral Committee MPSC. He currently undertakes biofouling inspections, marine surveying, commercial diving and fisheries habitat restoration projects here and internationally. He also likes candlelit dinners and long walks on the beach.

Neat and innovative biofouling treatment options that actually work

An informative talk on innovative real time examples in poisoning, dissolving, encapsulating, burning and blowing marine pests up including 5 different tools to kill oysters. These have been applied mostly with success and sometime on vessels.


aquaticbiosecurity.com


ANZPAC 2019
Neat And Innovative Biofouling Treatment Options That Actually Work
Dr Michael Sierp
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ph +61 434 078 851
Managing Director, Aquatic Biosecurity Pty Ltd
National Secretary Australasian Institute of Marine Surveyors AIMS
Senior Manager SA, OzFish
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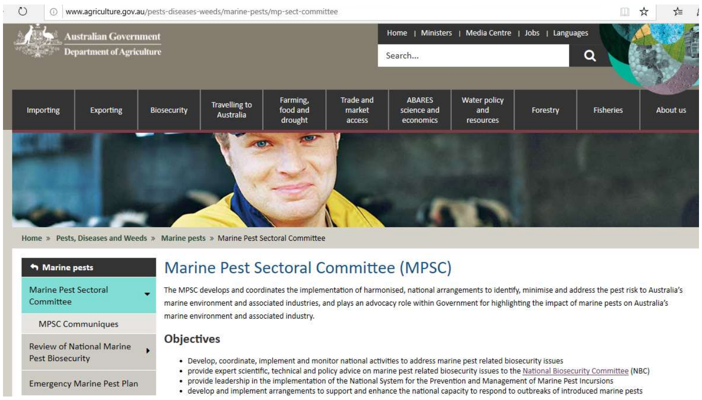
P800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ABARES science and economics
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Home > Pests, Diseases and Weeds > Marine pests > Marine Pest Sectoral Committee
Marine pests
Marine Pest Sectoral Committee
MPSC Communiques
Review of National Marine Pest Biosecurity
Emergency Marine Pest Plan
Marine Pest Sectoral Committee (MPSC)
The MPSC develops and coordinates the implementation of harmonised, national arrangements to identify, minimise and address the pest risk to Australia's marine environment and associated industries, and plays an advocacy role within Government for highlighting the impact of marine pests on Australia's marine environment and associated industry.
Objectives
Develop, coordinate, implement and monitor national activities to address marine pest related biosecurity issues
provide expert scientific, technical and policy advice on marine pest related biosecurity issues to the National Biosecurity Committee (NBC)
provide leadership in the implementation of the National System for the Prevention and Management of Marine Pest Incursions
develop and implement arrangements to support and enhance the national capacity to respond to outbreaks of introduced marine pests


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OzFish
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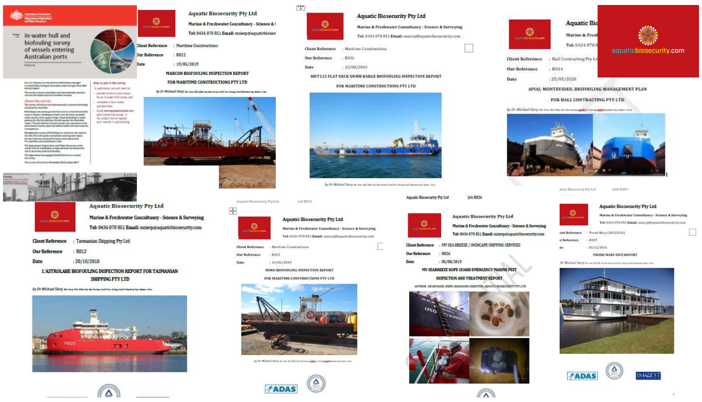
AUSTRALASIAN INSTITUTE OF MARINE SURVEYORS
Mb.No. 427
EST. 1986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Aquatic Biosecurity Pty Ltd


TURNING VESSELS AWAY IS VERY EXPENSIVE AND DAMAGING TO INDUSTRY
BIOFOULED VESSEL ORDERS:
COMPLEX DEVELOPMENT PROJECTS $$$$$$$$$
BUSY PORT BULK CARRIERS $$$$$$$$$
$MILLIONS

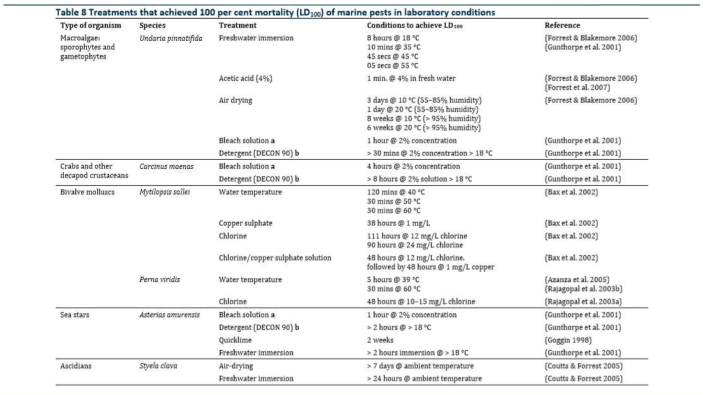
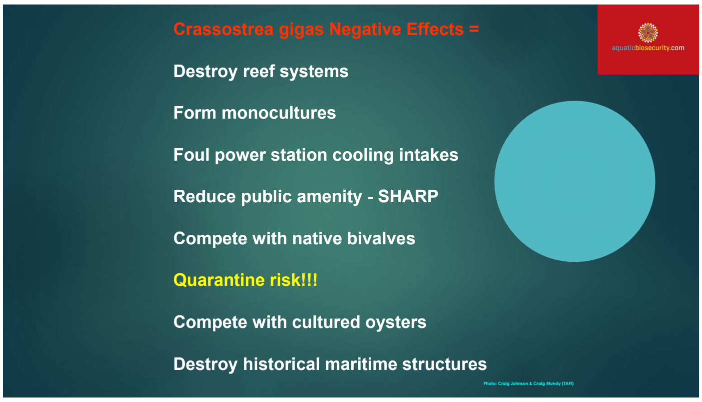


Table 8 Treatments that achieved 100 per cent mortality (LD_{100}) of marine pests in laboratory conditions

Type of organism	Species	Treatment	Conditions to achieve LD_{100}	Reference
Macroalgae: sporophytes and gametophytes	*Undaria pinnatifida*	Freshwater immersion	8 hours @ 18 °C 10 mins @ 35 °C 45 secs @ 45 °C 05 secs @ 55 °C	(Forrest & Blakemore 2006) (Gunthorpe et al. 2001)
		Acetic acid (4%)	1 min. @ 4% in fresh water	(Forrest & Blakemore 2006) (Forrest et al. 2007)
		Air drying	3 days @ 10 °C (55–85% humidity) 1 day @ 20 °C (55–85% humidity) 8 weeks @ 10 °C (> 95% humidity) 6 weeks @ 20 °C (> 95% humidity)	(Forrest & Blakemore 2006)
		Bleach solution **a**	1 hour @ 2% concentration	(Gunthorpe et al. 2001)
		Detergent (DECON 90) **b**	> 30 mins @ 2% concentration > 18 °C	(Gunthorpe et al. 2001)
Crabs and other decapod crustaceans	*Carcinus maenas*	Bleach solution **a**	4 hours @ 2% concentration	(Gunthorpe et al. 2001)
		Detergent (DECON 90) **b**	> 8 hours @ 2% solution > 18 °C	(Gunthorpe et al. 2001)
Bivalve molluscs	*Mytilopsis sallei*	Water temperature	120 mins @ 40 °C 30 mins @ 50 °C 30 mins @ 60 °C	(Bax et al. 2002)
		Copper sulphate	38 hours @ 1 mg/L	(Bax et al. 2002)
		Chlorine	111 hours @ 12 mg/L chlorine 90 hours @ 24 mg/L chlorine	(Bax et al. 2002)
		Chlorine/copper sulphate solution	48 hours @ 12 mg/L chlorine, followed by 48 hours @ 1 mg/L copper	(Bax et al. 2002)
	Perna viridis	Water temperature	5 hours @ 39 °C 30 mins @ 60 °C	(Azanza et al. 2005) (Rajagopal et al. 2003b)
		Chlorine	48 hours @ 10–15 mg/L chlorine	(Rajagopal et al. 2003a)
Sea stars	*Asterias amurensis*	Bleach solution **a**	1 hour @ 2% concentration	(Gunthorpe et al. 2001)
		Detergent (DECON 90) **b**	> 2 hours @ > 18 °C	(Gunthorpe et al. 2001)
		Quicklime	2 weeks	(Goggin 1998)
		Freshwater immersion	> 2 hours immersion @ > 18 °C	(Gunthorpe et al. 2001)
Ascidians	*Styela clava*	Air-drying	> 7 days @ ambient temperature	(Coutts & Forrest 2005)
		Freshwater immersion	> 24 hours @ ambient temperature	(Coutts & Forrest 2005)


Caulerpa taxifolia
-$11M

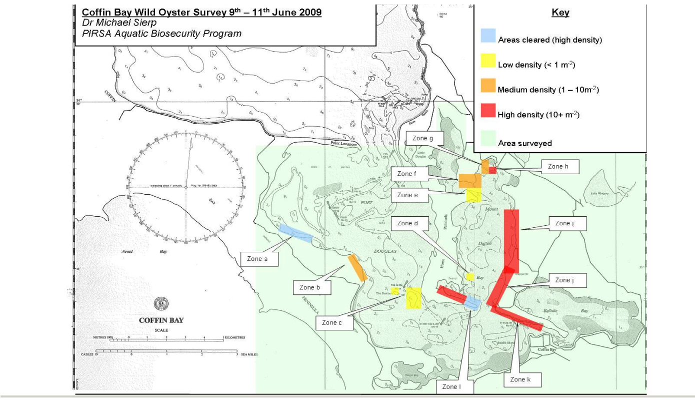

DUAL MARINE PEST AND DISEASE RESPONSE
PACIFIC OYSTERS AND POMS (OsHV-1)
Australia

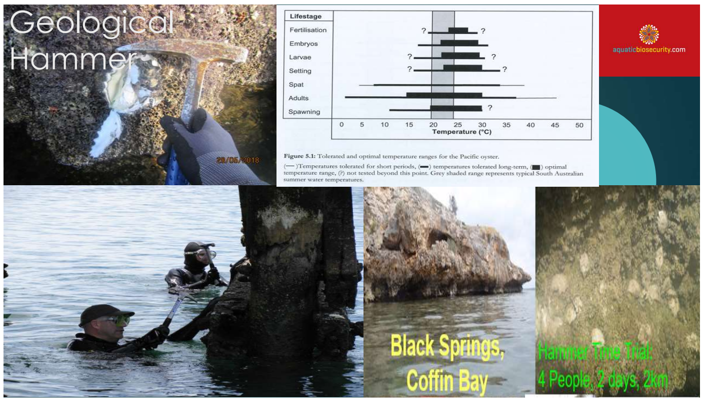

Crassostrea gigas Negative Effects =
Destroy reef systems
Form monocultures
Foul power station cooling intakes
Reduce public amenity - SHARP
Compete with native bivalves
Quarantine risk!!!
Compete with cultured oysters
Destroy historical maritime structures

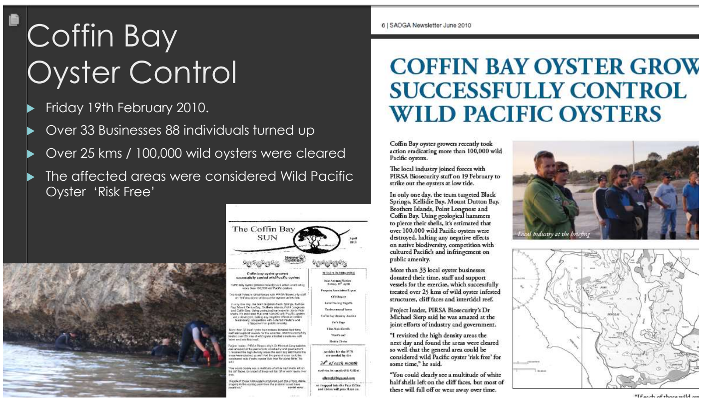

Tasmania
CLEARED 12 months before


Pipeclay bay Tasmania
Completely covered by feral oysters
18 Months

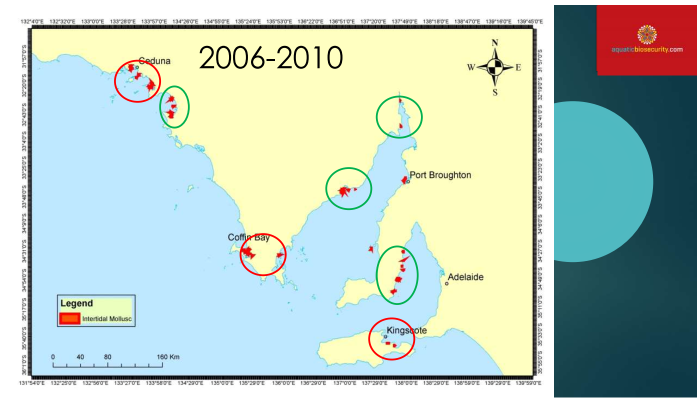

West Lakes SA

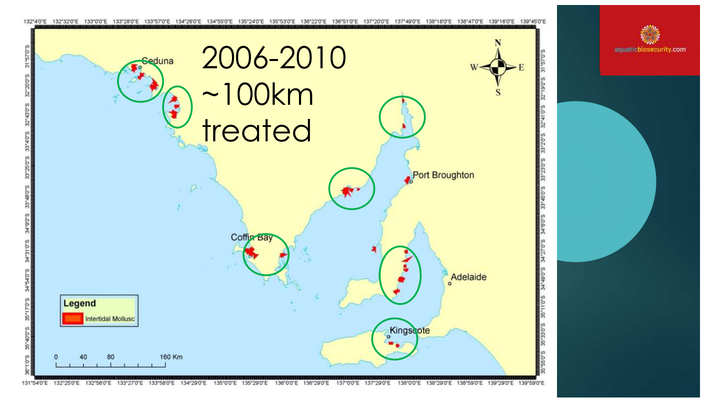

Coffin Bay Wild Oyster Survey 9th – 11th June 2009
Dr Michael Sierp
PIRSA Aquatic Biosecurity Program
Key
Areas cleared (high density)
Low density (< 1 m-2)
Medium density (1 – 10m-2)
High density (10+ m-2)
Area surveyed
Zone a
Zone b
Zone c
Zone d
Zone e
Zone f
Zone g
Zone h
Zone i
Zone j
Zone k
Zone l
COFFIN BAY

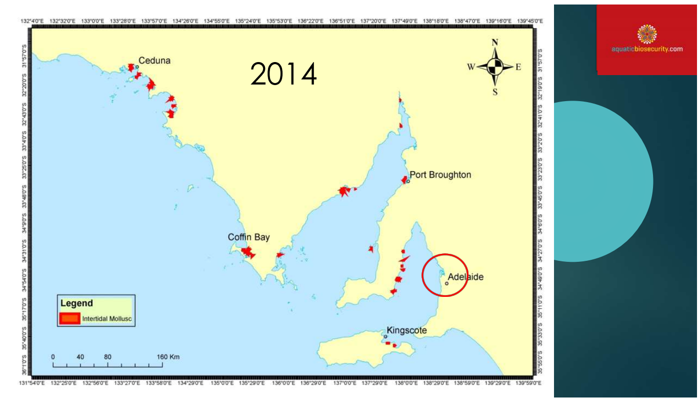

Geological Hammer
Lifestage
Fertilisation
Embryos
Larvae
Setting
Spat
Adults
Spawning
Temperature (°C)
Black Springs, Coffin Bay
Hammer Time Trial
4 People, 2 days, 2km

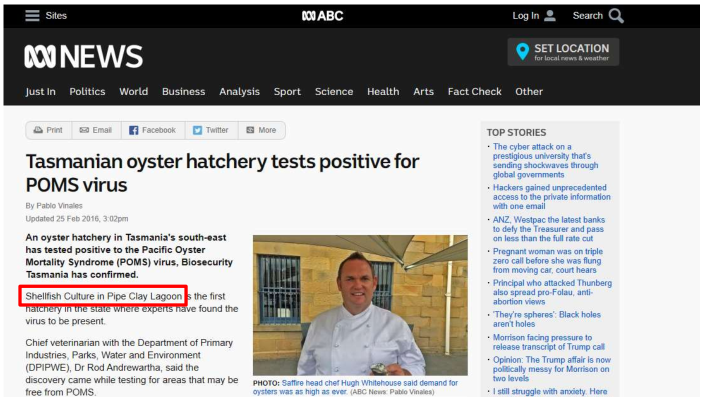

Coffin Bay Oyster Control
Friday 19th February 2010.
Over 33 Businesses 88 individuals turned up
Over 25 kms / 100,000 wild oysters were cleared
The affected areas were considered Wild Pacific Oyster 'Risk Free'
6 | SAOGA Newsletter June 2010
COFFIN BAY OYSTER GROW
SUCCESSFULLY CONTROL
WILD PACIFIC OYSTERS
The Coffin Bay SUN


Matts Point
Cape Vivonne
Thevenard Reef


2006-2010
Ceduna
Port Broughton
Coffin Bay
Adelaide
Kingscote
Legend
Intertidal Mollusc
0 40 80 160 Km


2006-2010
~100km
treated
Ceduna
Port Broughton
Coffin Bay
Adelaide
Kingscote
Legend
Intertidal Mollusc
0 40 80 160 Km





ABC NEWS

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Tasmanian oyster hatchery tests positive for POMS virus

By Pablo Vinales

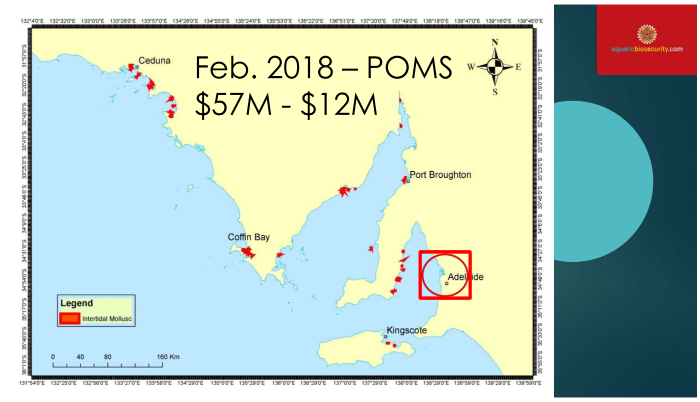
Updated 25 Feb 2016, 3:02pm

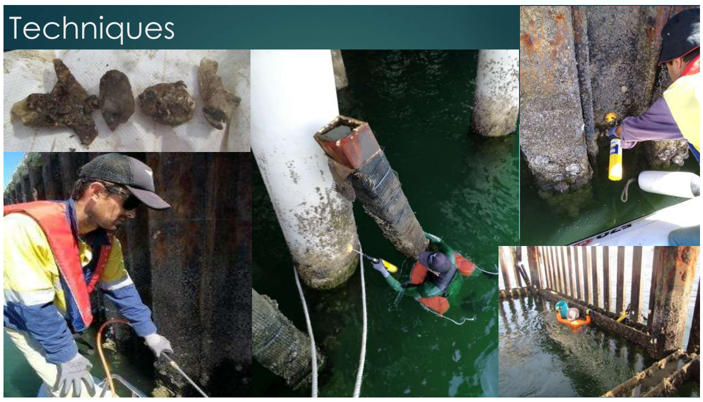
An oyster hatchery in Tasmania's south-east has tested positive to the Pacific Oyster Mortality Syndrome (POMS) virus, Biosecurity Tasmania has confirmed.

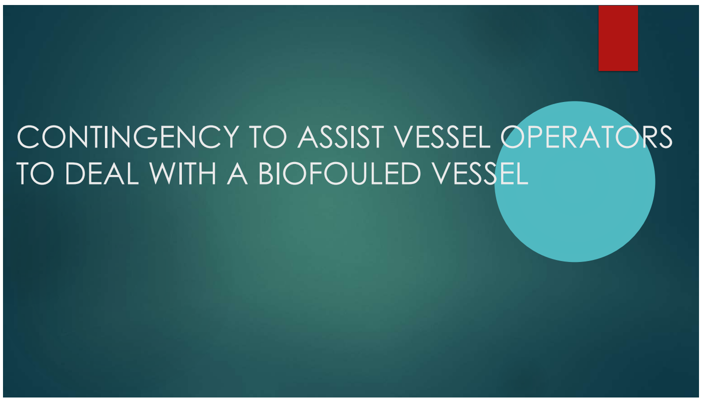
Shellfish Culture in Pipe Clay Lagoon is the first hatchery in the state where experts have found the virus to be present.

Chief veterinarian with the Department of Primary Industries, Parks, Water and Environment (DPIPWE), Dr Rod Andrewartha, said the discovery came while testing for areas that may be free from POMS.

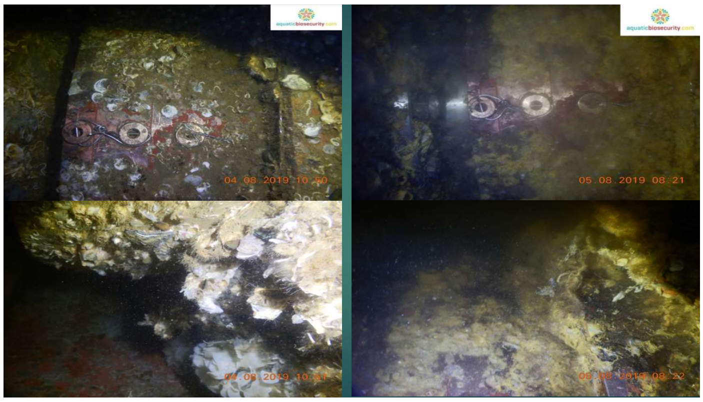
PHOTO: Saffire head chef Hugh Whitehouse said demand for oysters was as high as ever. (ABC News: Pablo Vinales)







The marine descaler, Rydlyme, dissolves biofouling and is non-toxic and biodegradable. A linear relationship between the level of fouling and the volume of Rydlyme required to digest fouling has been developed for this treatment (Lewis & Dimas 2007). Rydlyme technical application information recommends a Rydlyme:water dilution of 1:1 to be circulated in a closed system for at least four hours, and a freshwater flush of build-up to remove excessive scale (Rydlyme Marine 2004). At this concentration, 14 hours is the recommended application time to dissolve significant mussel growth (Lewis & Dimas 2007).



TAKE HOME MESSAGES

WE ARE CHANGING BEHAVIOUR BUT BEWARE OF THE ECHO CHAMBER

AVOIDING HABITAT DISTURBANCE IS KEY. REHABILITATION IS A TOOL

TOOLS WORK, WE NEED A BETTER TOOL BOX FOR CONTINGENCY

You will never work with dolphins…..?

BALLAST WATER

BIOFOULING

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Managing Director, Aquatic Biosecurity Pty Ltd

aquaticbiosecurity.com

Agnese Marchini
Senior researcher
University of Pavia, Italy

Agnese Marchini graduated in Biology in 2000 and obtained a PhD in Experimental Ecology in 2004 at the University of Pavia, Italy, with a study about fouling communities in the Lagoon of Venice.

She has been a visiting fellow at the University of Aveiro, Portugal, where she trained on taxonomy of marine amphipods, and a post-doc fellow at the Universities of Pavia and Ferrara, Italy, where she participated to several national and international projects. In particular, she has worked on benthos collected from man-modified habitats (ports, marinas, lagoons) of the Mediterranean Sea, Red Sea, Macaronesia and North-Eastern Atlantic, and has gained a vast experience on nonindigenous species occurring in the fouling communities. Since November 2016, Agnese Marchini is Senior Researcher in Ecology at the Department of Earth and Environmental Sciences, University of Pavia, where she supervises PhD and master theses and internships for incoming international students.

She has served as a reviewer for 40 international journals of ecology, marine biology, environmental monitoring, modelling and management, as well as for national and international funding programs. She is member of several scientific boards, including the Working Group on Invasive Alien Species (WGIAS) of the European Commission's Directorate General for Environment (DG Environment); the "Allochtonous species group" of the Italian Society of Marine Biology (SIBM), where she has been coordinator of the Horizon Scanning Exercise on marine alien species for Italy. Agnese Marchini has authored or co-authored 60 peer-reviewed articles and four book chapters; her researches have been presented at 70 scientific conferences. Her researches are covered by several national and international newspapers and she also writes educational articles for Italian magazines and blogs.

Fouling on recreational boats as a major spreading vector of non-indigenous species in the Mediterranean Sea

Agnese Marchini[1], Christos Arvanitidis[2], Jasmine Ferrario[1], Aitor Forcada[3], Anna Occhipinti-Ambrogi[1], Hanno Seebens[4], Aylin Ulman[1,5]

[1]University of Pavia, Pavia, Italy
[2]Hellenic Centre of Marine Research, Thalassokosmos, Heraklion, Crete, Greece
[3]Department of Marine Sciences and Applied Biology, University of Alicante, Spain [4]Senckenberg Biodiversity and Climate Research Centre (SBiK-F), Frankfurt, Germany [5]MerSea Consulting, Fethiye & Izmir, Turkey

This is the first large-scale study addressing the spreading of non-indigenous species (NIS) on recreational boats in the Mediterranean Sea, which is both the global hotspot for marine bioinvasions and a highly- attended destination for boating traffic. We collected fouling invertebrates from 50 marinas spanning 7 countries from Spain to Turkey, and from about 600 boat hulls, also interviewing their owners.

The surveyed marinas had between 2 and 27 NIS, whose richness was related to sea surface temperature, number of berths, proximity to Suez Canal, aquaculture sites or commercial harbours, absence of pontoons, biogeographic sector and climate type. Interestingly, 71% of sampled hulls, including those that had recently been cleaned professionally, hosted from 1 to 11 NIS. Boats with high NIS richness strongly correlated to home marinas with high NIS richness. The surveyed boaters travelled considerably (on average, 67 travel days and 7.5 visited marinas per year), showing high potential for spreading NIS.

FOULING ON RECREATIONAL BOATS AS A MAJOR SPREADING VECTOR OF NON-INDIGENOUS SPECIES IN THE MEDITERRANEAN SEA

AGNESE MARCHINI
Dept. of Earth and Environmental Sciences, University of Pavia, Italy

The Mediterranean Sea

- 2.51 millions km^2
- 23 countries
- 3 continents
- 5 millennia of human history
- …

The Mediterranean Sea

… and about 800 multicellular marine NIS

1959 1989 2019

Legislative background

UN Environment/
Mediterranean Action Plan
Barcelona Convention Secretariat

2005 2017

- Development of a **regional plan on hull fouling** encouraged (2005)
- Development of **national plans to prevent vectors** encouraged (2017)

Legislative background

UN Environment/
Mediterranean Action Plan
Barcelona Convention Secretariat

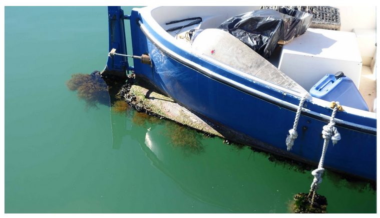
2005 2017

- Development of a **regional plan on hull fouling** encouraged (2005)
- Development of **national plans to prevent vectors** encouraged (2017)

European Commission	European Union
Marine Strategy Framework Directive 56/2008	IAS Regulation 1143/2014
→ promotes **monitoring**	→ promotes **prevention and control**

The reality

- **Very initial** phase of biofouling monitoring
- **No** biofouling prevention
- **No** biofouling control



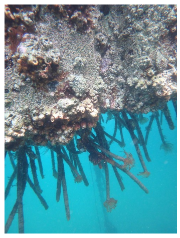
Recreational Boating in the Med

- 20% global boat fleet (about 1.5 millions boats)
- world leader of global super yacht production (Italy)
- numerous boatyard / haul-out facilities

Source: Plan Bleu (2011)

Understanding the role of recreational boating as vector of NIS introduction and dispersal

- Understanding the role of recreational **marinas as 'hotspots'** of introduction
- Identifying the factors that correlate with **high NIS richness** and NIS composition in marinas
- Investigating **biofouling** on Mediterranean recreational boats, with a focus on NIS
- Understanding the **patterns of recreational boating** in the Mediterranean (interviews)
- Understanding **level of awareness** of boaters on marine NIS



Methods

- Ports surveyed by modified rapid assessments / scrapes
- Boat hulls surveyed by snorkeling/dive/at the boatyard
- Questionnaires submitted to boat owners regarding
  - travel history
  - maintanance
  - awareness
- Species identification* and NIS assessment

* only macrofauna; no algae, no unicellular taxa

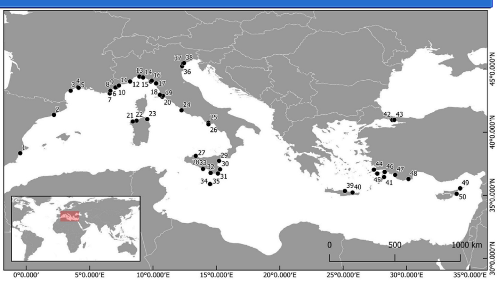
Methods

Abiotic factors:

- Environmental factors- salinity, sea surface temperature on sampling date, Koppen-Geiger climate classification, primary productivity, chlorophyll concentrations, biogeographic sector,
- Marina factors- # berths, marina size, total pier length, presence of shipyard, enclosement length, presence of floating pontoons,
- Proximity to other vectors- aquaculture, commercial harbours, Suez Canal

Study area(s)

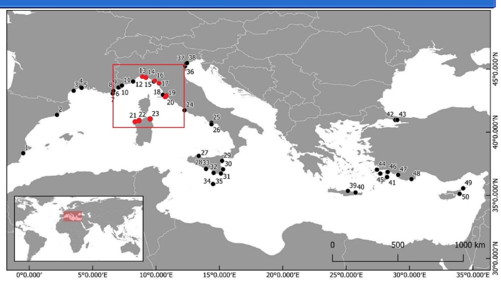
- **50 marinas** sampled between 2012 and 2016
- **7 countries:** Spain, France, Italy, Malta, Greece, Cyprus, Turkey
- **2** PhD students



Study area(s)

1) Differences in **NIS richness and composition** between commercial harbours and recreational marinas

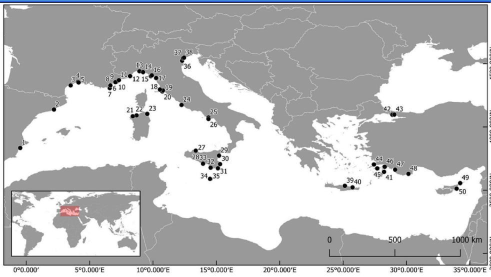
- **North-western Italy + Sardinia**
- **5** harbours + nearby marinas



Study area(s)

2) Abiotic factors correlated to NIS richness and composition in marinas

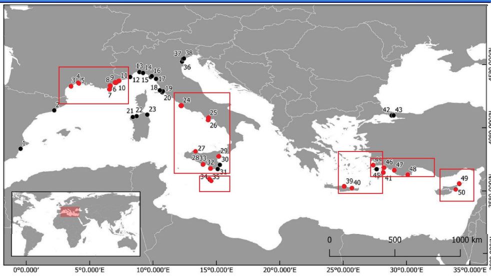
- Whole dataset: **50 marinas & their abiotic factors**



Study area(s)

3) NIS occurrence on boat hulls

- **6 countries**
- **25** marinas
- **~ 25** boaters interviewed **per marina** and hulls inspected underwater
- **~ 600 boats** interviews and boat samples collected



4th ANZPAC Workshop on Biofouling Management for Sustainable Shipping
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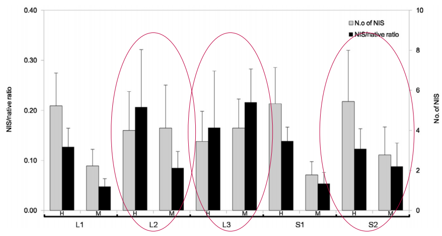
Main results: (1) harbours vs marinas

No strong differences in NIS richness between commercial harbours and recreational marinas



. Average number of NIS and NIS/native species ratio in harbours (H) and marinas (M) of each coastal stretch.

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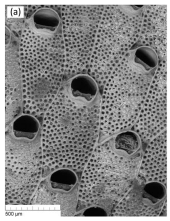
NIS **unique** to marinas

New NIS records for the Mediterranean Sea from marinas!



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BIOFOULING, 2017
https://doi.org/10.1080/08927014.2017.1351958

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Role of commercial harbours and recreational marinas in the spread of non-indigenous fouling species

Jasmine Ferrario, Sarah Caronni, Anna Occhipinti-Ambrogi and Agnese Marchini

Department of Earth and Environmental Sciences, University of Pavia, Pavia, Italy

ABSTRACT
The role of commercial harbours as sink and source habitats for non-indigenous species (NIS) and the role of recreational boating for their secondary spread were investigated by analysing the fouling community of five Italian harbours and five marinas in the western Mediterranean Sea. It was first hypothesised that NIS assemblages in the recreational marinas were subsets of those occurring in commercial harbours. However, the data did not consistently support this hypothesis: the NIS pools of some marinas significantly diverged from harbours even belonging to the same coastal stretches, including NIS occurring only in marinas. This study confirms harbours as hotspots for marine NIS, but also reveals that numbers of NIS in some marinas is higher than expected, suggesting that recreational vessels effectively facilitate NIS spread. It is recommended that this vector of NIS introduction is taken into account in the future planning of sustainable development of maritime tourism in Europe.

ARTICLE HISTORY
Received 5 October 2016
Accepted 4 July 2017

KEYWORDS
Commercial vessels; fouling; introduced species; macrozoobenthos; ports; recreational boating

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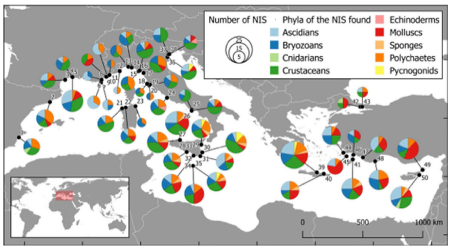
Main results: (2) NIS in marinas

74 NIS identified

2-27 NIS in marinas



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2-27 NIS in marinas

3 new records for the Mediterranean

51 new country records

PeerJ

A massive update of non-indigenous species records in Mediterranean marinas

Aylin Ulman[1,2,3], Jasmine Ferrario[1], Anna Occhpinti-Ambrogi[1], Christos Arvanitidis[3], Ada Bandi[1], Marco Bertolino[4], Cesare Bogi[5], Giorgos Chatzigeorgiou[3], Burak Ali Çiçek[6], Alan Deidun[7], Alfonso Ramos-Esplá[8], Cengiz Koçak[9], Maurizio Lorenti[10], Gemma Martinez-Laiz[11], Guenda Merlo[1], Elisa Princisgh[1], Giovanni Scribano[1] and Agnese Marchini[1]

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'local' NIS and **widespread** NIS

The most widespread NIS found in marinas (% of marina distribution).

Species	%	Species	%
Styela plicata	74	*Branchiomma bairdi*	30
Hydroides elegans	66	*Paraleucilla magna*	24
Amathia verticillata	62	*Ascidiella aspersa*	22
Caprella scaura	58	*Arcuatula senhousia*	22
Celleporaria brunnea	52	*Watersipora arcuata*	18
Paranthura japonica	52	*Ciona robusta*	16
Brachidontes pharaonis	34	*Tricellaria inopinata*	16
Hydroides dirampha	32	*Stenothoe georgiana*	16
Mesanthura romulea	30	*Dendostrea folium*	16
Paracerceis sculpta	30	*Magallana gigas*	16

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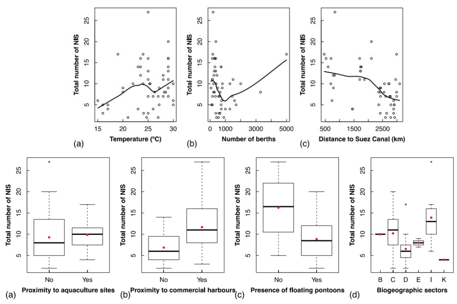
'local' NIS and widespread NIS

abiotic factors better correlated with NIS richness identified



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Research article

A Hitchhiker's guide to Mediterranean marina travel for alien species

Aylin Ulman[a,b,c,*], Jasmine Ferrario[a], Aitor Forcada[d], Christos Arvanitidis[c], Anna Occhipinti-Ambrogi[a], Agnese Marchini[a]

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[b] Sorbonne Université, CNRS, Laboratoire d'Ecogéochimie des Environnements Benthiques, LECOB, Banyuls-sur-Mer, France
[c] Institute of Marine Biology, Biotechnology and Aquaculture, Hellenic Centre of Marine Research, Thalassokosmos, Heraklion, 71003, Crete, Greece
[d] Department of Marine Sciences and Applied Biology, University of Alicante, Spain

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Main results: (3) NIS on boats

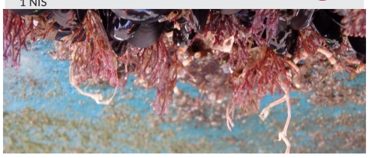
Few boats have **no fouling**

Most boats (71%) have at least 1 NIS

Up to **11 NIS** found on a single boat

NIS richness of a boat correlates with NIS richness in the marina

Sampling outcome	Total	%
No. vessels sampled	583	
No. vessels clean hull (= no fouling)	105	18
No. fouled vessels	480	82
No. sampled vessels hosting at least 1 NIS	413	71



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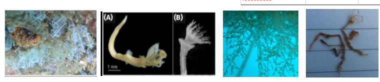
NIS also on **recently cleaned** boat hulls

Cleaning mode: D=dry; IW=in water

Marina locality	Last cleaning (weeks)	Cleaning mode	% fouled hull	% fouled niche areas	# NIS	NIS found on the hull
Agde	4	D	0	30	3	*Caprella scaura, Hydroides elegans, Paranthura japonica*
Famagusta	1.3	IW	10	30	5	*Amathia verticillata, Clavelina lepadiformis, H. elegans, Phallusia nigra, Paraleucilla magna*
Fethiye	1	IW	30	NA	5	*H. dirampha, H. elegans, B. pharaonis, Dendostrea folium, Sphaeroma walkeri*
Heraklion	2	IW	5	NA	7	*A. verticillata, C. scaura, Cymodoce fuscina, H. elegans, Paradella dianae, P. sculpta, S. walkeri*
Ischia Island	4	D	0	1	2	*C. scaura*
Karpaz	1	IW	0	2	3	*B. bairdi, D. folium, Malleus regula*
Le Grau-du-Roi	4	IW	100	100	4	*C. scaura, H. elegans, P. japonica, S. plicata*
Licata	1	D	2	NA	3	*A. verticillata, C. brunnea, H. elegans*
Sorrento	2	D	0	1	2	*A. verticillata, Tricellaria inopinata*



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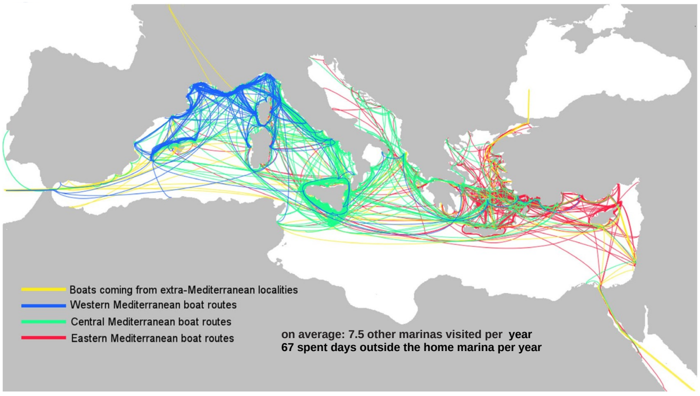
7 factors significantly predicted high NIS richness


Significant factors	Estimate	*SE*	*p*	Relative importance (%)
Intercept	0.570	0.107	<.001	
% visible fouling niche area	0.006	0.001	<.001	28.72
Time since last clean (months)	0.015	0.004	<.001	17.88
Boat length (m)	−0.016	0.006	<.01	11.77
Time since last paint (months)	0.006	0.003	<.05	10.75
% visible fouling hull estimate	0.003	0.001	<.05	10.52
Number of days spent travelling	0.001	0.001	<.05	9.73
Average cruising speed (kn)	−0.010	0.005	<.05	9.64



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Received: 21 January 2019 | Accepted: 8 August 2019
DOI: 10.1111/1365-2664.13502

RESEARCH ARTICLE

Journal of Applied Ecology

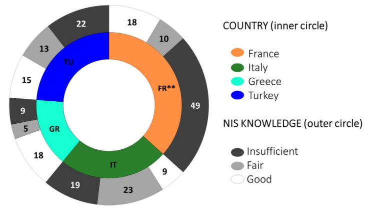
Alien species spreading via biofouling on recreational vessels in the Mediterranean Sea

Aylin Ulman[1] | Jasmine Ferrario[1] | Aitor Forcada[2] | Hanno Seebens[3] | Christos Arvanitidis[4] | Anna Occhipinti-Ambrogi[1] | Agnese Marchini[1]

Management challenges

1) Awareness



Martinez-Laiz *et al*., 2019. *Marine Pollution Bulletin*

Management challenges

1) Awareness

2) Monitoring


Standard protocols, taxonomy skills

Management challenges

1) Awareness

2) Monitoring

3) Prevention

4) Control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Monitoring marine alien species in ports with the SERC protocol



FOULING ON RECREATIONAL BOATS AS A MAJOR SPREADING VECTOR OF NON-INDIGENOUS SPECIES IN THE MEDITERRANEAN SEA

JASMINE FERRARIO,
ANNA OCCHIPINTI-AMBROGI, AYLIN ULMAN
Dept. Earth and Environmental Sciences, University of Pavia, Italy

CHRISTOS ARVANITIDIS
Hellenic Centre of Marine Research, Thalassokosmos, Heraklion, Crete, Greece

AITOR FORCADA
Dept. Marine Sciences and Applied Biology, University of Alicante, Spain

HANNO SEEBENS
Senckenberg Biodiversity and Climate Research Centre, Frankfurt, Germany

FRANK STUER-LAURIDSEN
CEO
LITEHAUZ, Denmark

Dr. Frank Stuer-Lauridsen is a Master of Biology (Copenhagen University) and a Ph.D. in Environmental Chemistry (Odense University). He has 25 years of experience in studies of industrial activities in the marine environment and coastal zone in many countries across the globe, e.g. in Jamaica, Namibia, Ghana, China, Singapore in addition to Denmark and Greenland.

Frank has been deeply involved in the environmental issues of shipping for the last 20 years with 11 years in his active companies LITEHAUZ, Ballast Water Monitoring and MARHAZ. Frank

- *was coordinator of environmental issues in the Danish Maritime Development Center and sat on the Steering Committee of "Green Ship of the Future";*
- *chaired the 2016 IMO workshop on ballast water pre-arrival risk assessment and was recently responsible for WMUs workshop on biofouling;*
- *is frequently a member of the Danish delegation to the MEPC as technical advisor;*
- *has on several occasions been consultant to the IMO Marine Division; and*
- *he was for three years a member of the GESAMP ballast water working group*

Frank has a professional background as researcher at the Danish National Environmental Research Institute (1990-1996), and senior consultant and chief project manager at the consultancy company COWI (1996-2005). He was later responsible for R&D as Head of Innovation at DHI Denmark until 2007 when he founded LITEHAUZ. He has published a dozen well cited academic papers.

A baseline study of the occurrence of non-indigenous species in Danish harbours

Jesper H. Andersen, Emilie Kallenbach, Mathias Brink Kjeldgaard and Steen W. Knudsen[1]; Wenche Eikrem, Camilla Fagerli, Eivind Oug, Trine Dahle, Jens Thaulow, Janne Gitmark, Anders Hobæk and Norman Green[2]; Martin Hesselsøe[3]; Josianne Støttrup, Jesper Kuhn, Dorte Bekkevold and Lars Magnus Wulf Jacobsen[4]; Peter Rask Møller, Christian Aakjær Olesen and Henrik Carl[5], Frank Stuer-Lauridsen[6]

[1]NIVA Denmark; [2]NIVA Norway; [3]NIRAS A/S, formerly AmphiConsult Aps; [4]DTU Aqua; [5]Natural History Museum of Denmark; [6]Litehauz ApS, Copenhagen, Denmark

We report the first nation-wide study of the occurrence of non-indigenous species (NIS) in Danish harbours. The sampling was carried out using both conventional and biomolecular methods (eDNA) pursuing two main objectives: to monitor NIS in 16 main commercial harbours and to assess the applicability of eDNA in NIS monitoring. The two largest harbours in Denmark, Esbjerg and Aarhus, were covered with intensive sampling and 14 harbours with a reduced programme. The eDNA programme covered 20 species with a species-specific operational test system (qPCR) and the conventional sampling programme included grab samples for water and sediments, plankton nets, traps, fouling plates, scrape poles, fish nets, and visual observations by snorkelling.

Using conventional sampling 26 NIS were recorded and 13 NIS were recorded using eDNA-based methods, in total 34 NIS excluding overlaps. The eDNA could be applied in all ports (although suspended solids impaired detection limits in Esbjerg), and while eDNA can obviously only report on the species targeted, eDNA results are in agreement with conventional sampling: Rare species are not found, the four fresh water species are not found in the brackish-saline waters sampled and five common species are found by both methods.

Based on the results, we conclude the following on NIS in Danish harbours: 1) more non-indigenous species are found in the western parts of Denmark (North Sea region) than in the eastern parts (Baltic Sea), and 2) two new NIS in Danish marine areas were recorded, i.e. the two bristle worms *Eteone heteropoda* (fam. Phyllodocidae) and *Streblospio benedicti* (fam. Spionidae). Regarding the applicability of biomolecular methods, we provide a proof-of-concept of the eDNA-based test systems developed for NIS monitoring. The results constitute a baseline for future studies in Danish ports and other hotspot areas.

A baseline study of the occurrence of non-indigenous species in Danish harbours

Dr. Frank Stuer-Lauridsen (LITEHAUZ, Denmark)

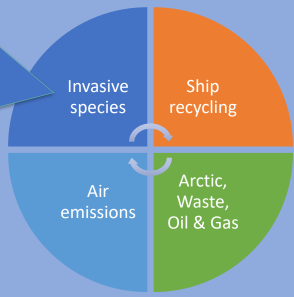
- NIS Monitoring study MONIS4
- 16 hotspots (ports)
- Conventional and eDNA
- The Danish monitoring programme

LITEHAUZ Maritime Environmental Consultancy

Equipment manufacturers
Ballast Water Treatment Systems
Hull cleaning system's testing and assessments

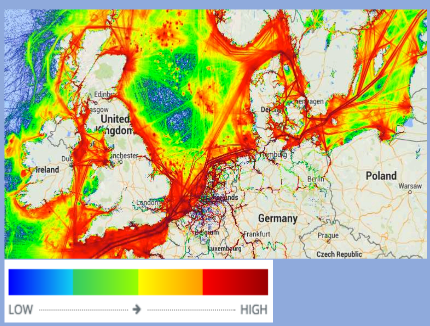
Authorities and DK EPA
Ballast water regulation
NIS monitoring/inspection
Management of hull cleaning
Pre-arrival risk assessments
Same Risk Area approach

Shipowners and associations
Risk assessments issues
Exemptions

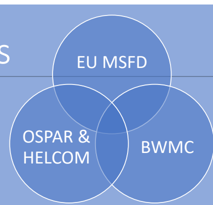


LITEHAUZ The traffic pattern

- Approx. 60,000 vessels per year pass through the Danish Straits
- Cargo vessels make 27,500 port calls in Denmark per year mainly from Scandinavian and Northern European ports



LITEHAUZ Driving forces



- Previous four projects:
  - Hotspot identification
  - Monitoring priorities for NIS when combining with existing programme
  - Technical issues
- Proposed programme
  - 13 hotspots
  - 44 existing stations
  - 48 locations with eDNA

LITEHAUZ

The NIS selection

Target Species List developed from "Established Species List", "Alert List" and "Black List"

Target Species include fish, crustaceans, bivalves, hydroids, macro algae and phytoplankton

20 Target Species are analyzed with qPCR

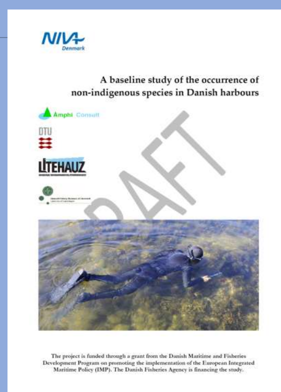
Species	Group/Phyla
Bonnemaisonia hamifera	Macro alga
Prorocentrum minimum	Dinoflagelate
Pseudochattonella farcimen	Heterokont flagellate
Pseudochattonella verriculosum	Heterokont flagellate
Karenia mikimotoi	Dinoflagelate
Carassius autatus	Pisces
Cyprinus carpio	Pisces
Colpomenia peregrina	Macro alga
Neogobius melanostomus	Pisces
Oncorhynchus mykiss	Pisces
Acipenser gueldenstaedtii	Pisces
Acipenser ruthenus	Pisces
Oncorhynchus gorbuscha	Pisces
Crassostrea gigas	Bivalve
Mya arenaria	Bivalve
Eriocheir sinensis	Crustacea
Karenia mikimotoi	Dinoflagelate
Paralithodes camtschaticus	Crustacea
Homarus americanus	Crustacea
Cordylophora caspia	Hydroid
Mnemiopsis leidyi	Ctenophora
Acipenser baerii	Pisces

LITEHAUZ

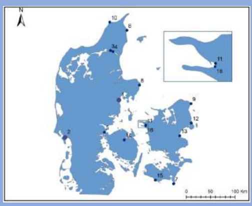
First nation-wide study of non-indigenous species in Danish harbours

Aims of the study:

- **Monitor, assess and report occurence of non-indigenous species in 16 selected Danish harbours mainly by eDNA.**
- **Apply full conventional method (Joint Harmonized Procedure, JHP) and biomolecular methods (eDNA).**
- **Provide proof-of-concept regarding the Danish strategy of combining conventional and biomolecular methods.**



Methodology - introduction



In all 16 ports:

Biomolecular (eDNA):

- Environmental DNA (eDNA) identified through species specific qPCR.
- 20 target species.

Limited conventional sampling

- Supplemented by dive transects (snorkeling) at night (fish, jellyfish, epifauna) and fish net.
- Sampling early summer (May-July) and autumn (September-October) 2017.

I

In two main ports – full JHP sampling

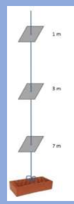

JHP well established platform:

- Physical parameters (temperature, salinity, oxygen) and secchi disc.
- Grab samples for water and sediment (benthic infauna, epifauna).
- Plankton nets (phyto- and zooplankton).
- Traps (mobile epifauna).
- Scrape poles and fouling plates (fouling organisms).
- Fish nets (Gill-net and Fyke-net)
- Generally triplicates in each section of port

Expanded JHP by including limited conventional samling:

- Snorkeling transects 500 m – night / day.

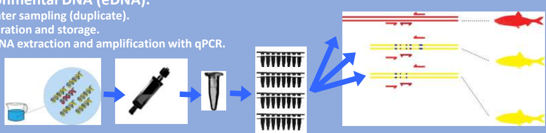




Methodology - biomolecular

Environmental DNA (eDNA).

1. Water sampling (duplicate).
2. Filtration and storage.
3. eDNA extraction and amplification with qPCR.



Water sampling, filtration and storage.

- >1,5 L
- Amphiltrator - 22µm Millipore "Sterivex filter".
- Short term storage - dry ice and -20 ºC freezing facility.
- Long term storage - -80 ºC freezing facility (potential fixation buffer).

eDNA extraction, amplification and analysis

- eDNA extraction and amplification with qPCR.
- Species specific identification system (primers and probes) for 20 species.
- Analysis for presence/absence of eDNA from target species.
- Three replicates for each target species.
- 20 NIS in 32 samples of water column from 16 ports in triplicate equals 3840 qPCR results

Methodology - biomolecular

Species specific detection systems

- primers and probes.

Table 2. Species specific primer and probe assay used for detection of environmental DNA from marine invasive species. Optimal concentrations are for final reaction volumes in qPCR set ups.

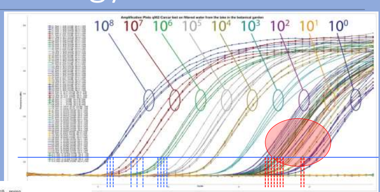
Assay ID number	Common name (Danish)	Species	primer (F and R) and probe name (P)	Sequence (5'-> 3'), primer and probe	Probe Modification 5'-end:	Probe Modification 3'-end:	Optimal concentration of primer or probe in final qPCR reaction volume (nM)
01	rødtot alge	*Bonnemaisonia hamifera*	Bonham_rbcL_F02	CAATTACTAGATTACCTGGGCAAT			1200
			Bonham_rbcL_R02	CTTCTTTTACAAAGTCCCGACCT			200
			Bonham_rbcL_P01	TCGTGCCATAACCATAGACTCTAAAGCC	FAM	BHQ-1	300
02	dinoflagelat	*Prorocentrum minimum*	Promin_28S_F03	CTTGGCAAGATTGTCGGGT			1200
			Promin_28S_R03	TATTCACTCACCCATAGACGA			1200
			Promin_28S_P03	ACACACAAGGCAAGAGACGATCAAGC	FAM	BHQ-1	300
03	heterokont flagelat	*Pseudochattonella farcimen*	PsFa28SF	GGGAGAAATTCTTTGGAACAAGG			200
			PsFa28SR	GCAACTCGACTCCACTAGG			800
			PsVeFa28SP1	TCAGAGAGGGTGACAATCCCGTCT	FAM	BHQ-1	300
04	heterokont flagelat	*Pseudochattonella serruculata*	PsVe28SF	GGGAGAAGTCCTTTGGAACAAGG			200
			PsVe28SR	GCAACTCGACTCCATTAGC			600
			PsVeFa28SP1	TCAGAGAGGGTGACAATCCCGTCT	FAM	BHQ-1	300
05	dinoflagelat	*Karenia mikimotoi*	KarmikF3	CCGAGTGACTGAATGTCCTC			200
			KarmikR3	GATCGCAGGCAAGCACATGA			200
			KarmikP3	GCAGTGCTACCAGACACACAGAG	FAM	BHQ-1	300
06	sølvkarusse	*Carassius auratus*	Caraur_COI_F01	TTCTTCCCCCATCATTCCTGT			200
			Caraur_COI_R01	GTATACTGTCCATCCGGAGG			600
			Caraur_COI_P02	TAGCTTCCTCTGGTGTTGAAGCCGGAG	FAM	BHQ-1	100
07	karpe	*Cyprinus carpio*	CpCyB_496_F	GGTGGGTTCTCAGTAGACAATGC			200
			CpCyB_573_R	GGCGGCAATAACAAATGGTAGT			400
			CpCyB_550_P	CACTAACACGATTCTTCGCATTCCACTTCC	FAM	TAMRA	200
08	østerstyv	*Colpomenia peregrine*	Colper_COX_3_F01	GCAAGCTTTTGAATATGCTAATG			400
			Colper_COX_3_R01	CAGCTAAAAATATTGTACCGATT			600
			Colper_COX_3_P01	TTCAGTTTTTTACATGGCTACAGGCTTC	FAM	TAMRA	100
09A	sortmundet kutling	*Neogobius melanostomus*	Neomel_COI_F01	CTTCTRGCCTCCTCTGGWGTTG			200
			Neomel_COI_R01	CCCWAGAATTGASGARATKCCGG			600
			Neomel_COI_P01	CAGGCAACTTRGCACATGCAG	FAM	BHQ-1	100
10	regnbueørred	*Oncorhynchus mykiss*	Oncmyk_CytB_F01	ACCTCCAGCCATCTCTCAGT			400
			Oncmyk_CytB_R01	AGGACGGGGAGGGAAAGTAA			600
			Oncmyk_CytB_P01	TGAGCCGTGCTAGTTACTGCTGTCCTT	FAM	BHQ-1	100
13	pukkellaks	*Oncorhyncus gorbuscha*	Oncgor_CO1_F09	TCCTTCCTCCTCCTCCTTTC			400
			Oncgor_CO1_R06	TGGCCCCTAAAATTGATGAG			1000
			Oncgor_CO1_P06	CAGGGGCATCCGTCGACTTAACTAT	FAM	BHQ-1	300
14	stillehavsøsters	*Magallana gigas*	Cragig_CO1_F07	TTGAGTTTTGCCAGGGTCTC			200
			Cragig_CO1_R09	ACCAGCAAGGTGAAGGCTTA			1200
			Cragig_CO1_P06	AACATTGTAGAAAACGGAGTTGGGGC	FAM	BHQ-1	200

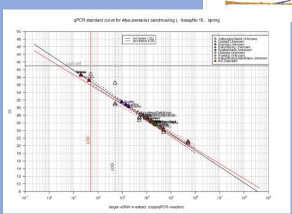
Methodology - biomolecular

qPCR – "quantitative PCR"

Estimation of amount of DNA in water samples by a standard curve.

- Concentrations of 100 mio copies/µL, 10 mio copies/µL, etc.
- DNA from water samples.





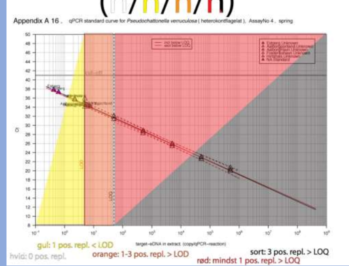
- The amplification curves for the water samples are compared to known concentrations.
- Amount of eDNA in the water sample can be calculated by the standard curve (if the eDNA concentration in the sample is above LoQ).

Methodology - biomolecular

Water samples analysed with qPCR are categorised:

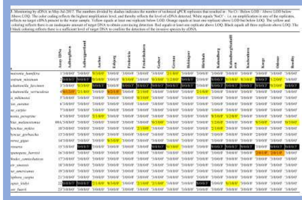
(Ct=Critical threshold, LoD=Limit of Detection, LoQ=Limit of Quantification)

1. Negative (white): No Ct observed in any of the triplicates – no amplification at all.
2. Weak possible positive (yellow): amplification observed in at least one triplicate but amplification below LoD
3. Possible positive (orange): Ct observed in at least one triplicate, and amplification detected aboved LoD but below LoQ.
4. Positive (red): Ct observed in at least one triplicate, with levels above LoQ.
5. Positive, possible to quantify (black): all triplicates with Ct amplification levels above LoQ.

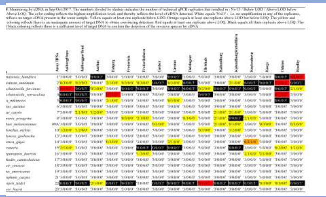


Results - eDNA qPCR identification of NIS

May-July



Sept - Oct



eDNA resultat	Interpretation
No Ct	No 'target eDNA' in water sample
Below LOD	Possible weak trace of eDNA from 'target species'
Above LOD below LOQ	Weak trace of eDNA from 'target species'
1Above LOQ	eDNA from 'target species'
3Above LOQ	Solid eDNA fra 'target species'

Conventional monitoring

Species_name	Aalborg Havn	Aalborg Portland	Aarhus	Esbjerg	Fredericia	Frederikshavn	Gedser	Grenaa	Helsingoer	Hirtshals	Kalundborg	Kalundborg Statiol Havn	Koebenhavn	Koege	Odense	Roedby
Bonnemaisonia hamifera	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Prorocentrum minimum	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1
Pseudochattonella farcimen	0	0	1	2	1	1	0	1	0	1	1	1	0	0	1	0
Pseudochattonella verruculosa	0	0	1	2	1	1	0	1	0	1	1	1	0	0	1	0
Karenia mikimotoi	1	1	1	2	1	1	0	1	1	1	1	1	1	0	1	0
Carassius auratus	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Cyprinus carpio	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Colpomenia peregrine	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Neogobius melanostomus	0	0	0	0	0	0	2	0	0	0	2	2	2	2	0	2
Oncorhynchus mykiss	1	1	1	0	0	0	0	1	1	0	1	1	1	1	1	0
Acipenser gueldenstaedtii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acipenser ruthenus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oncorhyncus gorbuscha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crassostrea gigas	2	2	0	2	0	0	0	0	2	0	1	0	2	0	0	0
Mya arenaria	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Rhithropanopeus harrisii	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1
Paralithodes camtschaticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eriocheir sinensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Homarus americanus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cordylophora caspia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mnemiopsis leidyi	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1	2
Acipenser baerii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Not found: 0

Found before not in MONIS4: 1 Found in MONIS4: 2

Conventional monitoring

Species_name	AalborgHavn	AalborgPortland	Aarhus	Esbjerg	Fredericia	Frederikshavn	Gedser	Grenaa	Helsingoer	Hirtshals	Kalundborg	KalundborgStatiol Havn	Koebenhavn	Koege	Odense	Roedby
Bonnemaisonia hamifera	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Prorocentrum minimum	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1
Pseudochattonella farcimen	0	0	1	2	1	1	0	1	0	1	1	1	0	0	1	0
Pseudochattonella verruculosa	0	0	1	2	1	1	0	1	0	1	1	1	0	0	1	0
Karenia mikimotoi	1	1	1	2	1	1	0	1	1	1	1	1	1	0	1	0
Carassius auratus	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Cyprinus carpio	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Colpomenia peregrine	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Neogobius melanostomus	0	0	0	0	0	0	2	0	0	0	2	2	2	2	0	2
Oncorhynchus mykiss	1	1	1	0	0	0	0	1	1	0	1	1	1	1	1	0
Acipenser gueldenstaedtii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acipenser ruthenus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oncorhyncus gorbuscha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crassostrea gigas	2	2	0	2	0	0	0	0	2	0	1	0	2	0	0	0
Mya arenaria	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Rhithropanopeus harrisii	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1
Paralithodes camtschaticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eriocheir sinensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Homarus americanus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cordylophora caspia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mnemiopsis leidyi	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1	2
Acipenser baerii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Not found: 0

Found before not in MONIS4: 1 Found in MONIS4: 2

GloFoul/ANZPAC Melbourne | 1-4 Oct 2019

Conventional monitoring

Species_name	AalborgHavn	AalborgPortland	Aarhus	Esbjerg	Fredericia	Frederikshavn	Gedser	Grenaa	Helsingoer	Hirtshals	Kalundborg	KalundborgStatiol Havn	Koebenhavn	Koege	Odense	Roedby
Bonnemaisonia hamifera	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Prorocentrum minimum	1	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1
Pseudochattonella farcimen	0	0	1	2	1	1	0	1	0	1	1	1	0	0	1	0
Pseudochattonella verruculosa	0	0	1	2	1	1	0	1	0	1	1	1	0	0	1	0
Karenia mikimotoi	1	1	1	2	1	1	0	1	1	1	1	1	1	0	1	0
Carassius auratus	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Cyprinus carpio	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
Colpomenia peregrine	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Neogobius melanostomus	0	0	0	0	0	0	2	0	0	0	2	2	2	2	0	2
Oncorhynchus mykiss	1	1	1	0	0	0	0	1	1	0	1	1	1	1	1	0
Acipenser gueldenstaedtii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Acipenser ruthenus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oncorhyncus gorbuscha	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Crassostrea gigas	2	2	0	2	0	0	0	0	2	0	1	0	2	0	0	0
Mya arenaria	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Rhithropanopeus harrisii	0	0	0	0	0	0	1	0	0	0	0	0	1	1	0	1
Paralithodes camtschaticus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Eriocheir sinensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Homarus americanus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cordylophora caspia	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mnemiopsis leidyi	2	2	2	2	2	2	2	2	2	1	2	2	2	2	1	2
Acipenser baerii	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

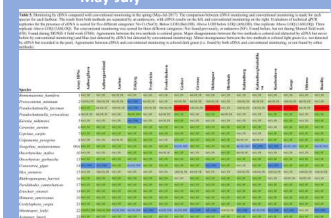
Not found: 0

Found before not in MONIS4: 1 Found in MONIS4: 2

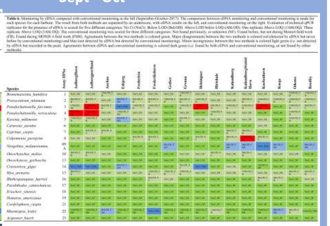
GloFoul/ANZPAC Melbourne | 1-4 Oct 2019

Conventional and eDNA

May-July



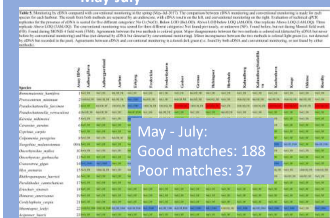
Sept - Oct



	CONVENTIONAL RESULT		
eDNA RESULT:	**Not previously reported**	**Found before, but not during Monis4 field work**	**Found during Monis 4 field work**
No Ct	NF_NoCt	FB_NoCt	FM4_NoCt
Below LOD	NF_BeLOD	FB_BeLOD	FM4_BeLOD
Above LOD below LOQ	NF_AbLOD	FB_AbLOD	FM4_AbLOD
1Above LOQ	NF_1AbLOQ	FB_1AbLOQ	FM4_1AbLOQ
3Above LOQ	NF_3AbLOQ	FB_3AbLOQ	FM4_3AbLOQ

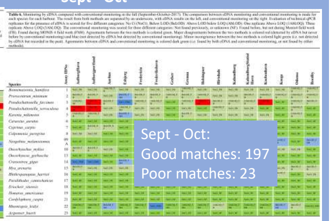
Conventional and eDNA

May-July



May - July:
Good matches: 188
Poor matches: 37

Sept - Oct



Sept - Oct:
Good matches: 197
Poor matches: 23

	CONVENTIONAL RESULT		
eDNA RESULT:	**Not previously reported**	**Found before, but not during Monis4 field work**	**Found during Monis 4 field work**
No Ct	NF_NoCt	FB_NoCt	FM4_NoCt
Below LOD	NF_BeLOD	FB_BeLOD	FM4_BeLOD
Above LOD below LOQ	NF_AbLOD	FB_AbLOD	FM4_AbLOD
1Above LOQ	NF_1AbLOQ	FB_1AbLOQ	FM4_1AbLOQ
3Above LOQ	NF_3AbLOQ	FB_3AbLOQ	FM4_3AbLOQ

GloFoul/ANZPAC Melbourne | 1-4 Oct 2019

LITEHAUZ Conventional and eDNA

Species	Assay ID No	May-July Aarhus	May-July Esbjerg	Sept - Oct Aarhus	Sept - Oct Esbjerg
Bonnemaisonia hamifera	1	BeLOD_FB	NoCt_FB	3AbLOQ_FB	NoCt_FB
Prorocentrum cordatum	2	BeLOD_FB	NoCt_FM4	NoCt_FB	BeLOD_FM4
Pseudochattonella farcimen	3	3AbLOQ_FB	NoCt_FM4	BeLOD_FB	NoCt_FM4
P. verruculosa	4	NoCt_FB	AbLOD_FM4	NoCt_FB	AbLOQ_FM4
Karenia mikimotoi	5	NoCt_FB	NoCt_FM4	NoCt_FB	BeLOD_FM4
Carassius auratus	6	NoCt_NF	NoCt_NF	NoCt_NF	NoCt_NF
Cyprinus carpio	7	NoCt_NF	NoCt_NF	BeLOD_NF	NoCt_NF
Colpomenia peregrina	8	BeLOD_NF	NoCt_NF	NoCt_NF	NoCt_NF
Neogobius melanostomus	09	NoCt_NF	NoCt_NF	NoCt_NF	NoCt_NF
Oncorhynchus mykiss	10	NoCt_FB	NoCt_NF	NoCt_FB	NoCt_NF
Oncorhyncus gorbuscha	13	NoCt_NF	NoCt_NF	NoCt_NF	NoCt_NF
Crassostrea gigas	14	NoCt_NF	BeLOD_FM4	NoCt_NF	BeLOD_FM4
Mya arenaria	15	NoCt_FB	NoCt_FB	NoCt_FB	NoCt_FB
Rhithropanopeus harrisii	16	NoCt_NF	NoCt_NF	NoCt_NF	NoCt_NF
Paralithodes camtschaticus	17	NoCt_NF	NoCt_NF	NoCt_NF	NoCt_NF
Eriocheir sinensis	18	NoCt_NF	NoCt_NF	NoCt_NF	NoCt_NF
Homarus americanus	19	NoCt_NF	NoCt_NF	NoCt_NF	NoCt_NF
Cordylophora caspia	21	NoCt_NF	NoCt_NF	NoCt_NF	NoCt_NF
Mnemiopsis leidyi	22	BeLOD_FM4	BeLOD_FM4	BeLOD_FM4	3AbLOQ_FM4
Acipenser baerii	23	NoCt_NF	NoCt_NF	NoCt_NF	NoCt_NF
Score		**12/1**	**13/5**	**12/1**	**14/4**

LITEHAUZ Conclusions

First study of non-indigenous species in 16 Danish harbours.

The conventional methodology detected 26 non-indigenous species

- **Higher diversity in Esbjerg harbour (2) compared to Aarhus harbour (1).**
- **The NIS found are generally known in Danish waters.**
- **New NIS include two marine bristle worms from Esbjerg harbour:**
  - *Streblospio benedicti*
  - *Eteone heteropoda*

The eDNA methodology detected 13 non-indigenous species

Non-indigenous species:
Pseudochattonella verruculosa
Heterosigma akashiwo
Karenia mikimotoi
Prorocentrum cordatum
Acartia tonsa
Penilia avirostris
Sargassum muticum
Alitta succinea
Polydora aggregata
Diadumene lineata
Molgula manhattensis
Amphibalanus improvisus
Austrominius modestus
Caprella mutica
Neosiphonia harveyi
Hemigrapsus sanguineus
Streblospio benedicti
Eteone heteropoda
Polydora cornuta
Ensis directus
Styela clava
Heterosiphonia japonica
Crepidula fornicata
Crassostrea gigas
Neogobius melanostomus

LITEHAUZ Conclusions - hard substrate

Settling plates (PVC) and rope of fixed type and length

- 9 units in Århus Port and in Esbjerg Port
- Deployed from early to late summer (May to September)
- Semi quantitative identification
- Six and nine species found

Scraping of subsea structures (RAS)

- 18 locations in in Århus Port and in Esbjerg Port
- Qualitative species identification under microscope
- No NIS found!

Non-indigenous species:
Diadumene lineata
Molgula manhattensis
Amphibalanus improvisus
Caprella mutica
Styela clava
Austrominius modestus
Heterosiphonia japonica
Hemigrapsus sanguineus
Crassostrea gigas
Neosiphonia harveyi

- Conclusion is that settling plates provides more information on the potential for NIS than the scraping method (RAS)

LITEHAUZ Conclusions by Danish EPA

Overall agreement between eDNA monitoring and conventional monitoring:

- rare species are not found,
- fresh water species are not found in the brackish-saline waters sampled,
- and five common species are found by both methods.

Maintain Danish monitoring strategy (but prepare for eDNA through selected applications).

Evaluate JHP scope in hot spots to suit Danish conditions.

LITEHAUZ Collaborators

- Jesper H. Andersen, Emilie Kallenbach, Mathias Brink Kjeldgaard and Steen W. Knudsen (NIVA Denmark);
- Wenche Eikrem, Camilla Fagerli, Eivind Oug, Trine Dahle, Jens Thaulow, Janne Gitmark, Anders Hobæk and Norman Green (NIVA Norway);
- Martin Hesselsøe (NIRAS A/S, formerly AmphiConsult Aps);
- Josianne Støttrup, Jesper Kuhn, Dorte Bekkevold and Lars Magnus Wulf Jacobsen (DTU Aqua);
- Peter Rask Møller, Christian Aakjær Olesen and Henrik Carl (Natural History Museum of Denmark);
- Frank Stuer-Lauridsen (Litehauz ApS)

- Sponsors: Ulrik Berggreen and Kim Larsen (Danish EPA)

LITEHAUZ

Thank you for your attention
www.LITEHAUZ.com
fsl@litehauz.com

Check out our ballast water monitor

bw-monitor.com

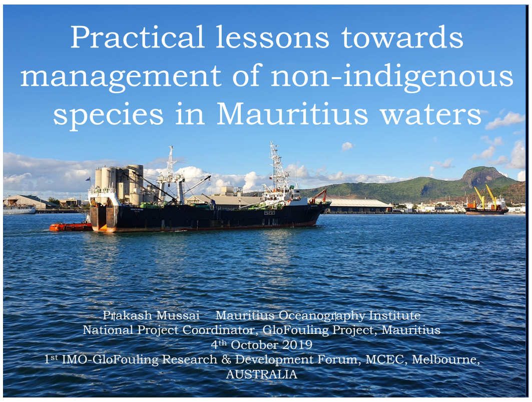
Prakash Mussai
Acting principal research scientist
Mauritius Oceanography Institute, Mauritius

Mr. Prakash Mussai, Acting Principal Research Scientist from Mauritius Oceanography Institute, is the National Project Coordinator for the GEF-UNDP- IMO GloFouling Project Mauritius. Before joining Mauritius Oceanography Institute, he has worked as Education officer and part-time lecturer at the University of Mauritius. Mr. Mussai has also worked on developing the Electronic Database of Marine Organisms of the Mauritian maritime zone at the Mauritius Oceanography Institute along with ODNIAFRICA for the development of African Registrar of Marine Species (AfReMas). For the past 10 years, he is also actively involved in Ballast Water Management Projects for the Shipping Division of the Ministry of Ocean Economy, Marine Resources, Fisheries and Shipping and is currently working on the National project of Ship's Biofouling.

Practical lessons towards management of non-indigenous species in Mauritius waters

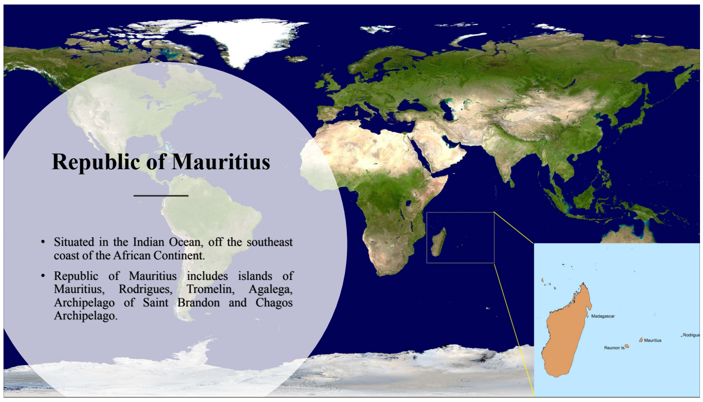
The Republic of Mauritius is actively working towards the sustainable development of its ocean economy. Mauritius has heavily invested for the development of a vector management approach to prevent introduction and spread of Non-Indigenous Species (NIS), with a particular focus on shipping activities. The major foundation relied on capacity building of individuals and institutions; and accounted for 50% of the investment. Furthermore, the risk-based management approach allowed for the development of a First- generation management decision support system. A first port biological baseline survey (PBBS) of Port Louis (Mauritius Island) was held in 2012, whereby, ten likely introduced marine species were identified. The first PBBS of Port Mathurin (Rodrigues Island) was completed in 2018 and the analyses are still under process.

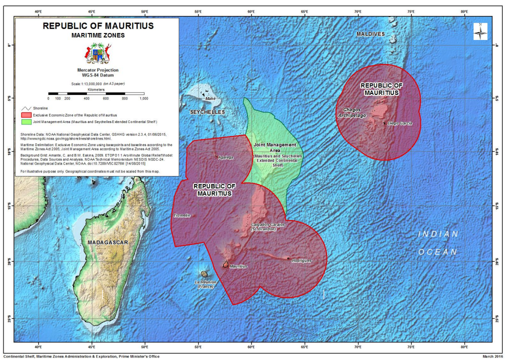
The current work on biofouling builds on a decade of past experience gained on NIS management through previous ballast water projects. Also, funded by the government of Mauritius the Ships' biofouling project comprises of three phases and encompasses several scientific activities. Half of the sum will be allocated towards further capacity build-up. The first two phases entail the development of a Biofouling Risk Assessment Decision Support (BRADS) tool and the development of a standardised hull sampling protocol for surveying of ships arriving at Port Louis harbour. While, the third phase of the project aims at the quantification of the levels of antifouling biocides persistent in the aquatic environment of Port Louis harbour. The ballast water management and biofouling management projects of Mauritius will contribute in the development of necessary regulations to mitigate, control and manage NIS in local waters.



Republic of Mauritius

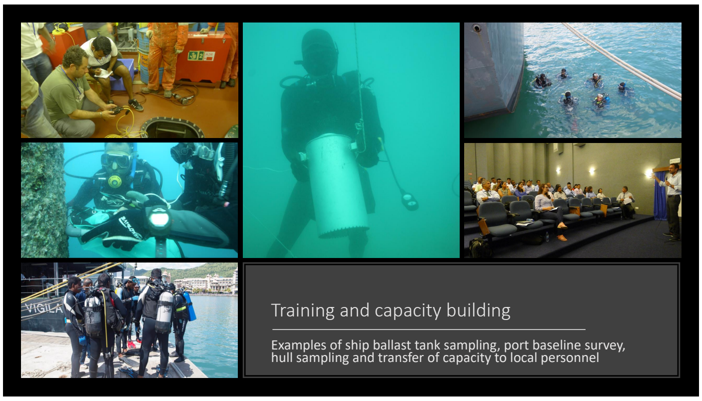
Ministry of Ocean Economy, Marine Resources, Fisheries & Shipping

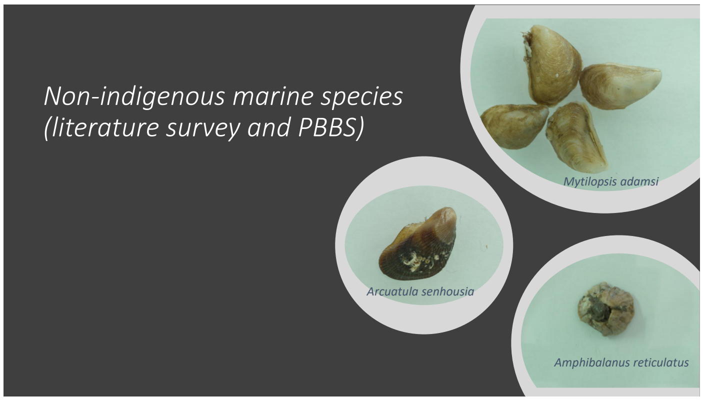




Republic of Mauritius

Maritime Zones





Non-indigenous marine species

Intentional introduction for Aquaculture

Scientific name	Organism Type	Status
Crassostrea commercialis	Oyster	**Introduced**
Crassostrea gigas	Oyster	**Introduced**
Crassostrea virginica	Oyster	**Introduced**
Ostrea edulis	Oyster	**Introduced**
Metapenaeus monoceros	Prawn	**Introduced**

Non-indigenous marine species

Intentional introduction for Aquaculture

Scientific name	Organism Type	Status
Melicertus latisulcatus (syn: *Penaeus latisulcatus*)	Prawn	**Introduced**
Penaeus monodon	Prawn	**Introduced**
Chlorella sp.	Plankton	**Introduced**
Treselmis sp.	Plankton	**Introduced**
Brachionus plicatilis	Rotifer	**Introduced**

Findings from previous studies

Non-indigenous marine species

Scientific name	Organism Type	Status
Halophila stipulacea	Sea Grass	**Crytogenic**
Acanthaster planci	Crown of Thorns Starfish	**Crytogenic**
Acanthophora spicifera	Red alga	**Crytogenic**
Gracilaria salicornia	Alga	**Crytogenic**
Tubastraea coccinea	Orange-cup coral	**Crytogenic**

1st Port Louis baseline survey (2012)

Non-indigenous marine species

	Organism Type	Status
Mytilopsis adamsi	Mussel	Introduced
Arcuatula senhousia	Mussel	Introduced
Amphibalanus reticulatus	Barnacle	Introduced
Amphibalanus amphitrite	Barnacle	Introduced/crytogenic
Amphibalanus sp.	Barnacle	Introduced

Of these, some are of concern: especially *Mytilopsis adamsi and Arcuatula senhousia*

1st Port Louis baseline survey (2012)

Non-indigenous marine species

Scientific name	Organism Type	Status
Megabalanus coccopoma	Barnacle	**Introduced**
White Balanid *Sp.*	Barnacle	**Likely Introduced**
Calyptraeid	Limpet	**Likely Introduced**
Spirobranchus sp.	Fanworm	**Likely Introduced**
Marphysa sp.	Polychaete worm	**Crytogenic**

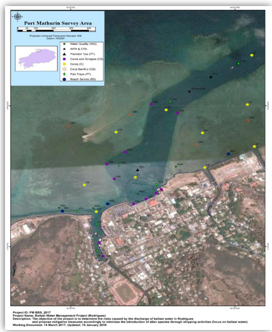
The Port baseline survey – **<u>10 additional Non-Indigenous Species (Total of 25)</u>**

1st Port Mathurin survey (2019)

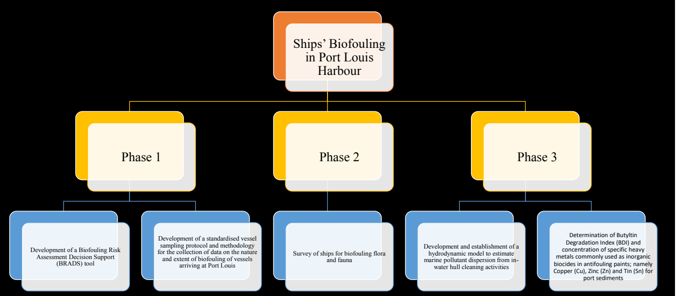
Non-indigenous marine species

The Port baseline survey:

1. No presence of indigenous marine species
2. **Additional taxonomic assessment required**



Ships' Biofouling in Port Louis



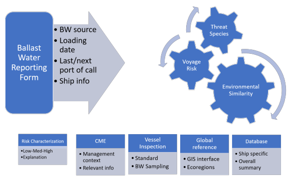
Biofouling team

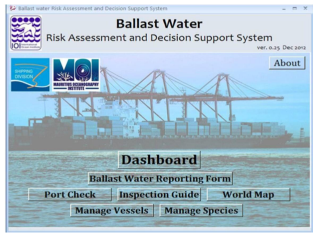
Phase 1 –
Risk Decision Support

In progress

In progress

In progress





BW Risk Assessment & Decision Support (BWRADS) System

1st Generation

Decision Support Tool

- With means available, we are aiming to decide which higher-risk vessels to target for inspection. Rather than inspecting all vessels
- Inspection would then be **initial** in all cases, only followed by **detailed** inspection.
- User interface (dependent)
  - Generates vessel operational profile

- Based on international best practice
  - Includes exemptions/incentives for well managed compliant vessels
  - Permit based?
- Highlights vessels requiring initial inspection
- Web-based platform
- Merge BWRADS with BRADS?

Development of a Biofouling Risk Assessment Decision Support

Referred as "BRADS", at this stage

Component 2 –
Development of a standardised vessel sampling protocol

Biofouling sampling protocol (overview)

- Vessel access and permissions must be granted and arranged.
- Contact with the vessel should be maintained once on-site, and communications continued as appropriate throughout the sampling process.

- Sampling team briefings and preparations should be conducted prior to arrival at the site, and again at the site, as necessary.
- All appropriate safety protocols (e.g. boating, diving, sample handling, preservation, etc.) must be observed and communicated accordingly.

Development of a standardised vessel sampling protocol

Current status

Biofouling sampling protocol (overview)

Step 1: Initial inspection

- Dive team conducts the 1st dive to assess the state of biofouling.
- Level of Fouling (LoF) designations are noted for each area inspected.
- Divers then return to the surface and liaise with the topside team (preferably on-board a small boat).

LoF determination

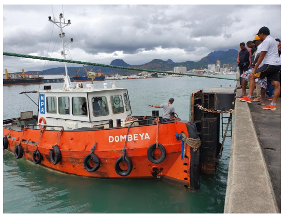
State of hull	LoF designation
Clean hull, no visible fouling or slime layer	0
Presence of slime layer/biofilm, no macrofouling	1
Light/patchy macrofouling, 1-5% cover	2
Moderate/patchy macrofouling, 6-15% cover	3
Extensive macrofouling, 16-40% cover	4
Very heavy macrofouling, 41-100% cover	5

Development of a standardised vessel sampling protocol

Current status

Development of a standardised vessel sampling protocol

Current status



Development of a standardised vessel sampling protocol

Current status

Biofouling sampling protocol (overview)

Step 2: Determination of sampling activity

- The topside sampling team will note the LoF designations from the divers, using the field sampling form.
- Based on the designations as assessed by the dive team, determinations will be made and communicated regarding the sampling to be conducted.
- No sampling or further assessment is required for hull areas with LoF of 0 or 1.
- The appropriate number of fine mesh sample bags, each containing pre-filled labels, will be issued to the dive team(s), along with the instructions as to where and how samples are to be taken.
- Dive teams will have the appropriate sampling equipment, including scrapers (plastic if possible), quadrat, u/w camera.

Development of a standardised vessel sampling protocol

Current status

Step 3: Collection of biological specimens

- The 2nd dive will be made by between 1 to 4 dive teams (depending on numbers of available, qualified divers). Each dive team will be allocated a specific set of sampling locations to target.
- Samples will be collected into 0.5mm mesh bags, using appropriate scraper or dive knife.
- Special attention will be paid on maintaining the integrity of the biological specimens, as well as the hull coating of the vessel.

Development of a standardised vessel sampling protocol

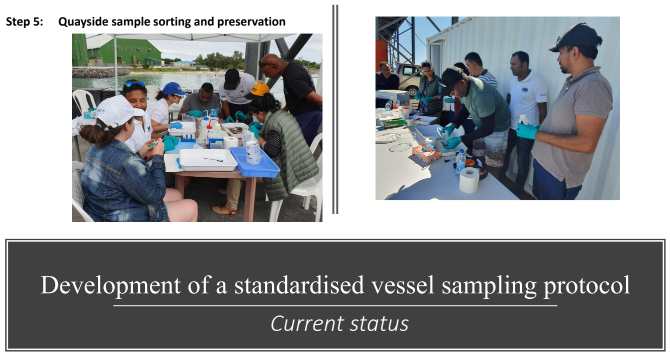
Current status

Step 4: Topside sample transfer

- Sampling managers collect sample bags (fine mesh size) from divers.
- Sample contents, including label, are transferred into ziplock bags, jars or equivalent. These are then stored on ice in an appropriate container.
- All samples collected are allocated a sampling number and captured on the field sample log.

Development of a standardised vessel sampling protocol

Current status


Step 5: Quayside sample sorting and preservation
Development of a standardised vessel sampling protocol
Current status


July 2019:
Hull sampling in Port Louis harbour


THANK YOU
For more information:
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Professor, Chesapeake Biological Laboratory,
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Dr. Mario Tamburri received a Bachelor's degree from University of California Santa Barbara, a Master's degree fromUniversity of Alabama, and a Ph.D. from the University of South Carolina in biology and marine science. His basic science research focuses on how chemical cues regulate basic biological and ecological processes of aquatic organisms, including larval settlement. Dr. Tamburri has worked inenvironments ranging from estuaries to the deep sea. Recently, he has focused much of his work on new innovations to address environmental problems from climate change toinvasive species.

Dr. Tamburri is now a Professor at theChesapeake Biological Laboratory, University of Maryland Center for Environmental Science, and Director two environmental innovation programs, the Alliance for Coastal Technologies (ACT) and the Maritime Environmental Resource Center (MERC). ACT is a NOAA- and EPA-funded effort dedicated to fostering the development and adoption of effectiveand reliable sensors andplatforms for studying and monitoring coastal, ocean and freshwater environments. Similarly, MERC is a State of Maryland and US Maritime Administration initiative that provides test facilities, expertise, information, technologies, and decision tools to address key environmental issues facing the international maritime industry. Dr. Tamburri has published nearly 100 peer- reviewed publications, technical reports and book chapters and has severed on multiple national and international scientific committees, including: an Ocean Studies Board on Ocean Infrastructure at the National Academies; a working group member of the US EPA Science Advisory Board, International Council for the Exploration of the Sea (ICES) and International Organization for Standardization (ISO); and a founding member of Global TestNet.

An independent performance evaluation of a vessel in-water biofouling cleaning and capture system

Like all substrates placed in natural waters, the external wetted surfaces of commercial vessels are quickly colonized by a succession of diverse sessile or sedentary micro- and macro-organisms. This biofouling of ships has been a long-standing challenge for vessel owners and operators because it can interfere with operations and may result in increased corrosion, drag, fuel consumption, and greenhouse gas emissions. Vessel biofouling has also been recognized as a significant (if not the most dominant) vector for the global-scale transfer and introduction of non-indigenous or invasive marine species. A range of in-water biofouling cleaning technologies are evolving to prevent macrofouling growth and/or to remove and capture existing macrofouling and removed antifouling coating biocides, thus increasing vessel in-service efficiencies while minimizing biosecurity risks.

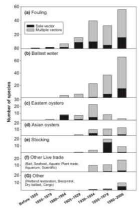
In 2018, the Alliance for Coastal Technologies (ACT) and Maritime Environmental Resource Center (MERC) collaborated with several partners to carry out the first-ever independent and comprehensive evaluation of an in-water cleaning system. In 2019 ACT/MERC also held a workshop on in-water cleaning systems and the assessment of their performance. Our goals were to: (a) quantify the performance of an in-water macrofouling removal and capture system (and thus help facilitate its transition into routine operations), (b) work internationally to refine in-water cleaning testing approaches and protocols, and (c) build broad regulatory and permitting agency awareness on the issues associated with vessel biofouling and in-water cleaning. As with all new innovations designed to address specific environmental concerns or regulations, independent, standardized and rigorous evaluations to quantify the performance of in-water cleaning systems to prevent and/or remove macrofouling from vessel wetted surfaces (hulls and niche areas) effectively and safely, are essential. This presentation will summarize our work to date, initial lessons learned and consensus on testing approaches and challenges, and our plans for next steps.

An Independent Evaluation of a Vessel In-Water Biofouling Cleaning and Capture System

Mario Tamburri – UMCES, ACT and MERC
Greg Ruiz – SERC
Matt First – NRL
Chris Scianni – CSLC
Ian Davidson – Cawthron

Vessel Biofouling

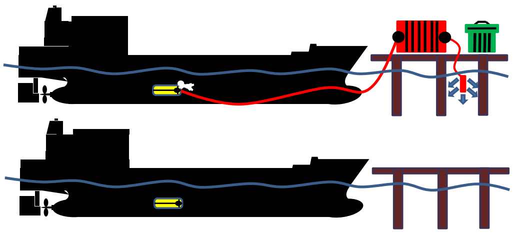
- Vessel Operations:
  - Macrofouling resulting in increased roughness, drag, fuel consumption and exhaust emissions
  - Macrofouling can interfere with water systems
  - Current vessel hull husbandry based on antifouling coatings (biocide & non-stick) and in-water cleaning
- Biosecurity Regulations:
  - 2011 - IMO Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species
  - 2017 - Biofouling Management to Minimize the Transfer of Nonindigenous Species from Vessels Arriving at California Ports (*management reporting*)
  - 2018 - Biofouling on Vessels Arriving to New Zealand (*excessive biofouling can be ordered to leave*)
  - 2019 - IMO established GloFouling Program



Ruiz et al., 2015

Vessel In-Water Cleaning

- Continuum from reactive in-water cleaning to remove biofouling to proactive in-water cleaning to prevent biofouling
- How well do they clean?
- How well do they reduce biosecurity risks?
- How well do they reduce water quality risks?



Modified from: Scianni and Georgiades 2019

Independent Technology Evaluations

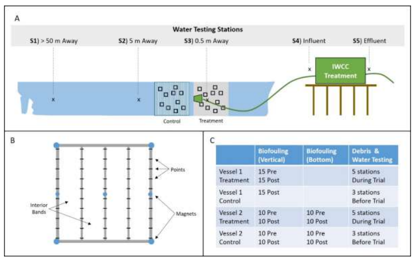
Evaluations of In-Water Cleaning Systems

- Removal Technology/Service Providers:
  - CleanSubSea Envirocart
  - ECOsubsea
  - SGS EnviroHull
  - SGS Whale Shark
  - Sinku
  - TecHullClean

- Prevention Technology/Service Providers:
  - HullWiper
  - SeaRobotics HullBUG

Evaluation Test Protocols

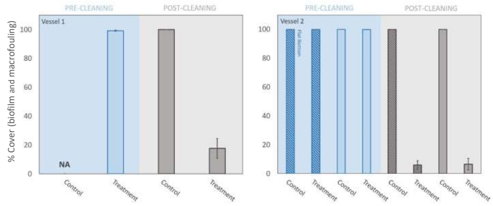
- Biofouling removal efficacy
  - Macrofouling and biofilms
  - No live vs dead
- Capture/retention efficacy
- Treatment and debris removal efficacy
  - Copper, zinc, other biocide
  - TSS and PSD
  - Environmental conditions



Evaluations of a Removal and Capture System

Evaluations of a Removal and Capture System

- Biofouling removal efficacy



Examples of before and after, Vessel 2

Workshop: Evaluating In-Water Cleaning Systems

- 24 international experts, 23-24 April 2019, Honolulu, Hawaii
- Develop an understanding of the current state of science regarding test methods and approaches for evaluating in-water cleaning systems – lessons learned, what are the challenges, and what is feasible
- Build consensus on comprehensive but practicable test protocols for verification of in-water cleaning systems performance, which meet the needs of both the shipping industry and regulatory authorities – vessel operations, biosecurity and chemical contamination

Conclusions and Recommendations

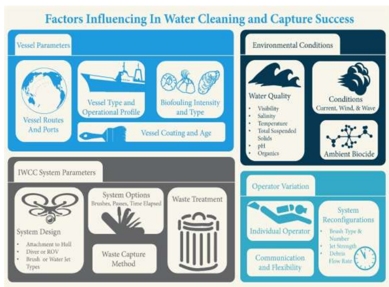
- Rigorous, independent and standardized evaluations of in-water cleaning systems are possible
- Standardize test protocols are important for acceptance, approvals and cross comparisons
- Current systems may be able to address vessel operational needs, but biosecurity goals and water quality issues (e.g., copper discharge) may still be a challenge

Conclusions and Recommendations

- In-water cleaning systems are currently designed for hull and not niche surfaces
- Need for uniform terminology – removal and prevention
- Impacts on coating and internal biofouling are distinct and need specific testing protocols
- Unit of replication should be the individual test vessel
  (when possible – different ship types, fouling ratings, coatings, etc.)
- Biofouling surveys can be conducted in low visibility water, and on niche areas with diver observations
  (but photo/video documentation needed)
- Sampling for water quality impacts should include analyses for both biocides and microplastics

Conclusions and Recommendations

- Important variables that can impact the performance and testing of in-water cleaning systems



- Not feasible to test all but a few key variables should be prioritized
- All important variables should be kept in mind when granting permits, approvals and/or certifications

Next Steps

- 2019 – Submit publication on initial evaluation of in-water cleaning removal system
- 2019 – Initiate evaluations of in-water cleaning prevention systems
- 2020 – Initiate process of evaluations of traditional manual diver in-water cleaning
- 2020 – Explore in-water cleaning removal systems for use on off-shore platforms
- 2021 – Additional series of in-water cleaning evaluations

Acknowledgements

- Testing Team:
  - Mario Tamburri, ACT/MERC/CBL
  - Matt First, US NRL
  - Greg Ruiz, SERC
  - Chris Scianni, CSLC
  - Ian Davidson, SERC
  - Jules Kuo, Hawaii DLNR
  - Plus technical staff, QA/QC, analytical services, etc.
- Technical Advisory Committee:
  - William Hertel, US NSWCC
  - Eugene Georgiades, MPI New Zealand
  - Graeme Inglis, NIWAR New Zealand
  - Carolyn Junemann, MARAD
  - David Elias, RWQCB San Francisco
  - Regina Bergner, USCG
  - Myron Honda, Hawaii DLNR
  - Johnny Eliasson, Chevron Shipping
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  - Maryland Port Administration (MD DOT)
  - US Maritime Administration (MARAD)
  - California State Lands Commission (CSLC)

ALLIANCE FOR COASTAL TECHNOLOGIES

Dan McClary
Biosecurity specialist
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Dan is a biosecurity specialist at Ramboll with over 30 years of marine science research, consulting and management experience. He has extensive expertise in helping businesses assess the effects and impacts of industry on the environment, and has successfully navigated regulatory guidelines for a wide variety of commercial clients and government agencies. Dan's work over the last decade has focussed on providing both operational and strategic biosecurity and environmental management advice to exploration companies, other industry and central and local government agencies.

When Theory Meets Reality: Evaluation of Protocols for Assessing Reactive In-water Cleaning & Capture Systems

The Ministry for Primary industries contracted Ramboll to evaluate the utility of protocols to assess the efficacy of reactive in-water cleaning and capture (RICC) systems to manage biosecurity and environmental contamination risks. After an extensive review of RICC systems available globally, two were chosen to undergo field evaluations. This presentation focuses on the first of those trials which was conducted in July of this year. We provide here an evaluation of the challenges faced in conducting RICC system evaluations in a dynamic commercial setting, and particularly in matching theoretical expectations with the reality of working in operationally hazardous environments.

WHEN THEORY MEETS REALITY:
PROJECT UPDATE: EVALUATION OF PROTOCOLS FOR ASSESSING REACTIVE IN-WATER CLEAN & CAPTURE SYSTEMS

Dan McClary
Emily Jones
Ramboll New Zealand
Auckland

RATIONALE

The NZ Ministry for Primary Industries (MPI) has proposed a testing framework and performance criteria for biosecure *reactive in-water clean and capture* (**RICC**) *systems*

The CRMS (Biofouling) went live on 15 May 2018

Urgent need for in-water cleaning tools that will meet NZ's biosecurity and environmental standards

OBJECTIVES

i. Identify and test the efficacy of RICC systems on vessels > 40 m in length, fouled, that are painted with biocidal antifouling coatings;

ii. Complete modelling of chemical contamination caused by the application of the RICC systems according to the New Zealand port scenarios using the MAMPEC model, and;

iii. Provide an assessment of the utility of the testing framework (MPI 2017) and chemical sampling plan.

PROGRESS

- Compile information on available hull cleaning technologies ✓
- Screening assessment of efficacy at meeting biosecurity outcomes for RICC systems ✓
- Detailed assessment of potential RICC systems ✓
  - Must be demonstrably suitable for effective 'clean & capture' of hard fouling
- Selection of RICC systems for field testing ✓
- Conduct field trials ✓
- Reporting — September - February

SELECTION CRITERIA

Requirements:

- Systems demonstrably capture arisings
- Systems suitable for large vessels
- Systems suitable for reactive cleaning of fouled vessels
- Systems at an advanced stage of development ('Technology Readiness Level')

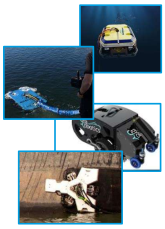
CANDIDATE SYSTEMS...

System Name	Developer/Owner	Website
CleanROV	CleanHull Ltd	www.cleanhull.no
DG Green Cleaning System	DG-Diving Group	www.dg.fi
Eco friendly hull cleaner	TecHullClean	www.techullclean.com
Eco Hull Cleaning System	Atlantida CRW	www.atlantidacrw.com
ECOsubsea	ECOsubsea AS	www.ecosubsea.com
Envirocart	Cleansubsea Holdings Pty Ltd	www.grdfranmarine.com.au
Environmentally friendly Hull Cleaning System (EFHCS)	Mermaid Marine Service	www.hullcleaning.dk
Environmentally Sensitive Hull Cleaning Systems (ESHCS)	Seatech Commercial Diving Service Ltd	www.seatechdiving.co.uk
Fleet Cleaner	Fleet Cleaner	www.fleetcleaner.com
HullBug	Searobotics Corporation	www.searobotics.com
Hulltimo Automated Hull Cleaning	Hulltimo SA	services.crmservice.eu/raiminisite
Hullwiper	Hullwiper Ltd	www.hullwiper.co
KeelCrab Sail One	Aeffe s.r.l.	www.keelcrab.com/en/keelcrab-sail-one/
Magnetic Hull Crawler (MHC)	Cybernetix (TechnipFMC)	www.cybernetix.fr
RovingBAT-Clean	ECA Robotics	www.ecagroup.com
Underwater Hull Cleaning Robot	Daewon Systems	wesbite not found
Underwater Hull Cleaning Robot	Samsung Heavy Industries	www.samsungshi.com/Eng/product/tech_prd05.aspx
un-named recapture system	Bay Underwater Services	www.bayunderwater.co.nz
un-named recapture system	NZ Diving and Salvage/DiveCo NZ	www.nzds.co.nz / www.diveco.co.nz
Whaleshark Remora and Beluga	Subsea Global Solutions	www.all-sea.com/environmentally-friendly-hull-cleaning-in-the-port-of-vancouver/

IN-WATER CLEAN AND CAPTURE

Pro-active In-water Cleaning & Capture (PICC)

- Hull maintenance focus
- Minimise fouling loads for improved operational efficiency
- Predominantly aimed at preventing or controlling slime layer (e.g., microfouling, biofilms)
- Regularly scheduled, routine maintenance
- Manageable and minimal impact on vessel operations



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IN-WATER CLEAN AND CAPTURE

Reactive In-water Cleaning & Capture (RICC)

- Rapid response focus
- Removal of heavier fouling loads
- ‘Soft’ and ‘hard’ macrofouling
- Non-routine: unscheduled to unexpected
- Can interrupt routine vessel operations

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CHOSEN SYSTEMS

Two very similar RICC systems chosen:

- High volume suction
- Diver-operated cart systems for the planar hull surfaces
- Shrouded hand tools/containment systems for niche area cleaning
- Micro-level ultra filtration with post-process treatment
- Wharfside or barge mountable

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SAMPLING

Vessel and RICC system sampling (imagery, seawater samples, biofouling and paint scrapes) prior to, during, and immediately after hull cleaning operations

- Digital still and video imagery is used (documentation of success)
- Seawater samples collected at discreet intervals (contaminants, particulates, suspended solids)
- Biofouling scrapes collected prior to cleaning (contaminants)
- Leach layer scrapes collected prior to cleaning (contaminants)

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SAMPLING PLAN

Timing	Sample Type	No.
Prior to Cleaning	Digital stills and video imagery Biofouling samples Seawater samples (contaminants) Biofilm scrapes Leach layer (paint) scrapes	As required 12 40 (per vessel) 12 (per vessel) 12 (per vessel)
During Cleaning	Digital stills and video imagery Seawater samples (contaminants) Process water (contaminants, particulates, TSS) Dye tests (video imagery) Volumetric calculations	As required 54 18 9 9
After Cleaning	Digital stills and video imagery Physical samples of any remaining biofouling	As required 12 As required
	Subtotal per RICC system (3 reps)	**496**

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SAMPLING BEFORE CLEANING

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Prior to Cleaning

Divers to collect discrete water samples for contaminants (Zn, Cu) and total suspended solids (TSS) analysis

Timing	General location	Specific location/interval	Samples for contaminants	Samples for TSS
Prior to cleaning	a: > 50m from hull and proposed discharge point	0.5m below surface	3 (1 subdivided for QC) = 4	3
(once per vessel)	b: > 50m from hull and proposed discharge point	0.5m above seabed	3 (1 subdivided for QC) = 4	3
	c: < 0.5m from hull	0.5m depth	4 locations, 3 replicates = 12	2 locations, 3 replicates = 6
	d: < 0.5m from hull	2.0m above seabed	4 locations, 3 replicates = 12	2 locations, 3 replicates = 6
	e: proposed discharge point	0.5m below surface	3 (1 subdivided for QC) = 4	3
	f: proposed discharge point	0.5m above seabed	3 (1 subdivided for QC) = 4	3
Subtotal – prior			**n = 40**	**n = 24**

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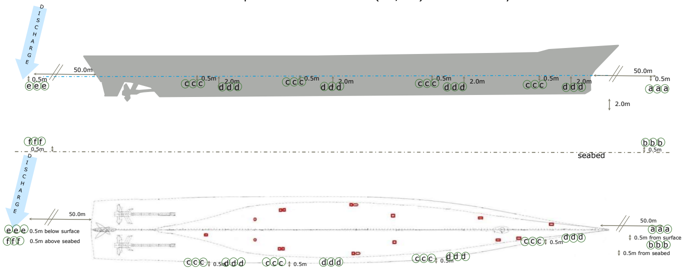
Prior to Cleaning

Divers to collect discrete water samples for contaminants (Zn, Cu) and TSS analysis



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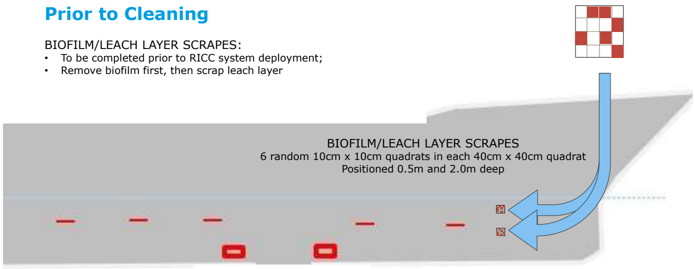
Prior to Cleaning

BIOFILM/LEACH LAYER SCRAPES:
- To be completed prior to RICC system deployment;
- Remove biofilm first, then scrap leach layer



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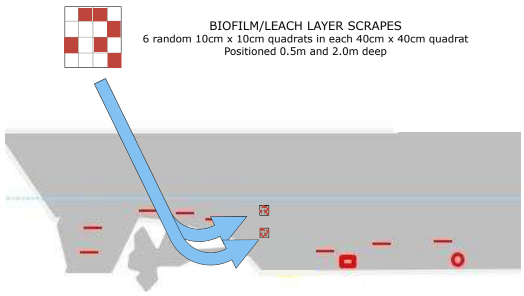

BIOFILM/LEACH LAYER SCRAPES
This set will either be located on an accessible niche area or, if none suitable, on the hull plating

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SAMPLING DURING CLEANING

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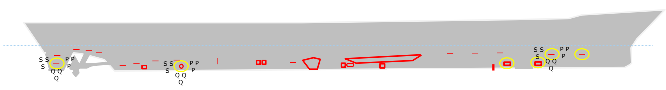
During Cleaning

NICHE CLEANERS:

Divers collect discrete water samples adjacent to the system for contaminants (Zn, Cu, TSS) analysis; digital still and video recordings also made



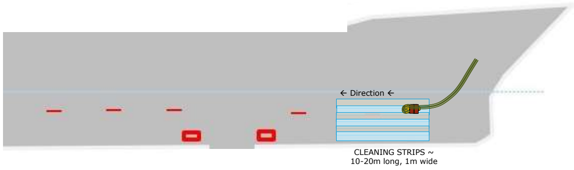
Niche cleaning and sampling area (possible)
P: 3 reps upstream
Q: 3 reps adjacent
S: 3 reps downstream

RAMBØLL

During Cleaning

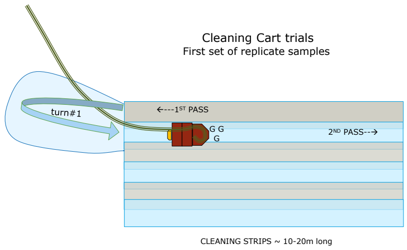
CLEANING CARTS:

Divers to collected discrete water samples adjacent to the system for contaminants (Zn, Cu, TSS) analysis; digital still and video recordings also made



During Cleaning

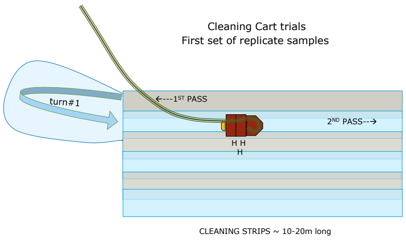
CLEANING CART TRIALS: First set of replicate samples



G: 0.5m upstream of unit (3 reps, 1^{st} of 3 locations)

During Cleaning

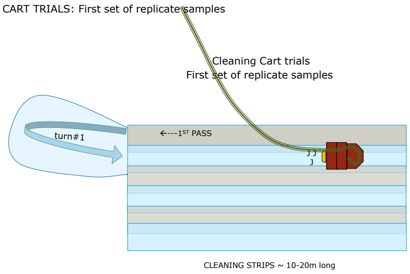
CLEANING CART TRIALS: First set of replicate samples



H: 0.5m adjacent to unit (3 reps, 1^{st} of 3 locations)

During Cleaning

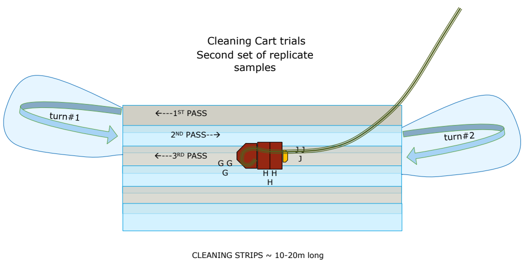
CLEANING CART TRIALS: First set of replicate samples



J: 0.5m downstream of unit (3 reps, 1^{st} of 3 locations)

During Cleaning

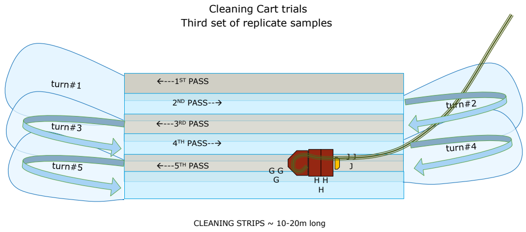
CLEANING CART TRIALS: Second set of replicate samples



G: 0.5m upstream of unit (3 reps, 2^{nd} of 3 locations)
H: 0.5m adjacent to unit (3 reps, 2^{nd} of 3 locations)
J: 0.5m downstream of unit (3 reps, 2^{nd} of 3 locations)

During Cleaning

CLEANING CART TRIALS: Third set of replicate samples



G: 0.5m upstream of unit (3 reps, 3^{rd} of 3 locations)
H: 0.5m adjacent to unit (3 reps, 3^{rd} of 3 locations)
J: 0.5m downstream of unit (3 reps, 3^{rd} of 3 locations)

THE TESTING…

RAMBOLL

THEORY & REALITY

Modifications / Additions to Testing Protocols:

- Added sampling for chemical contamination
- Reduced pre-clean sampling to once per vessel tested
- Pre-field work plan further modified when onsite
- Sampling sequenced to suit vessel configuration

RAMBOLL

THEORY & REALITY

Reality Check # 1:

- Timing: last minute vessel operations can impact sampling
  - Changes in vessel availability / substitution – often at last minute
  - Changes in scheduling – personnel flexibility and redundancy essential
  - Commercial implications of sampling

RAMBOLL

THEORY & REALITY

Reality Check # 2:

- Commercial implications
  - Vessel operations costly and subject to external factors (commercial/operational needs, weather)
  - Testing is time consuming (vessel immobilized for 3-4 days)
  - Cleaning system components are costly (individual components may cost $00s to $000s, with limited/no shelf life once used)
  - Cleaning operations are costly (8-10 person teams, typically >12h days onsite)
  - Contaminants analyses are costly

RAMBOLL

THEORY & REALITY

Reality Check # 3:

- System Reliability
  - Extremely sophisticated systems: nothing is 100% reliable
  - Breakdowns/disruptions can occur anywhere in a very long system chain
  - Contingency planning critical to success

RAMBOLL

THEORY & REALITY

Reality Check # 4:

- Collecting discrete samples from mobile cleaning systems
  - RICC systems typically designed to cover a large surface area as quickly/efficiently as possible (commercial driver)
  - HSE challenges associated with collecting discrete samples as the system approaches
  - Working close to/under vessels requires surface supply – entanglement risk is high; protocols modified to suit
  - Tightly choreographed sampling program leads to increased HSE and sample integrity risks
  - Continuous sampling using pumps may be more effective in some circumstances but have limitations

RAMBOLL

THEORY & REALITY

Reality Check # 5:

- Coordination of sampling from the filtration system can be problematic
  - System volumetric calculations are not straightforward
  - Flow rates vary during sampling
  - Coordination of sample timing at the cleaning head and discharge point problematic
  - Collecting samples "downstream" subject to vagaries in current regime –very location dependent

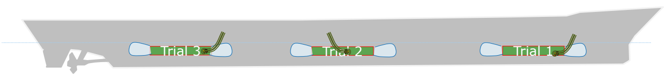
THEORY & REALITY

Reality Check # 6:

- Vessel configuration and operations can have a major impact on design
  - Presence of hull appendages, anodes, sensors, stabilisers etc affects distribution of sampling effort
  - 'Turning areas' may be limited, requiring amendments to the sampling design
  - Late schedule changes may impose restrictions on sampling

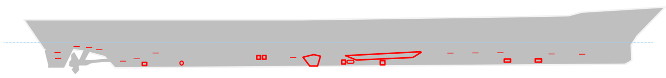
Theory: Cleaning Plan

Three separate trials, different locations on the vessel



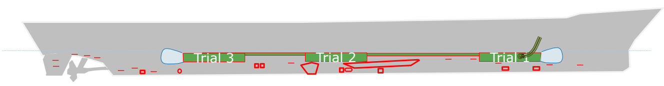
Reality: Cleaning Plan

Hull configuration (appendages, anodes and other interruptions to the planar surface of the hull) affects operation of the RICC system



Reality: Cleaning Plan

Three separate trials, different locations on the vessel but sequentially ordered



THEORY & REALITY

Reality Check # 7:

- Different system types (mobile or fixed) may require different sampling methods
  - Disturbance of water flows adjacent to mobile or fixed systems both by operators and samplers can influence results
  - Dye testing should be used to inform sampling points
  - Tools for testing need to be modified to suit conditions and for ease of use adjacent to mobile equipment

THEORY & REALITY

Reality Check # 8:

- As noted in the Protocols, components must be assessed individually and collectively.
  - Often different subsystems are used during cleaning, e.g:
    - hand tools used to prepare areas for adherence by fixed location cleaning subsystems
    - fixed area and mobile systems both used to clean whole vessel
    - hand tools used to 'mop up' areas after treatment by cart systems

RAMBOLL

...DID ANYTHING ACTUALLY WORK??

Yes!

- Despite challenges, sampling for biosecurity/containment efficacy is relatively straightforward
  - Assessment of cleaning efficacy is readily achievable
  - Dye testing should be used to identify potential 'leak' points across the entire system
  - All system components should be tested as a unified package
  - Be prepared to think on your feet and be flexible

RAMBOLL

ACKNOWLEDGEMENTS

MPI Project Team

Dr Eugene Georgiades (Project Lead)
Abraham Growcott
Tracey Bates
Nicky Fitzgibbon

This project is funded by the MPI Operational Research Team

Oceans1 Marine Consulting:

Tim Harriden, Ivor Bruce

RAMBOLL

QUESTIONS?

RAMBOLL

CHRIS SCIANNI
Senior environmental scientist, Marine Invasive Species Program (MISP)
California State Land Commission, USA

Chris Scianni is a Senior Environmental Scientist with the California State Lands Commission's Marine Invasive Species Program (MISP). During his 12 years with the MISP, Chris' work has focused on biofouling management policy and research. He led the development of California's biofouling management regulations and continues to work with MISP scientists and inspection teams to implement and enforce these regulations. Chris is also a scientific diver trained and certified by the American Association of Underwater Scientists and is one of a small group of scientific divers in North America with experience diving and collecting biological samples from commercial ships. Chris received a Bachelor of Science degree in Marine Biology from California State University, Long Beach and a Master of Science degree in Marine Science with an emphasis in Biological Oceanography from Moss Landing Marine Laboratories through California State University, Stanislaus.

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

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

A Regulator's Perspective on In-Water Cleaning

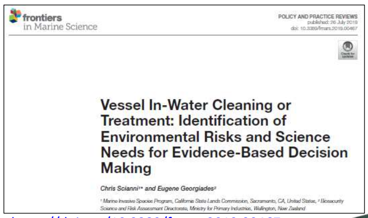
4th ANZPAC Workshop on Biofouling Management for Sustainable Shipping

Melbourne, Victoria, AUS | 1 October 2019

Chris Scianni
CALIFORNIA STATE LANDS COMMISSION
MARINE INVASIVE SPECIES PROGRAM

Acknowledgement

Eugene Georgiades, NZ MPI


frontiers in Marine Science
POLICY AND PRACTICE REVIEWS

Vessel In-Water Cleaning or Treatment: Identification of Environmental Risks and Science Needs for Evidence-Based Decision Making

Chris Scianni and Eugene Georgiades

https://doi.org/10.3389/fmars.2019.00467

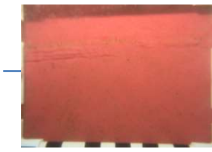
What Are We Concerned About?

Biosecurity

Water Quality

What Are The Approaches to Vessel In-Water Cleaning?

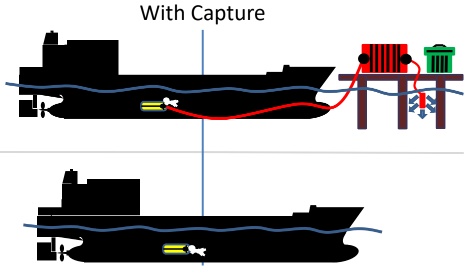
Proactive



Reactive

What Are The Approaches to Vessel In-Water Cleaning?

With Capture



Proactive — Reactive

No Capture

What Are The Approaches to Vessel In-Water Cleaning?

With Capture

Proactive — Reactive

No Capture

What Are The Approaches to Vessel In-Water Cleaning?

With Capture

Proactive		Reactive
Proactive In-Water Cleaning and Capture		Reactive In-Water Cleaning and Capture
Proactive In-Water Cleaning		Reactive In-Water Cleaning

No Capture

What Are The Approaches to Vessel In-Water Cleaning?

With Capture

Proactive		Reactive
Proactive In-Water Cleaning and Capture		Reactive In-Water Cleaning and Capture
Proactive In-Water Cleaning		**Reactive In-Water Cleaning**

No Capture

What Are The Approaches to Vessel In-Water Cleaning?

Reactive In-Water Cleaning

Acceptable Biosecurity Risk?	✗
Acceptable Water Quality Risk?	✗*

*may be acceptable if biocide-free coating

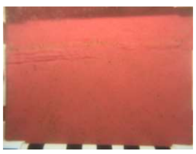
What Are The Approaches to Vessel In-Water Cleaning?

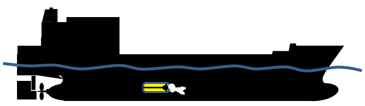
With Capture

Proactive		Reactive
Proactive In-Water Cleaning and Capture		Reactive In-Water Cleaning and Capture
Proactive In-Water Cleaning		Reactive In-Water Cleaning

No Capture

What Are The Risks Associated With Each Approach?





Proactive In-Water Cleaning

Acceptable Biosecurity Risk?	✓
Acceptable Water Quality Risk?	✗*

*may be acceptable if biocide-free coating or in some jurisdictions dependent on concentration/quantity of biocide release

What Are The Approaches to Vessel In-Water Cleaning?

With Capture

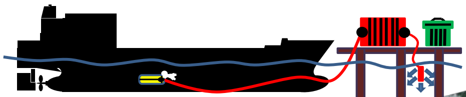
Proactive		Reactive
Proactive In-Water Cleaning and Capture		Reactive In-Water Cleaning and Capture
Proactive In-Water Cleaning		Reactive In-Water Cleaning

No Capture

What Are The Approaches to Vessel In-Water Cleaning?

Proactive In-Water Cleaning and Capture

Acceptable Biosecurity Risk?	✓*
Acceptable Water Quality Risk?	✓*



*Assuming system appropriately minimizes risks

What Are The Approaches to Vessel In-Water Cleaning?

With Capture

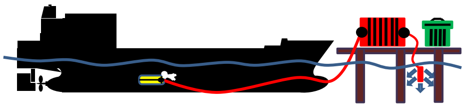
	Proactive	Reactive
With Capture	Proactive In-Water Cleaning and Capture	Reactive In-Water Cleaning and Capture
No Capture	Proactive In-Water Cleaning	Reactive In-Water Cleaning

No Capture

What Are The Approaches to Vessel In-Water Cleaning?

Acceptable Biosecurity Risk?	✓*
Acceptable Water Quality Risk?	✓*

Reactive In-Water Cleaning and Capture



*Assuming system appropriately minimizes risks

Is it ever acceptable to not capture?

Fouling Type	Coating Type	Biosecurity	Water Quality	Result
Microfouling	Biocide-Free	No Capture	No Capture	No Capture
	Biocidal	No Capture	Capture	Capture
Macrofouling	Biocide-Free	Capture	No Capture	Capture
	Biocidal	Capture	Capture	Capture

Where do These Risks Occur?

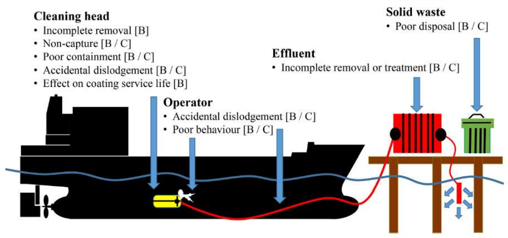
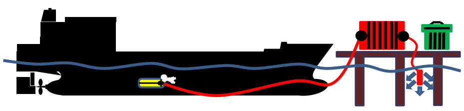


FIGURE 1 | Identification of biosecurity [B] and chemical contamination [C] risks associated with operation of reactive in-water cleaning and capture (RICC) systems [Adapted from Morrisey and Woods (2015) and Alliance for Coastal Technologies Maritime Environmental Resource Center (ACT/MERC) (2019)].

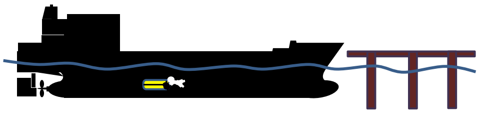
Scianni and Georgiades, 2019. Front Mar Sci. https://doi.org/10.3389/fmars.2019.00467

What Do We Need to Know?

- How well do they clean?
- How well do they reduce biosecurity risks?
- How well do they reduce water quality risks?



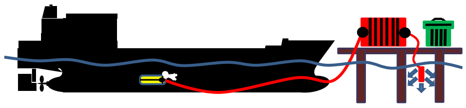
How is this *currently* regulated in California?



Without Capture
- U.S. EPA Vessel General Permit requirements
  - California-specific conditions
  - Essentially not allowed in impaired waterbodies

** DISCLAIMER: This represents my understanding. Seek EPA guidance for further clarity.

How is this *currently* regulated in California?



With Capture
- National Pollutant Discharge Elimination System (NPDES)
  - U.S. Clean Water Act
  - Implemented by the State Water Resources Control Board

California Water Boards
State Water Resources Control Board
Regional Water Quality Control Boards

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
SAN FRANCISCO BAY REGIONAL WATER QUALITY CONTROL BOARD

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
LOS ANGELES REGIONAL WATER QUALITY CONTROL BOARD

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
SAN DIEGO REGIONAL WATER QUALITY CONTROL BOARD

** DISCLAIMER: This represents my understanding. Seek EPA guidance for further clarity.

What's Our Role?

California Water Boards
State Water Resources Control Board
Regional Water Quality Control Boards

NPDES Permits

California State Lands Commission
State of California

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
SAN FRANCISCO BAY REGIONAL WATER QUALITY CONTROL BOARD

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
LOS ANGELES REGIONAL WATER QUALITY CONTROL BOARD

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY
SAN DIEGO REGIONAL WATER QUALITY CONTROL BOARD

Final Thoughts

- Vessel Incidental Discharge Act uncertainty
- Other pollutants of concern
- How well do systems reduce risks?

www.slc.ca.gov

THANK YOU & QUESTIONS

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Principal Adviser, Policy and Trade
Ministry for Primary Industries, New Zealand

Trecia Smith is a Principal Adviser in the Policy and Trade Branch of the Ministry for Primary Industries. She works on marine biosecurity policy and her current focus is the review of the IMO's Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species. Trecia has been with the Ministry since 2008, and before that the Ministry for the Environment. Her background is environmental policy, spanning climate, resource and biosecurity policy related areas. She has worked in local and central government.

Mind the Gap

Robust science, targeted research and clear objectives are essential to getting good outcomes, but how do we get good policy to achieve those outcomes?

In New Zealand, we are fortunate to have a community of excellent researchers working across public and private spheres to make sure decision makers have the information they need to make good decisions. However, sometimes there can be a gap between what the science and research is telling us, what people want (or need) and the regulatory frameworks. MPI through its operational research fund is working on understanding what is happening at the 'front line' of in-water cleaning.

Decision making is split between local and central government, with a number of regulatory regimes in play. In the marine area, there are multiple interests including Māori, aquaculture, shipping, industry providers, fishers, and recreational users to take into account. In-water cleaning is part of the tool box for reducing the spread of marine pests – but the methods and the nature of the material removed affects the risks being managed at a site level.

MPI wants to understand stakeholder's perceptions, needs, concerns or barriers, as well as any opportunities to improve awareness and biosecurity outcomes. As the work is still underway we will present a background to in water cleaning from a policy perspective and outline the approach taken to the research.

Mind the Gap

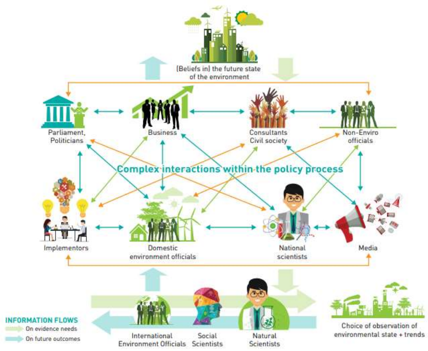
Trecia Smith
Border and Biosecurity Policy

Ministry for Primary Industries
Manatū Ahu Matua

Biosecurity New Zealand
Tiakitanga Pūtaiao Aotearoa

What is (good) policy?

- Achieving goals
  - Connectivity & complexity
- Analysis
  - Evidence, incl. research
- Advice
  - Free & frank
  - Not political
- Action
  - Decision making process
  - Regulatory tools (or not)
  - Implement (faithfully)

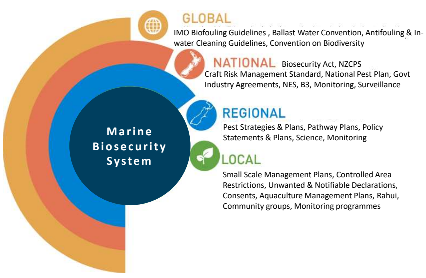


Policy in action…

… in the real world(s)…

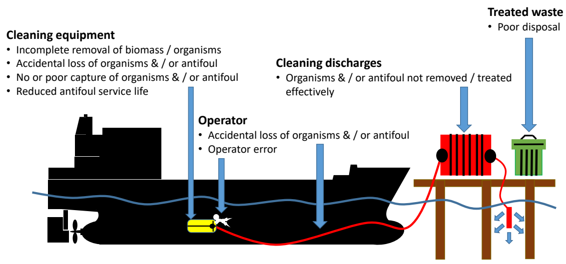
Strengthening the Science-Policy Interface: A gap analysis (2017)

Context… marine biosecurity in New Zealand



- Roles
  - Crown
  - Māori
  - Councils
  - Industry
  - Service providers
- Different values & aspirations
- Legislation, regulation & plans
- Range & mix of tools

In-water cleaning … where are the risks?



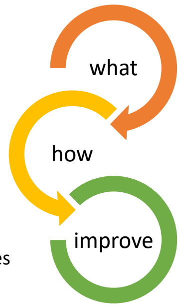
Scianni & Georgiades (2019)

In-water cleaning … what do we know?

- Multiple regimes (managing different risks)
- Different practice communities
  - Science / research, coastal / marine policy, risk management, regulators
  - Vessel operators & service providers
- Antifouling & In-water Cleaning Guidelines (uptake?)
- Different approaches have evolved – e.g. Kermedecs
- Risks are contingent on
  - State of the hull, operating profile, voyage history
  - Site values e.g. high biodiversity or working ports
  - Types & uses of in-water cleaning systems
- Mixed understanding of issues & ways forward
- Increasing demands

What do we want to find out?

- What is happening across the system
  - Māori, Crown, local government & key stakeholders
- Awareness of approval / consent processes
- Perceptions, needs, concerns or barriers
- Opportunities to improve awareness & practice
- Biosecurity benefits from other regulatory regimes



Operational research – filling the gaps

- Workshops & hui
  - Range of people around the country
  - Māori experts
  - Wide ranging discussions
- What was discussed
  - Roles/responsibilities
  - Ways to improve understanding and training
  - National approaches
- Work in progress
  - Draft report before the end of the year

What is good policy?

- Achieving goals
  - Minimising the spread of marine pests
- Analysis
  - Impacts, values at risk
- Advice
  - Effects on Māori, vessels, industries, communities – costs / benefits
  - System(s) settings, tools
  - Understanding options / trade offs
- Action
  - Complementary tools (systems & scales)
  - Implementing, monitoring, reviewing…

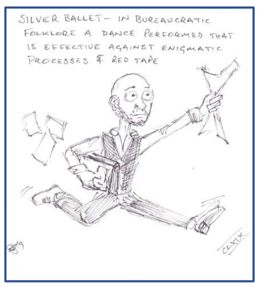
The Policy Project
Responsive today, shaping tomorrow

How do we get there?

- Fill the gaps
  - Robust evidence & analysis
  - Participatory processes during the analysis stage
- Understand the range of risks & any unintended consequences
- Seek opportunities & produce outputs that fit (multiple) needs
- Build capacity & share information (thanks ANZPAC & GloFouling!)
- Ongoing dialogue & participation

Thank you…

- The Kind Doctors
  - Georgiades, Kluza, Bell
- MPI Crew
  - Tracey Bates, Jen Brunton, Sue Escott-Brown
- Scientists extraordinaire
  - NIWA, Cawthron
- NZ whānui
  - Ashleigh Johnston
  - Sarah Hucker
- International Partners



Ministry for Primary Industries
Manatū Ahu Matua

Biosecurity New Zealand
Tiakitanga Pūtaiao Aotearoa

SONIA GORGULA
Director, Marine Biosecurity Unit, Biosecurity Animal Division
Australian Government Department of Agriculture, Australia

Sonia Gorgula has over a decade of experience working in policy roles focused on the regulation of vessels' biofouling in federal and state government agencies, in Australia and the United States respectively. In her current role with the Australian Department of Agriculture (the department) she leads a number of activities, including the development of national in-water cleaning policy, the evidence base for the department's decision-making on biofouling risk, Australia's input to the review of the IMO Biofouling Guidelines and capacity building for improved biofouling management practices via Australia's engagement in the GloFouling Partnerships Program.

Career highlights include running the prevention program for marine biosecurity for the State of Hawaii during 2011-2014, which included coordination of Hawaii's response to marine debris landings across the islands. In this role she also chaired working groups such as the Alien Aquatic Organism Task Force and the Coastal Sub- committee of the Western Regional Panel on Aquatic Nuisance Species, the latter which resulted in the identification of consistent approaches for biofouling management across the US Pacific North-West Coastal States. Highlights while working in the department include finalizing an initial approach for the regulation of biofouling via a 2011 Regulation Impact Statement, overseeing a species-based risk assessment that resulted in an exotic biofouling species list for Australia and the finalization of biofouling management guidelines for the Offshore and Petroleum Sector. In a short role at the Primary Industries and Regions South Australia she also helped develop an approach to marine pest risk assessment, for population of a national priority marine pest list.

Sonia completed a Bachelor of Science in Marine Biology at Flinders University in Adelaide, South Australia in 2003. In 2004 she went on to complete honors (First Class) at the University of Adelaide on the characterization of anthropogenic impacts on subtidal urban reefs in South Australia.

Steps towards an Australian standard for the in-water cleaning of biofouling

The Australian Department of Agriculture (the department) is developing supporting arrangements to ensure the effective and efficient implementation of future biofouling management requirements under the *Biosecurity Act 2015*.

Proactive in-water cleaning to minimise the accumulation of biofouling is recognised as a pragmatic solution to minimise marine biosecurity risks. However, all in-water cleaning activities have the potential to present unacceptable biosecurity and contaminant risks when adequate controls are not in place. In 2013 the Australian and New Zealand Governments released the *Antifouling and In-Water Cleaning Guidelines*, which contain biosecurity thresholds to support decision making regarding in-water cleaning activities. A 2018 review of the Guidelines and their effectiveness identified the need for increased clarity on the approval processes for acceptable in-water cleaning practices in Australia. Concurrently, requests for in-water cleaning in Australia have increased, particularly with recent technological advancements and the adoption of mandatory biofouling requirements for vessels operating in New Zealand, California and impending Australian requirements. The department is developing a national standard to provide a mechanism for consistent decision making and facilitate in-water cleaning activities that adequately minimise biosecurity and contaminant risks.

The standard is intended to be robust, achievable, effective and, to the extent possible, consistent with international standards that are also under development. This presentation will outline the proposed approach and opportunities for collaboration and engagement in the finalisation of the standard during 2020.

Australian Government
Department of Agriculture

Steps towards an Australian standard for the in-water cleaning of biofouling

Session 11 – In-Water Cleaning

Sonia Gorgula – Department of Agriculture

Joint 4th Australian, New Zealand and Pacific Workshop on Biofouling Management for Sustainable Shipping and 1st Research and Development Forum for the GEF-IMO-UNDP GloFouling Partnerships

Melbourne, Australia 30 September – 4 October 2019

Australian Government
Department of Agriculture

Presentation Overview

- The role of the Department
- A brief history on in-water cleaning policy
- The 2015 Guidelines and their review
- Current policy development, challenges and opportunities
- Options for national in-water cleaning standards

Australian Government
Department of Agriculture

The Department of Agriculture

- Develop and implement policies and programs to ensure Australia's agricultural, fisheries, food and forestry industries remain competitive, profitable and sustainable
- Support sustainable and productive management and use of rivers and water resources
- Biosecurity Act 2015 – minimise impacts to plant, animal and human health through the introduction and spread of pests and diseases

http://www.agriculture.gov.au/

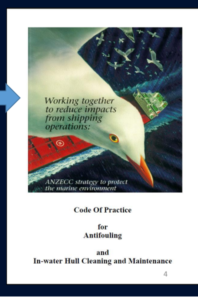
A Brief history - the Australian perspective

1997

Australian and New Zealand Environment and Conservation Council (ANZECC) Code of Practice for Antifouling and In-water Hull Cleaning and Maintenance

Concerns from In-water ship hull cleaning

- Toxic chemicals from anti-fouling coatings
- Non-indigenous marine species



A Brief history - the Australian perspective

1997

Australian and New Zealand Environment and Conservation Council (ANZECC) Code of Practice for Antifouling and In-water Hull Cleaning and Maintenance

Practices to minimise contaminant and biosecurity risks

- Part 1 – application, use, removal and disposal of anti-fouling coatings
- Part 2 – In-water Cleaning and Maintenance (applicable to commercial vessels)

- Applicable only to a subset of large commercial vessels
- Prohibited in-water cleaning without a permit
- Accepted tributyltin-based coatings on vessels > 25m in length

Changes in international policies

1999

- IMO assembly resolution for MEPC to develop a global, legally binding instrument to address harmful environmental effects of organotin compounds

2001

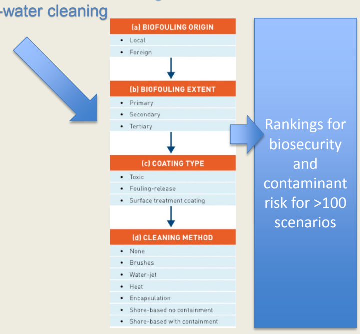
- International Convention on the Control of Harmful Antifouling Systems on Ships (AFS Convention) – introduced in 2001, enters into force 2008

2007

- Australia ratifies the AFS Convention *(at variance with the ANZECC GL)*
- Commonwealth *Protection of the Sea (Harmful Anti-Fouling Systems) Act 2006*

2010 Review of Technology, Risk Scenarios

1. Reviewed anti-fouling coatings & novel technologies
2. Assessed benefits & risks of in-water cleaning
3. Ranked scenarios of in-water cleaning



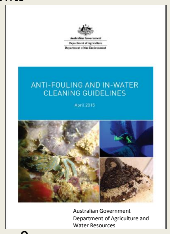
Australian and New Zealand Anti-Fouling and In-Water Cleaning Guidelines

2011

- Australian and New Zealand Redrafting Correspondence Group formed to draft new guidelines
- Participants included maritime industry, Defence, State and Territory Governments, marinas, ports, yachting, bulk commodities and not-for profits

2013

- Australian and New Zealand Anti-Fouling and In-Water Cleaning Guidelines released (revised in 2015)



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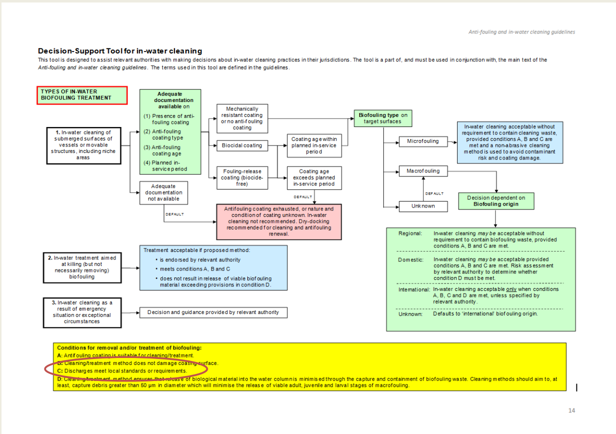


9

A National Standard for In-Water Cleaning

Drivers:

- Maritime industry need proactive solutions
- Complexities in approval processes
- Requests are increasing
- Increase in biofouling requirements
- Advancements in technology

Steps for developing the standard

Phase 1

Set the biosecurity standard *[for in-water cleaning of non-biocidal coatings and/or grooming?]*

Phase 2

Set the contaminant standard (*for in-water cleaning of biocidal coatings)*

11

Objectives of a proposed Australian In-Water Cleaning Standard

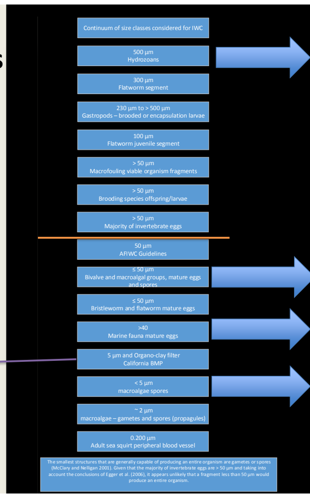
1. Achievable
2. Based on science
3. Consistent with IMO Guidelines (minimise macro-fouling)
4. Considers best available technology and future advancements
5. Is reviewed periodically

Agreements with operators are proposed to be established that:

1. Include requirements to monitor and mitigate risk
2. Establish auditing arrangements
3. Agree on how the technology can be used and at which locations

Where do we set the In-Water Cleaning standard?

Considerations for Biosecurity



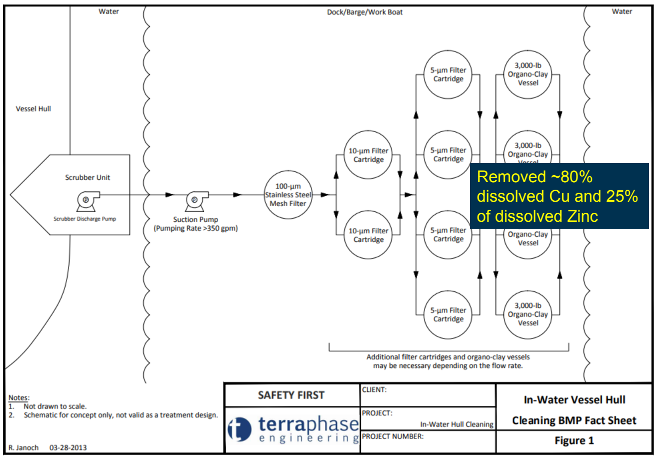
5 microns and Organo-clay filter used in California (copper and zinc)

500 microns – Hydrozoans

≤ 50 microns – Bivalves, macroalgae, bristleworm, flatworm mature eggs

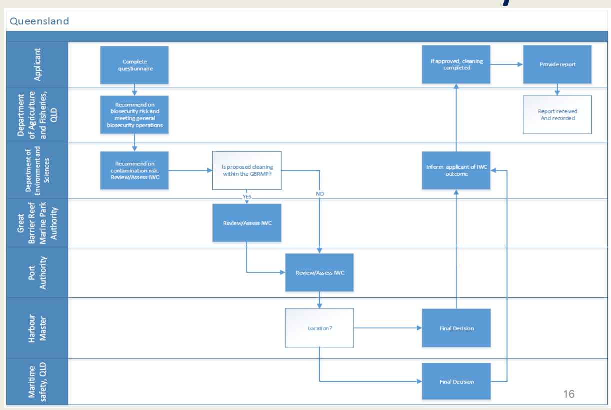
>40 microns – Marine fauna mature eggs

<5 microns – macroalgal spores



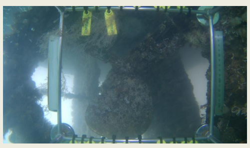
Removed ~80% dissolved Cu and 25% of dissolved Zinc

Who is involved? Case Study



Challenges

- Defining in-water cleaning
- Independent verification of technologies to meet the standard
- Maintaining currency and consistency
- Auditing to facilitate and secure approvals
- Determining appropriate locations in Australia
- Time constraints
- Determining the decision-makers, roles and process



International engagement

Trans-Tasman

Australian Government Department of Agriculture

Ministry for Primary Industries Manatū Ahu Matua

International Governments

International Maritime Organization

IMO International Maritime Organization

IMO GloFouling Partnerships

Industry-led

BIMCO

IMarEST

Testing and Protocols

Alliance for Coastal Technologies

Maritime Environmental Resource Center

International Engagement

- Strategic Partner of GloFouling Partnerships' Programme (since 2018)
- Leading coordinated input to the review of the 2011 IMO Biofouling Guidelines. Co-sponsored submission with New Zealand and the Netherlands that established the review in 2018.
- Australia and New Zealand co-chair an informal IMO biofouling correspondence group (est. 2018) in the margins of MEPC.
- Engaging with BIMCO, New Zealand and California in the development of In-Water Cleaning Standards

Timelines

Exact timings are currently being determined.

- 2019-20 financial year
    - Literature review of minimum viable propagule size
    - Identify and conduct additional science and technical input
- Engagement on a draft standard during early-mid 2020
- Ideally implementation commences concurrently with a new Australian Biofouling policy in late 2020

To learn more:

marinepests@agriculture.gov.au
http://www.marinepests.gov.au
http://www.agriculture.gov.au/biosecurity/avm/vessels/biofouling

Contact:
Sonia Gorgula / Assistant Director / Marine Biosecurity Unit
Department of Agriculture
Sonia.Gorgula@agriculture.gov.au

Source: Neptune Marine Services

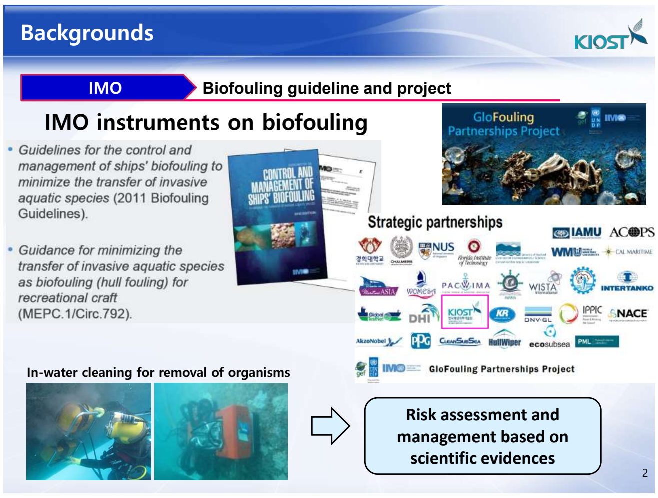
JUNG-HOON KANG
Director, Marine Biosecurity Unit, Biosecurity Animal Division
Korea Institute of Ocean Science and Technology, Korea

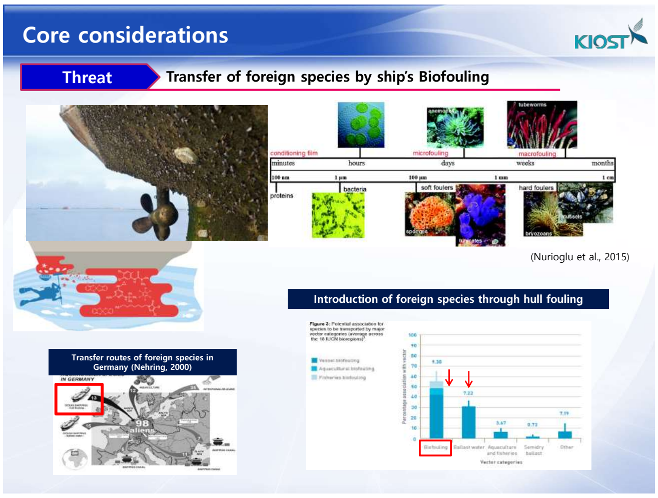
Development for assessment and management of the risk arising from the wastes considering in- water hull cleaning activity

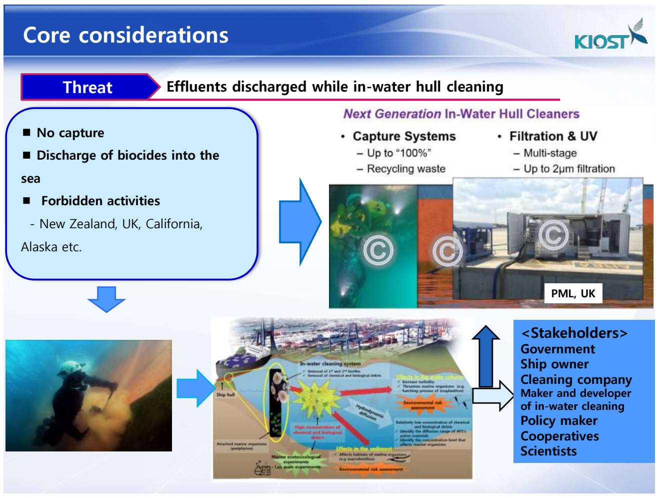
Jung-Hoon Kang[1], Min-Chul Jang[1], Moonkoo Kim[1], Jee-Hyun Jung[1], Kyoungsoon Shin[2] [1]Korea Institute of Ocean Science and Technology, Geoje, Korea

The International Maritime Organization (IMO) has recognized the risk of hull fouling and announced '2011 Guidelines for the control and management of ship's biofouling to minimize the transfer of invasive aquatic species' and is planning international regulations to enforce them in the future. In this study, to effectively respond to future international regulation, we have developed the biological risk assessment techniques for in- water cleaning by referring to the study results of Australia and New Zealand, which are the leading countries in hull fouling management. First of all, 40 codes of in-water cleaning scenarios considering Korea's port environment were made and then Risk Priority Number (RPN) scores were calculated based on the four subject matters that affect intrusion of alien species during in-water cleaning. Ranking of the scenarios by RPNaverage scores was estimated using expert judgment and its results showed that the groups of four highest-risk scenarios all involve cleaning of macrofouling on the international vessels with no waste capture system. We also performed in-water cleaning for R/V EARDO (domestic vessels and spot fouling) vessel at Busan's Gamcheon Port in Korea and found as a medium risk due to the RPN value was <1,000. Therefore, considering the results of biological risk assessment, it was evaluated as possible for in-water cleaning in the port only if in-water cleaning was carried using an appropriate capture system. Consequently, these studies will help to establish the regulation of ship's hull fouling management in the port.

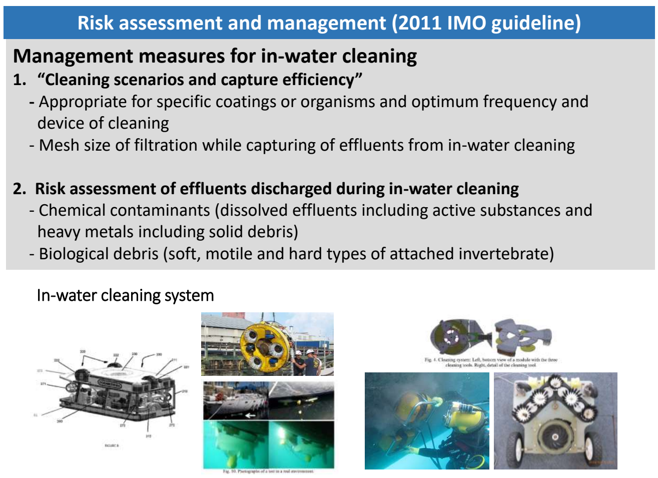

1st GEF-UNDP-IMO GloFouling R&D Forum
KIOST
Development for assessment and management of the risk arising from the wastes considering in-water hull cleaning activity
Jung-Hoon Kang
Melbourne, Austrailia, 3 October, 2019

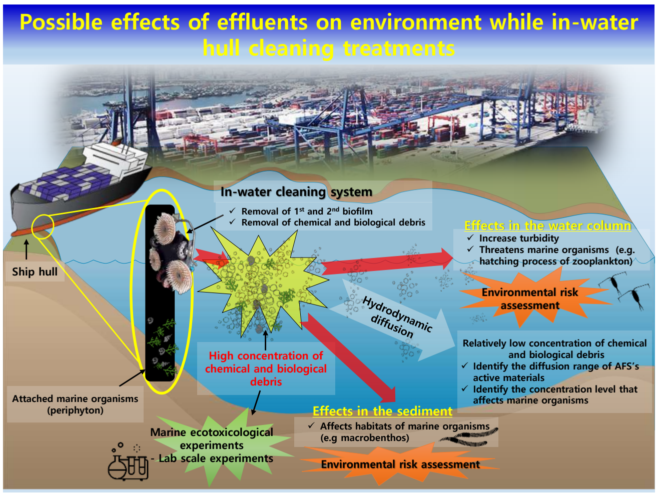

Backgrounds
KIOST
IMO
Biofouling guideline and project
IMO instruments on biofouling
Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species (2011 Biofouling Guidelines).
Guidance for minimizing the transfer of invasive aquatic species as biofouling (hull fouling) for recreational craft (MEPC.1/Circ.792).
CONTROL AND MANAGEMENT OF SHIPS' BIOFOULING
GloFouling Partnerships Project
Strategic partnerships
GloFouling Partnerships Project
In-water cleaning for removal of organisms
Risk assessment and management based on scientific evidences
2

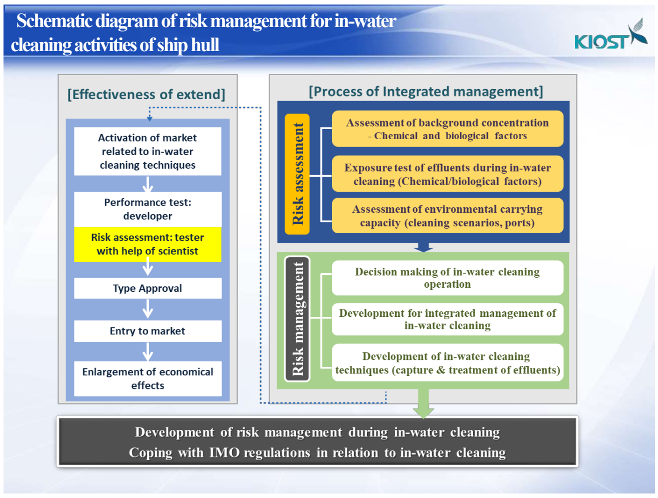

Core considerations
KIOST
Threat
Transfer of foreign species by ship's Biofouling
conditioning film
microfouling
macrofouling
minutes
hours
days
weeks
months
proteins
bacteria
soft foulers
hard foulers
(Nurioglu et al., 2015)
Introduction of foreign species through hull fouling
Transfer routes of foreign species in Germany (Nehring, 2000)

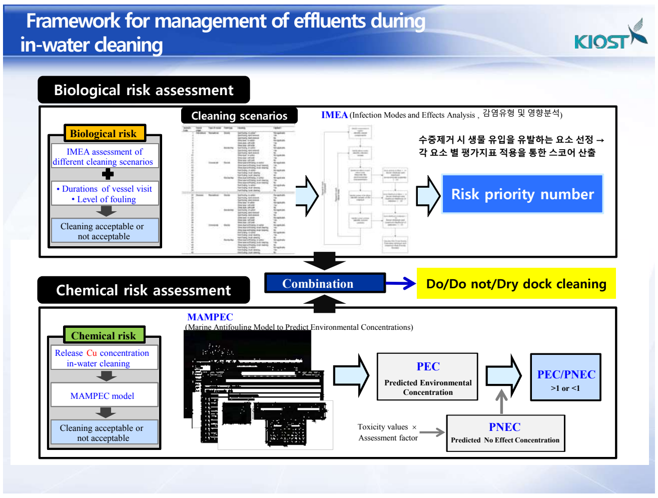

Core considerations
KIOST
Threat
Effluents discharged while in-water hull cleaning
No capture
Discharge of biocides into the sea
Forbidden activities
- New Zealand, UK, California, Alaska etc.
Next Generation In-Water Hull Cleaners
Capture Systems
– Up to "100%"
– Recycling waste
Filtration & UV
– Multi-stage
– Up to 2μm filtration
PML, UK
<Stakeholders>
Government
Ship owner
Cleaning company
Maker and developer of in-water cleaning
Policy maker
Cooperatives
Scientists


Questions ?
KIOST
"is there a significant difference in risk between in-water cleaning and the option of no action?"
1. Chemical contamination risk
2. Biosecurity risk
Management measures during in-water cleaning ?
What kinds of cleaning methods accept biosecurity and chemical contamination risks?
Assessment of cleaning scenarios?

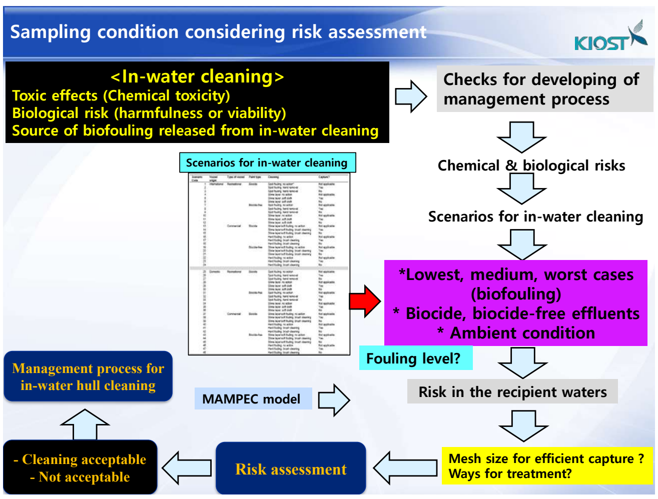

Risk assessment and management (2011 IMO guideline)
Management measures for in-water cleaning
1. "Cleaning scenarios and capture efficiency"
- Appropriate for specific coatings or organisms and optimum frequency and device of cleaning
- Mesh size of filtration while capturing of effluents from in-water cleaning
2. Risk assessment of effluents discharged during in-water cleaning
- Chemical contaminants (dissolved effluents including active substances and heavy metals including solid debris)
- Biological debris (soft, motile and hard types of attached invertebrate)
In-water cleaning system


Possible effects of effluents on environment while in-water hull cleaning treatments
In-water cleaning system
✓ Removal of 1st and 2nd biofilm
✓ Removal of chemical and biological debris
Ship hull
Effects in the water column
✓ Increase turbidity
✓ Threatens marine organisms (e.g. hatching process of zooplankton)
Environmental risk assessment
Hydrodynamic diffusion
High concentration of chemical and biological debris
Relatively low concentration of chemical and biological debris
✓ Identify the diffusion range of AFS's active materials
✓ Identify the concentration level that affects marine organisms
Attached marine organisms (periphyton)
Effects in the sediment
✓ Affects habitats of marine organisms (e.g macrobenthos)
Marine ecotoxicological experiments
- Lab scale experiments
Environmental risk assessment

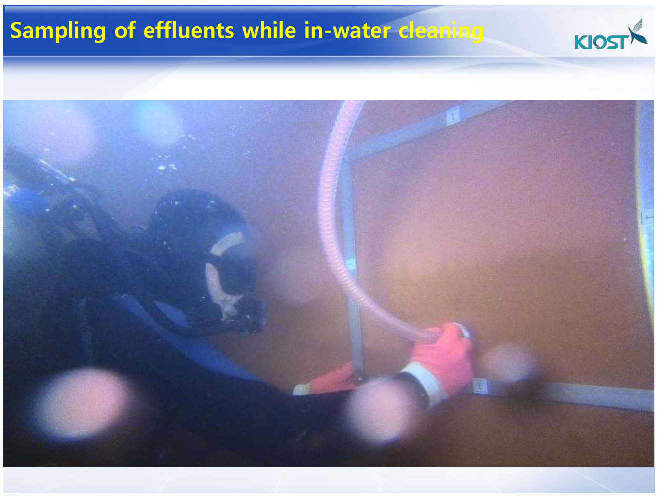

Schematic diagram of risk management for in-water cleaning activities of ship hull
KIOST
[Effectiveness of extend]
Activation of market related to in-water cleaning techniques
Performance test: developer
Risk assessment: tester with help of scientist
Type Approval
Entry to market
Enlargement of economical effects
[Process of Integrated management]
Risk assessment
Assessment of background concentration - Chemical and biological factors
Exposure test of effluents during in-water cleaning (Chemical/biological factors)
Assessment of environmental carrying capacity (cleaning scenarios, ports)
Risk management
Decision making of in-water cleaning operation
Development for integrated management of in-water cleaning
Development of in-water cleaning techniques (capture & treatment of effluents)
Development of risk management during in-water cleaning
Coping with IMO regulations in relation to in-water cleaning


Framework for management of effluents during in-water cleaning
KIOST
Biological risk assessment
Cleaning scenarios
IMEA (Infection Modes and Effects Analysis , 감염유형 및 영향분석)
Biological risk
IMEA assessment of different cleaning scenarios
• Durations of vessel visit
• Level of fouling
Cleaning acceptable or not acceptable
수중제거 시 생물 유입을 유발하는 요소 선정 →
각 요소 별 평가지표 적용을 통한 스코어 산출
Risk priority number
Combination
Do/Do not/Dry dock cleaning
Chemical risk assessment
MAMPEC
(Marine Antifouling Model to Predict Environmental Concentrations)
Chemical risk
Release Cu concentration in-water cleaning
MAMPEC model
Cleaning acceptable or not acceptable
PEC
Predicted Environmental Concentration
PEC/PNEC
>1 or <1
Toxicity values × Assessment factor
PNEC
Predicted No Effect Concentration


In-house projects for risk assessment of effluents
KIOST
Phase I (2017~2018)
Preliminary study for risk assessment of water-jet effluents
Phase II (2019~2022)
"Development of risk assessment and management process of ship's biofouling debris discharged during in-water cleaning"
Development of techniques for risk assessment based on water-jet washing and exposure of plates treated by coating
Risk assessment of effluents discharged during in-water cleaning
Analysis of active substances
Toxicity test
Analysis of ship's biofouling
Framework for management of in-water cleaning

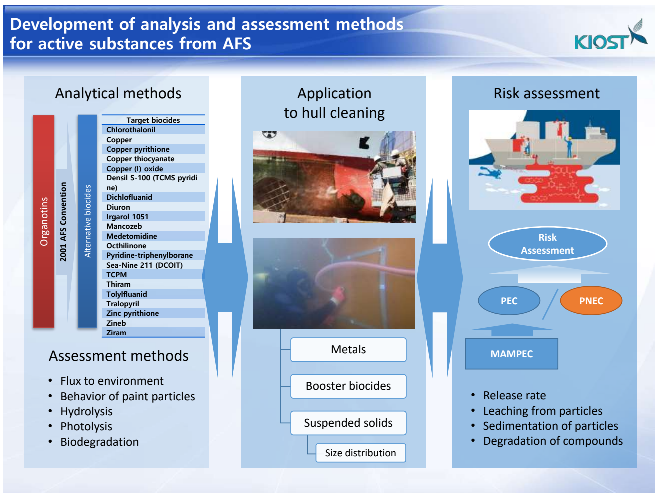

Sampling condition considering risk assessment
KIOST
<In-water cleaning>
Toxic effects (Chemical toxicity)
Biological risk (harmfulness or viability)
Source of biofouling released from in-water cleaning
Checks for developing of management process
Chemical & biological risks
Scenarios for in-water cleaning
Scenarios for in-water cleaning
*Lowest, medium, worst cases (biofouling)
* Biocide, biocide-free effluents
* Ambient condition
Fouling level?
Management process for in-water hull cleaning
MAMPEC model
Risk in the recipient waters
- Cleaning acceptable
- Not acceptable
Risk assessment
Mesh size for efficient capture ?
Ways for treatment?


Plan to get samples from hull cleaning
KIOST
Direct cleaning by diver
In-water cleaning techniques
UNDERWATER HULL CLEANING ROBOT SYSTEM
Hydroblasting
Removal samplings
Panel tests

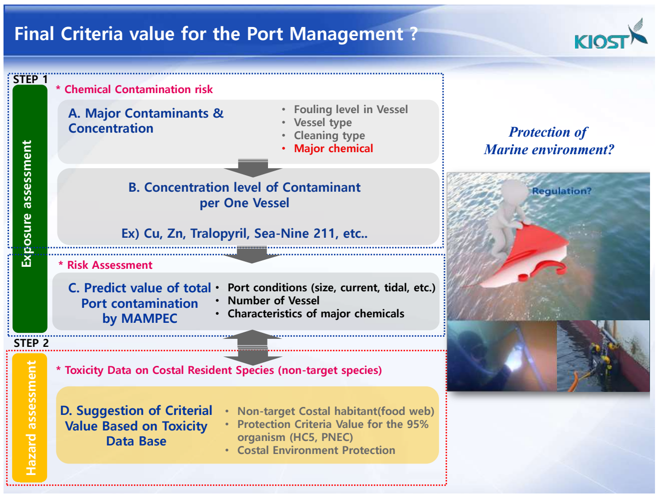


Sampling of effluents while in-water cleaning
KIOST

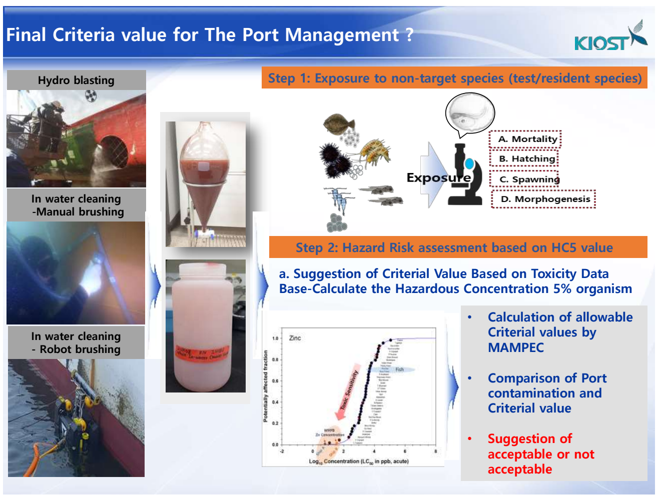
Sampling of wastes discharged during in-water hull cleaning
Coastal
Offshore
Global



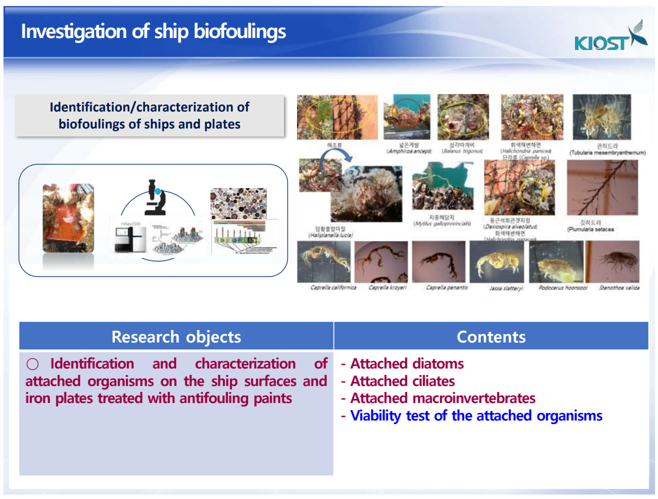
Development of analysis and assessment methods
for active substances from AFS
KIOST
Analytical methods
Organotins
2001 AFS Convention
Alternative biocides
Target biocides
Chlorothalonil
Copper
Copper pyrithione
Copper thiocyanate
Copper (I) oxide
Densil S-100 (TCMS pyridine)
Dichlofluanid
Diuron
Irgarol 1051
Mancozeb
Medetomidine
Octhilinone
Pyridine-triphenylborane
Sea-Nine 211 (DCOIT)
TCPM
Thiram
Tolylfluanid
Tralopyril
Zinc pyrithione
Zineb
Ziram
Assessment methods
Flux to environment
Behavior of paint particles
Hydrolysis
Photolysis
Biodegradation
Application
to hull cleaning
Metals
Booster biocides
Suspended solids
Size distribution
Risk assessment
Risk Assessment
PEC
PNEC
MAMPEC
Release rate
Leaching from particles
Sedimentation of particles
Degradation of compounds



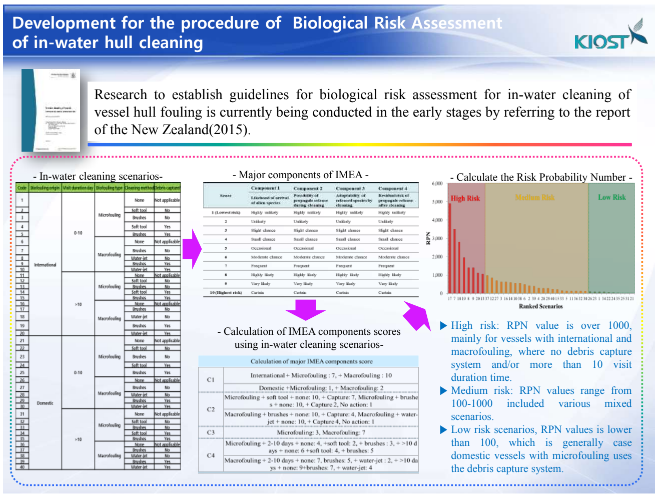
Final Criteria value for the Port Management ?
KIOST
STEP 1
Exposure assessment
* Chemical Contamination risk
A. Major Contaminants & Concentration
Fouling level in Vessel
Vessel type
Cleaning type
Major chemical
B. Concentration level of Contaminant per One Vessel
Ex) Cu, Zn, Tralopyril, Sea-Nine 211, etc..
* Risk Assessment
C. Predict value of total Port contamination by MAMPEC
Port conditions (size, current, tidal, etc.)
Number of Vessel
Characteristics of major chemicals
STEP 2
Hazard assessment
* Toxicity Data on Costal Resident Species (non-target species)
D. Suggestion of Criterial Value Based on Toxicity Data Base
Non-target Costal habitant(food web)
Protection Criteria Value for the 95% organism (HC5, PNEC)
Costal Environment Protection
Protection of Marine environment?
Regulation?

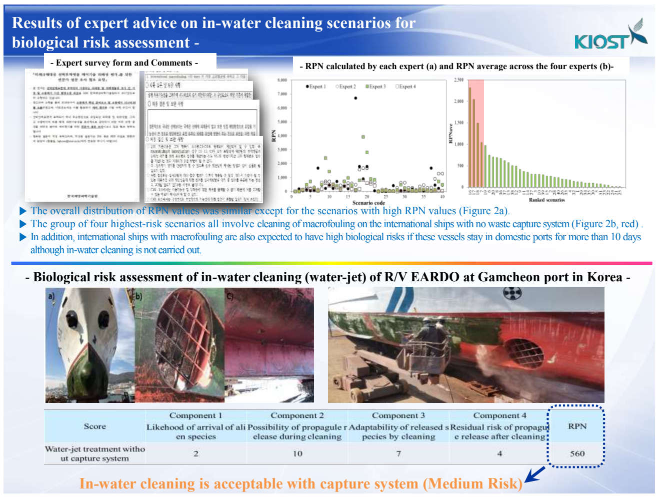


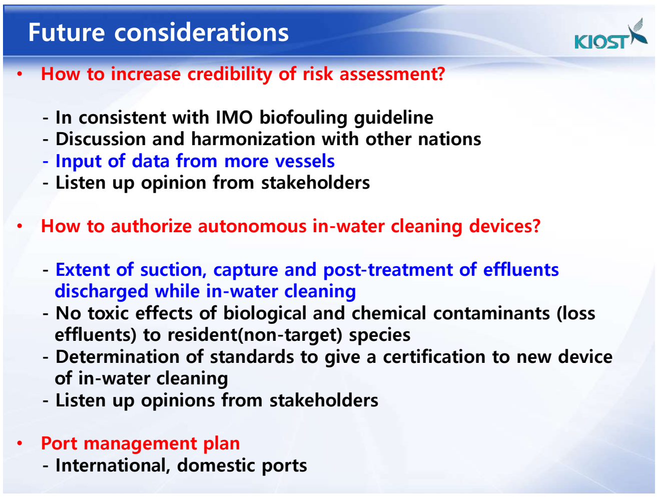
Final Criteria value for The Port Management ?
KIOST
Hydro blasting
In water cleaning -Manual brushing
In water cleaning - Robot brushing
Step 1: Exposure to non-target species (test/resident species)
Exposure
A. Mortality
B. Hatching
C. Spawning
D. Morphogenesis
Step 2: Hazard Risk assessment based on HC5 value
a. Suggestion of Criterial Value Based on Toxicity Data
Base-Calculate the Hazardous Concentration 5% organism
Zinc
Calculation of allowable Criterial values by MAMPEC
Comparison of Port contamination and Criterial value
Suggestion of acceptable or not acceptable



Investigation of ship biofoulings
KIOST
Identification/characterization of biofoulings of ships and plates
Research objects
○ Identification and characterization of attached organisms on the ship surfaces and iron plates treated with antifouling paints
Contents
- Attached diatoms
- Attached ciliates
- Attached macroinvertebrates
- Viability test of the attached organisms


Development for the procedure of Biological Risk Assessment of in-water hull cleaning
KIOST
Research to establish guidelines for biological risk assessment for in-water cleaning of vessel hull fouling is currently being conducted in the early stages by referring to the report of the New Zealand(2015).
- In-water cleaning scenarios-
- Major components of IMEA -
- Calculate the Risk Probability Number -
High Risk
Medium Risk
Low Risk
RPN
Ranked Scenarios
- Calculation of IMEA components scores using in-water cleaning scenarios-
Calculation of major IMEA components score
C1 International + Microfouling : 7, + Macrofouling : 10
Domestic +Microfouling: 1, + Macrofouling: 2
C2 Microfouling + soft tool + none: 10, + Capture: 7, Microfouling + brushes + none: 10, + Capture 2, No action: 1
Macrofouling + brushes + none: 10, + Capture: 4, Macrofouling + water-jet + none: 10, + Capture 4, No action: 1
C3 Microfouling: 3, Macrofouling: 7
C4 Microfouling + 2-10 days + none: 4, +soft tool: 2, + brushes : 3, + >10 days + none: 6 +soft tool: 4, + brushes: 5
Macrofouling + 2-10 days + none: 7, brushes: 5, + water-jet : 2, + >10 days + none: 9+brushes: 7, + water-jet: 4
▶ High risk: RPN value is over 1000, mainly for vessels with international and macrofouling, where no debris capture system and/or more than 10 visit duration time.
▶ Medium risk: RPN values range from 100-1000 included various mixed scenarios.
▶ Low risk scenarios, RPN values is lower than 100, which is generally case domestic vessels with microfouling uses the debris capture system.


Results of expert advice on in-water cleaning scenarios for biological risk assessment -
KIOST
- Expert survey form and Comments -
- RPN calculated by each expert (a) and RPN average across the four experts (b)-
Expert 1
Expert 2
Expert 3
Expert 4
RPN
Scenario code
RPNave
Ranked scenarios
▶ The overall distribution of RPN values was similar except for the scenarios with high RPN values (Figure 2a).
▶ The group of four highest-risk scenarios all involve cleaning of macrofouling on the international ships with no waste capture system (Figure 2b, red) .
▶ In addition, international ships with macrofouling are also expected to have high biological risks if these vessels stay in domestic ports for more than 10 days although in-water cleaning is not carried out.
- Biological risk assessment of in-water cleaning (water-jet) of R/V EARDO at Gamcheon port in Korea -
a)
b)
c)
Score | Component 1 Likehood of arrival of alien species | Component 2 Possibility of propagule release during cleaning | Component 3 Adaptability of released species by cleaning | Component 4 Residual risk of propagule release after cleaning | RPN
Water-jet treatment without capture system | 2 | 10 | 7 | 4 | 560
In-water cleaning is acceptable with capture system (Medium Risk)


Future considerations
KIOST
• How to increase credibility of risk assessment?
- In consistent with IMO biofouling guideline
- Discussion and harmonization with other nations
- Input of data from more vessels
- Listen up opinion from stakeholders
• How to authorize autonomous in-water cleaning devices?
- Extent of suction, capture and post-treatment of effluents discharged while in-water cleaning
- No toxic effects of biological and chemical contaminants (loss effluents) to resident(non-target) species
- Determination of standards to give a certification to new device of in-water cleaning
- Listen up opinions from stakeholders
• Port management plan
- International, domestic ports


Planning project has started from 1st September this year
KIOST
IMO
Planning project for development of techniques for risk reduction of marine Bio-fouling
KIOST
주관 KIOST 한국해양과학기술원 공동 해양기술정책연구소


Thank you for your attention!

GEOFF SWAIN
Director, Center for Corrosion and Biofouling Control
Florida Institute of Technology, USA

Dr. Geoff Swain is Professor of Oceanography and Ocean Engineering and the Director of the Center for Corrosion and Biofouling Control at the Florida Institute of Technology (FIT). He started his career at the University of Southampton, UK to develop novel methods for corrosion and biofouling control for the Royal Navy and the Department of Energy. In the early 1980's he moved to Aberdeen, Scotland where he joined a company that conducted corrosion and biofouling surveys on offshore structures in the North Sea. He joined FIT in 1984 and established the Center for Corrosion and Biofouling Control. The Center is fully staffed, has a laboratory on campus, static and dynamic seawater test facilities at Port Canaveral, two research boats and has active research grants with the Office of Naval Research and the shipping and coatings Industries. Notable accomplishments include the design of the cathodic protection system for the Living Seas at Disney World, developing an ASTM method for evaluating fouling release coatings, establishing a quality control procedure for dry docking and fouling control coatings for Royal Caribbean International, and pioneering the development of in-water grooming to maintain ship hulls in a smooth and fouling free condition. He has published over 50 refereed articles on the subject. He is a member of the National Association of Corrosion Engineers, the Society of Naval Architects and Marine Engineers, the American Society for Testing and Materials and the Marine Biological Association of the U.K.

In-Water Grooming to Maintain Ship Hulls: from Research to Reality

Geoffrey Swain, Harrison Gardner and Kelli Hunsucker[1]; Ben Kinaman[2]
[1]Florida Institute of Technology, Melbourne, FL, USA [2]Greensea Systems, Inc., Richmond, Vermont 05477

Ship hull grooming is being developed as a proactive method to manage the long-term performance of fouling control coatings. The concept is to develop autonomous underwater vehicles equipped with grooming tools that can be deployed on the ship hull at a frequency that maintains the surface in a smooth and fouling free condition without creating a discharge that needs capture and treatment. The project may be divided into three distinct topics; grooming tool development, vehicle requirements, and control and navigation. The grooming tool development has focused on the design of low power vertically rotating self-attaching brushes that are designed to exert sufficient force to remove silt, biofilm and incipient fouling without damaging the surface. Long term data applying these tools to ablative copper and fouling release systems has demonstrated that fouling can be controlled with no increase in wear, discharge or roughness to the coating.

The vehicle requirements are to provide sufficient power and attachment to move the grooming tool over the hull of the vessel and to incorporate a control and navigation system that enable a large degree of autonomy. Several different remotely operated vehicles have been evaluated and developed during the trials. The present design includes a tracked skid which attaches to the hull using a v-ram with a top mounted power, propulsion, navigation and control module. The vehicle will be equipped with sensors and control systems will be developed that enable grooming to proceed with minimum operator requirements.

In-Water Grooming to Maintain Ship Hulls
from Research to Reality

Biofouling Management , Melbourne, Australia, October 2019

Geoffrey Swain Caglar Erdogan, Harrison Gardner, Michael Harper, John Hearin, Kelli Z. Hunsucker, J. Travis Hunsucker, Kodi Liberman, Mark Nanney, Emily Ralston, Abraham Stephens, Melissa Tribou, Ann Wassick, Bruce Walker

Center for Corrosion and Biofouling Control
Florida Institute of Technology
Melbourne, FL

Office of Naval Research
Environmental Quality Program:
Benign Antifouling and Fouling Release Materials

N00014-09-1-0843, *N00014-11-1-0915, N00014-16-1-3050*
STTR N6833518C01471

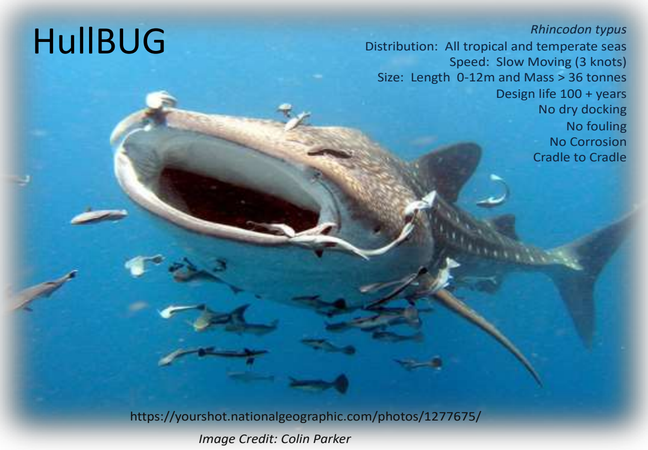


Image Credit: Colin Parker

Outline

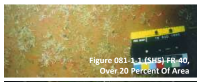
- Drivers
- Definition
- Test Facilities
- Grooming
- Cleaning
- Reality

Drivers

US Navy DDG-51 Frigate

Schultz, M. P. , Bendick, J. A. , Holm, E. R. and Hertel, W. M.(2011) 'Economic impact of biofouling on a naval surface ship', Biofouling, 27: 1, 87 — 98

- Navy ships spend 40-60% of their time pier-side when fouling pressure greatest.
- Criteria to trigger a full hull clean
  - 081-2.1.4 ABLATIVE AND SELF-POLISHING PAINTS Fouling of FR-40 or greater, over 20 percent of the hull, exclusive of docking block areas and appendages.
  - 081-2.1.5 FOULING RELEASE COATING SYSTEMS Fouling of FR-50 or greater is observed over 10 percent of a hull coated with a fouling release coating system contact NAVSEA Code 00C. Cleaning advice for ships coated with fouling release coating systems on a case basis.
- Primary costs of hull fouling is due to increased fuel consumption.
- Savings of $12M/ship over 15 years if hull condition maintained at FR-10 (deteriorated coating/light slime).



Drivers

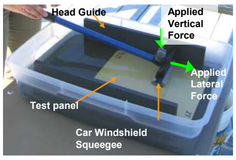
Is there a Better Way
to
Manage Biofouling?

The best way, it's simple, clean more often!
Wendy Simmons Oct 1, 2019

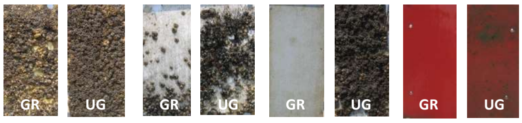
Grooming Concept (Dr Stephen McElvany)

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

Early Research

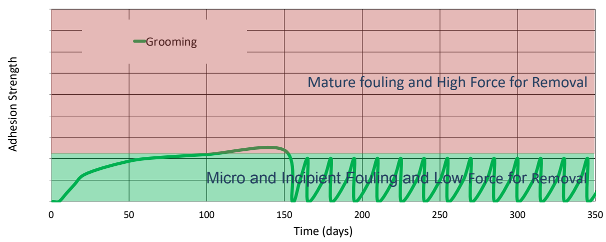


Epoxy	95% Barnacles
Teflon	25% Barnacles
Silicone	Biofilm
Copper	None

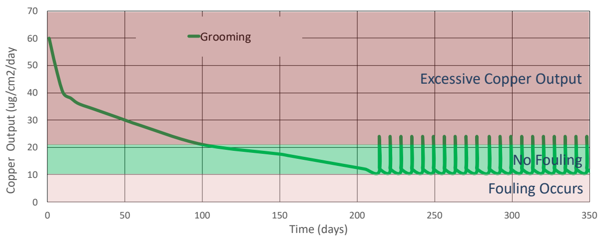


Tribou, M. and G. Swain. The use of proactive in-water grooming to improve the performance of ship hull antifouling coatings. Biofouling 26:1, 47-56 Jan 2010.

Grooming Mechanism Fouling Release

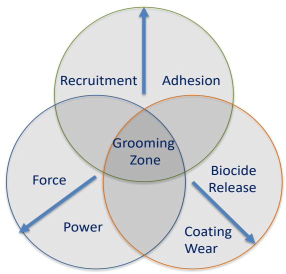


Grooming Mechanism Ablative Copper



Grooming Brush Development

Requirements



Variables

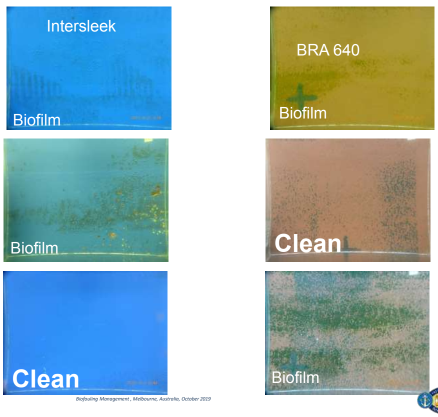
- Bristle type
  - Material
  - Bristle tip geometry
- Tuft design
  - Bristle diameter
  - Bristle length
  - Number of bristles
  - Packing factor
  - Composite
- Arrangement
  - Brush diameter
  - Tuft placement
  - Shroud
- Operation
  - Tip speed
  - Normal force
  - Translation rate

Brush Development

Standard Grooming Brush

Hybrid Grooming Brush

Fouling Release Grooming Brush

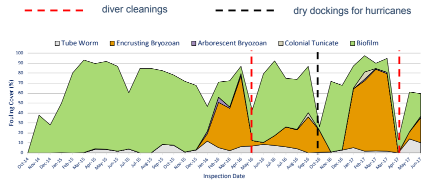


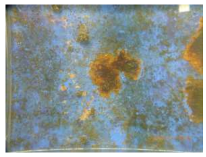
Large Scale Test Facility Port Canaveral 2012 – present

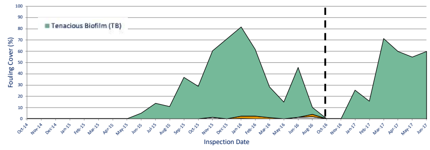
Method

- Three 8ft x 15ft Floating steel panels coated with
  - International Interspeed BRA640
  - Intersleek 1100
- Groomed with a remotely operated vehicle equipped with a grooming tool.
- DFTs and roughness measured yearly, and when dry docked for hurricanes
  - ~500 DFT measurements taken over whole surface, templates used to take repeat measurements in same locations
  - ~400 rt50 measurements taken over whole surface (TQC Hull Roughness Analyser)

Results Fouling Release

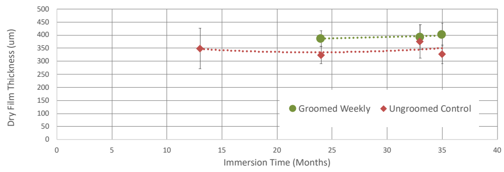




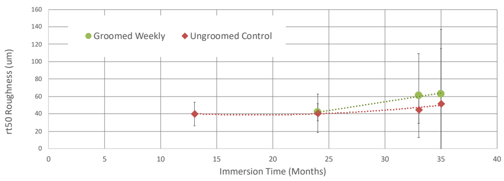


Results Fouling Release

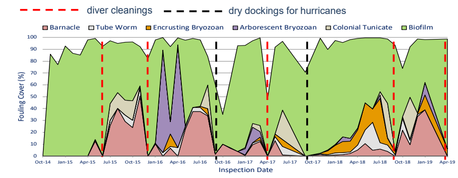
Dry Film Thickness

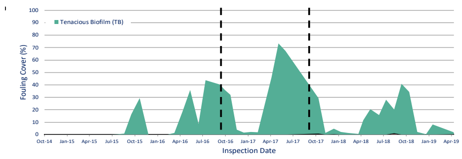


Coating Roughness



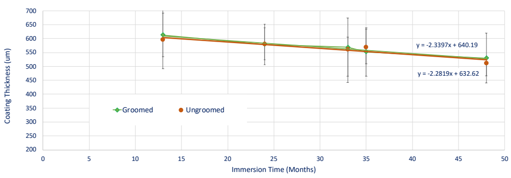
Results Ablative Copper



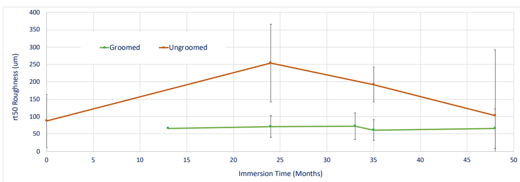


Results Ablative Copper

Dry Film Thickness



Coating Roughness



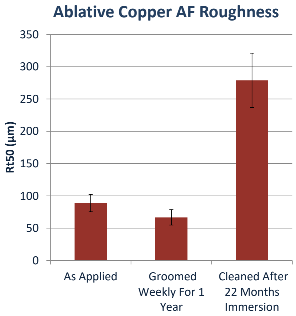
Results Cleaning Fouled Coatings

Interspeed Ablative Copper | Intersleek Fouling Release

Pre-cleaning

Aggressive Cleaning 4,000 to 28,000 µg/cm² ≡ 200 to 1,400 days at 20 µg/cm²/day

Grooming vs Cleaning

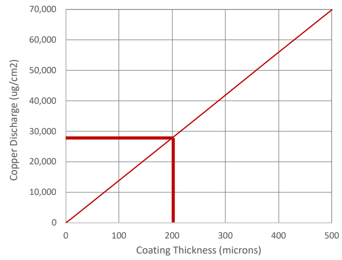


Copper Release Rate Calculations

ISO 10890
Paints and varnishes —Modelling of biocide release rate from antifouling paints by mass-balance calculation

$$M = L*a*w*\rho*DFT/NV$$

M = Mass Biocide Released (micrograms/cm2)
L = 100 (Percent Biocide Released)
a = 0.86 (mass fraction of biocide in biocidal ingredient)
w = 41.79 (% by mass content of biocide in paint)
ρ = 2.26 (density of paint g/cm3)
DFT = ?? (dry film thickness (um))
NV = 58.03 (volume solids content of paint)



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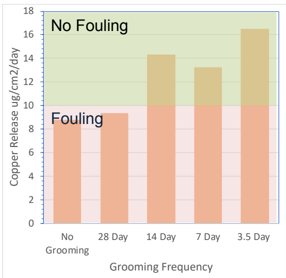
Biofouling Management, Melbourne, Australia, October 2019

Copper Release Rate Grooming vs Cleaning

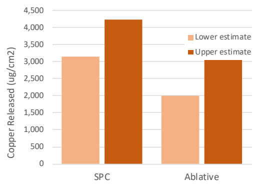
Grooming

CCBC Grooming Studies using changes in DFT and ISO 10890



Aggressive Cleaning

In-water cleaning of vessels: Biosecurity and chemical contamination risks. MPI Technical Paper No: 2013/11. Donald Morrisey, Jennifer Gadd, Mike Page, Oliver Floerl and Chris Woods, John Lewis, Andrew Bell, Eugene Georgiades



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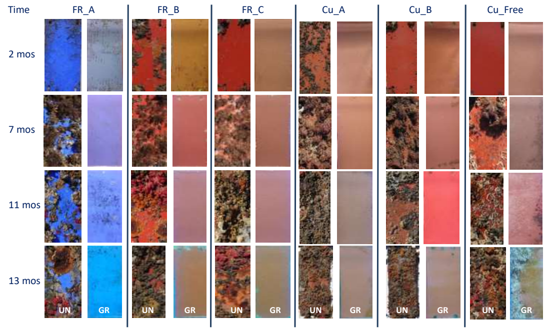
Grooming Other Coatings



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Summary

Grooming

Cleaning + Capture

Specifications	Grooming	Mini Pamper
Vehicle and Tool Weight (kg)	25	130
Power (W)	300	29,800
Cleaning Swath (m)	0.6	0.7
Cleaning Velocity (m/s)	0.2	0.7
Efficiency (%)	70	67.2
Grooming Rate (m2/min)	227	1,100
Time to groom DDG-51 (hrs)	13	2.7

- Proactive
- Gentle Grooming Tools
- No Divers
- No Fouling
- Coating Longevity
- Minimum Discharge
- Reduced GHG Emissions
- Prevents Invasive Species

- Reactive
- Powerful Brushes or Water Jets
- Divers Usually Required
- Fouling Penalty
- Coating Damage
- Treatment for Discharge
- Increased GHG Emissions
- Risk of Invasive Species

Center for Corrosion and Biofouling Control Florida Institute of Technology, Melbourne FL
Biofouling Management, Melbourne, Australia, October 2019

To Reality

Large scale testing has demonstrated that grooming can maintain fouling control coatings in a smooth and fouling free condition

Remaining Questions

- What is the optimum grooming frequency?
  - Requirements at different locations
  - Requirements for different operational schedules
  - Requirements for different coatings
- What is the optimum grooming tool design and operation?
  - Requirements for coating type
  - Priority areas of a ship

Center for Corrosion and Biofouling Control Florida Institute of Technology, Melbourne FL
Biofouling Management, Melbourne, Australia, October 2019

To Reality

GREENSEA

Small Business Technology Transfer *N6833518C01471*

Technical Advances to make Grooming Operational

- Hardening of grooming tool design
- Vehicle selection
- Incorporate Greensea OPENSEA navigation and control system
- Incorporate feature based navigation.
- Testing at ship scale

Regulations for discharge

ERIC HOLM
Research scientist
U.S. Navy's Naval Surface Warfare Center, USA

Eric Holm is a research scientist (ecologist) in the Corrosion and Coatings Technology branch at the U.S. Navy's Naval Surface Warfare Center – Carderock Division. He received his Ph.D. in Zoology from Duke University, where his research examined the ecology and genetics of settlement site choice of barnacles. He has more than 30 years of experience working with invertebrate biofouling organisms, in particular acorn barnacles and serpulid tubeworms. At the Naval Surface Warfare Center, Eric has been active in programs investigating the performance of antifouling and fouling-release hull coatings at both ship- scale and panel-scale including impacts on hydrodynamic drag, and the effects of hull cleaning tools on coating physical condition. His basic research includes investigations of the initial attachment and adhesion of biofouling organisms, and how they are influenced by material surface properties and genetics.

Development of a test apparatus and method of evaluating the impact of hull cleaning tools on coating wear and biocide release

Naval Surface Warfare Center, Carderock Division

Development of a Test Apparatus and Method for Evaluating the Impact of Hull Cleaning Tools on Coating Wear and Biocide Release

This brief is provided for information only and does not constitute a commitment on behalf of the U.S. Government to provide additional information on the program and/or sale of equipment or system. (NAVSEAINST 5230.12A)

NSWCCD: Elizabeth Haslbeck, Eric Holm, Kody Lieberman
NIWC: Patrick Earley, Ignacio Rivera

CAPT Cedric McNeal
Commanding Officer, NSWCCD

4th ANZPAC Workshop on Biofouling Management for Sustainable Shipping

Lawrence Tarasek, SES
Technical Director, NSWCCD

Biofouling Control

Primary means of control is by coatings

- Biocide-containing
  - Heavy metal biocides
  - Organic biocides
- Biocide-free
  - Fouling-release
- Hybrid coatings

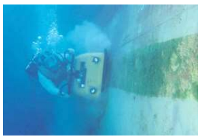
Problems:

- Regulatory concerns
  - Volatile organic content (VOC)
  - Biocide inputs
- Coating performance
  - Operational profile
  - Operational area
  - Niches

Hull Cleaning

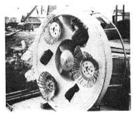
When the biofouling control coating fails, only option for restoring vessel performance may be to clean the hull:

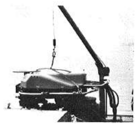
- In dry dock
  - Expensive
  - Time consuming
  - Possibly limited by dry dock availability
- In the water
  - Inexpensive
  - Quick



In-water Cleaning – the US Navy Experience

- 1970's and 1980's
  - Cleaning implemented to extend service life of vinyl copper-based coatings
    - Rotating brush tools
    - Removed cupric compounds (salts) from coating surface
    - Extended service life from 1-2 years to 3+ years
- 1980's and 1990's
  - Cleaning implemented to extend service life of ablative copper-based coatings
    - Rotating brush tools
    - Removed leached layer, reduced diffusion path length
    - Supported extension of intervals between dry-docking from 3-5 years to 5-7 years, and later to 8-12 years

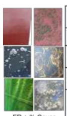




In-water Cleaning – the US Navy Experience

Hull cleaning practices

- Tools – primarily rotating brush (limited use of waterjets)
- Triggers for cleaning
  - Inspection and performance criteria
  - Ships have an opportunity for inspection as frequently as quarterly
    - Realized inspection frequency is twice per year
  - Decision to clean is based primarily on the fouling (rating) condition at the time of inspection
    - Antifouling coatings – fouling rating of 40 over 20% of the hull
    - Fouling-release coatings – fouling rating of 50 over 10% of the hull



Fouling Rating	Organisms
10-20	Slime/diatom
30	Soft macrofouling
40-50	Small calcareous
60-100	Larger forms and/or mixed forms

FR + % Cover

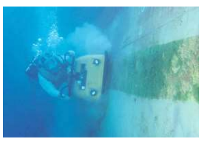
In-water Hull Cleaning – Costs and Benefits

Benefits of in-water hull cleaning

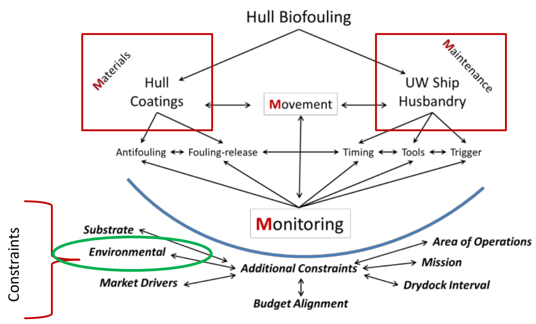
- Exceptionally cost-effective means of restoring vessel operating efficiency
- Can restore efficacy of biofouling-control coating

Unintended consequences of in-water hull cleaning

- Discharge of paint components (biocides, particulates)
- Impact on coating integrity/efficacy/service life (paint thickness, surface properties)
- Release of attached biofouling
- Regulatory scrutiny



Finding the Right Solution



Knowledge and Capability Gaps

- We currently lack the comprehensive understanding of the impact of in-water cleaning necessary to support development of regulations, or compliant devices or practices, that balance benefits, impact on coatings, and environmental inputs
  - Environmental inputs
    - Chemical
    - Biological
  - Impact on coatings
    - Thickness
    - Damage
    - Subsequent efficacy
  - As affected by the type of coating – antifouling vs. fouling-release vs. hybrid
  - As affected by the type of cleaning tool – contact vs. non-contact
  - As affected by the cleaning strategy – reactive vs. proactive

A standard method is needed for efficiently testing cleaning tools, and measuring their impacts and environmental inputs.

Options for Testing

Existing standard methods are not directly applicable.

https://www.elcometer.com/en/physical-test-equipment/washability-abrasion/elcometer-1720-abrasion-and-washability-tester.html

- Elcometer Washability Tester
  - ASTM D2486, D4828, D4213, D3450
  - DIN methods
  - ISO methods
- Advantage: High quality data, reproducible
- Disadvantages:
  - Focus is architectural and not biofouling control coatings
  - Adaptation of relevant cleaning tools is limited at best
  - No ability to measure environmental inputs

Options for Testing

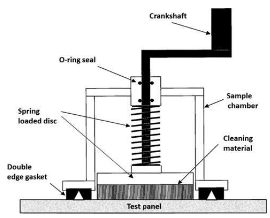
- Non-standard methods
  - **On-ship evaluation**
  - Quantify decrease in paint thickness with various cleaning tools
  - Advantage: Application of full-scale tool
  - Disadvantages:
    - Limited ability to resolve small changes in paint thickness
    - Limited ability to measure environmental inputs
    - High risk to ship (possibility of coating failure)

Options for Testing

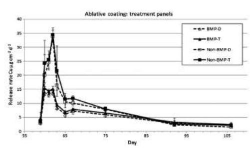
- Non-standard methods
  - **Panel tests** - coated panels mounted in a raceway
  - Advantages:
    - Application of full-scale tool
    - High data quality
    - No risk to a ship
  - Disadvantages:
    - High cost
    - Limited ability to measure environmental inputs

Options for Testing

- Non-standard methods
  - **In-water hull cleaning sampling device (Earley et al., 2014)**
  - Quantify inputs of biocides following 'surface refreshment'
  - Advantages:
    - Addresses biocide inputs
    - Mimics simple, hand-held cleaning tools used on small craft by divers
  - Disadvantages:
    - Does not replicate full-scale cleaning tools used on large vessels
    - Not focused on impacts to the coatings



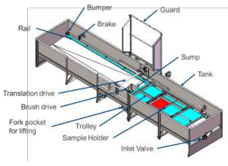
Earley et al. (2014) Biofouling 30:51–68

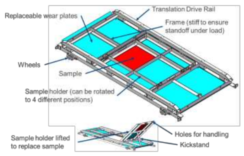


Standardized Device and Method

In order to address weaknesses of other methods, we are developing a device and standard process to evaluate the impact of in-water cleaning tools on hull paints, and associated biocide inputs.

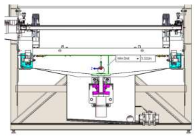
- Cleaning tools applied to test surfaces (painted panels) in such a way as to match operational characteristics as used in field – transit speed, rotation rate, normal force
- Materials chosen to minimize introduction of chemicals into sample water that may interfere with measurement of biocides or other paint components
- 20+ detailed design requirements including logging of operational parameters (brush rotation rate, translation rate, torque); designed for easy swapping of cleaning brushes and hydraulic motors

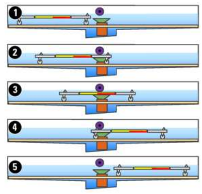




Standardized Device and Method

- Single pass of coated test panel over cleaning tool
  - Cleaning head is adaptable to multiple tools types
  - Currently configured to handle brushes
  - 7 brushes in initial test (USN qualified)
- Quantify changes in paint thickness or surface properties
- Captured volume of water, subsample for follow-on water quality analysis
  - Dissolved metals
  - Particulate matter
  - Copper, zinc (currently)
- Currently no analysis of biological inputs
  - Would require waiting for antifouling coatings to foul or use of inert substrate





Conclusions

- In-water hull cleaning is a cost-effective means of restoring coating and ship performance
  - Regulators are challenged – regulations on coatings may conflict with regulations on cleaning, need to find appropriate balance between benefits and costs
- In-water cleaning impacts coatings
  - There is a poor quantitative understanding of these impacts
    - Paint thickness and coating system service life
    - Environmental inputs
  - Improved understanding may aid regulators, technology developers, and end users
- A standardized tool and method may help inform the problem
- Could use to evaluate inputs of biological material into the environment
  - Efficacy and post-cleaning survival
  - Impact on BoD

Acknowledgements

- Sponsored by US DoD Environmental Security Technology Certification Program (ESTCP)
- Thanks to our collaborators: Derek Michelin (Battelle), Nathan Gabriel (Battelle), Chris Baer (Battelle)

Thank You!

Questions?

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Biofouling Control

Commerce

Defense

Drivers:

- Hull preservation
  - Corrosion
- Efficiency
  - Cost of operations
  - Profit
- Operational efficacy
  - Speed
  - Range
  - Refueling frequency
  - Signature
- Other
  - Environmental regulations
  - Interval between dry-docking

In-water Cleaning is Subject to Regulation

Hull Husbandry - USA	IMO	US EPA	CALIF	ME#	MASS#	Class SOC.^
Out-of-water Hull Maintenance		Y	Y		Y	Y
Underwater Hull Cleaning	Y*	Y*	Y@	Y	Y	Y
Underwater Cleaning – Sea Chest and Niche Areas	Y					
Propeller Polishing	Y		Y			
Anchor Chain Washing/Rinsing		Y				

* Remove macrofouling growth. Minimize release of biocides, coating debris, and viable macrofouling. @ California does not allow cleaning of copper-based antifouling coatings in impaired waters
^ Class Societies: applies to merchant fleet
# Maine (ME), Massachusetts – State Vessel General Permit 401 certification
Maine: prohibits in-water hull cleaning
Massachusetts: Prohibits discharges associated with in-water cleaning (specifically removal of biofouling) in waters within 3 nm

- Other regulations
  - International
  - National
  - Regional

Adapted from: USEPA, 800-R-11-004, November 2011, Underwater Ship Husbandry Discharges

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Chemical Compositions and Toxicity Potentials of Antifouling Biocides released during Ship's Hull Cleaning

Uncontrolled release of the effluent generated during ship's hull cleaning as a biofouling measure can be of great concern to the environment. As a worst-case scenario of the release, wastewater from ship's haul-out cleaning by hydroblasting was collected and analyzed to understand the potential impacts of the release to the marine environment. Metals and booster biocides in the effluents from three ships covering from regional to oceanic voyages were analyzed. Total suspended solids and particle size distribution in the wastewater were also characterized. Copper and zinc were the most abundant metals in the wastewater, with the ranges of 6.24 – 87.4 ppm and 78.3 – 511 ppm as total concentrations, respectively. Dissolved copper and zinc concentrations ranged from 1.44 to 9.11 ppm and from 1.80 to 22.6 ppm, respectively, exceeding local regulatory discharge standards and NOEC or LC50 values of almost all test species reported in the ECOTOX database. Zinc pyrithione and copper pyrithione were the most abundant booster biocides, exceeding the LC50s of 35 – 60% of test species, based on the database. Particle size distributions differ among hull cleaning cases, with most particles in the size range of less than 50 μm. Risk assessment based on the MAMPEC revealed that adverse effects on the marine environment are expected by the release of the wastewater without further treatments. The results were also compared with those acquired during in-water cleaning operations by divers for the same vessels. These chemical and toxicological characterizations of wastewater from ship's hull cleaning will give insights to the biofouling management in terms of chemical hazard concerns.

1st GEF-UNDP-IMO GloFouling R&D Forum
Melbourne, Australia, 1-4 October 2019

Chemical Compositions and Toxicity Potentials of Antifouling Biocides released during Ship's Hull Cleaning – Case studies

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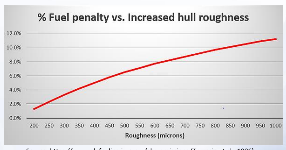
Introduction

Vessel biofouling

The issues
- One of the main vectors for the transfer of Invasive aquatic species
- Increased drag & more fuel consumption
- GHG emission

Photo source: University of California West Coast Ballast Outreach (Steve Mercer)

Measures
Hull cleaning (haul-out or in-water)
- Biosecurity risk mitigation
- Improved vessel fuel efficiency



Source: https://www.glofouling.imo.org/ghg-emissions (Townsin et al., 1986)

Concerns
- Biosecurity risk
- Water quality degradation (metals, booster biocides, paint particles, ……)

Objectives

To understand possible risk to the marine environment brought by ships' hull cleaning

- To determine metal, booster biocide, suspended solid concentrations in the effluents discharged during ships' hull cleaning
- To characterize particle size distribution in the wastewater effluent
- To determine toxicity of the whole effluents
- To predict environmental concentration of active ingredients and characterize risks

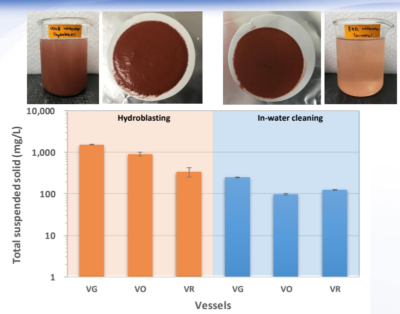
Materials and methods

Vessels	Length (m)	Tonnage	Coverage	Major AF composition
Vessel G (VG)	99.8	5,894	Global	
Vessel O (VO)	63.8	1,370	Oceanic	
Vessel R (VR)	49.0	357	Regional	

Materials and methods_In-water cleaning

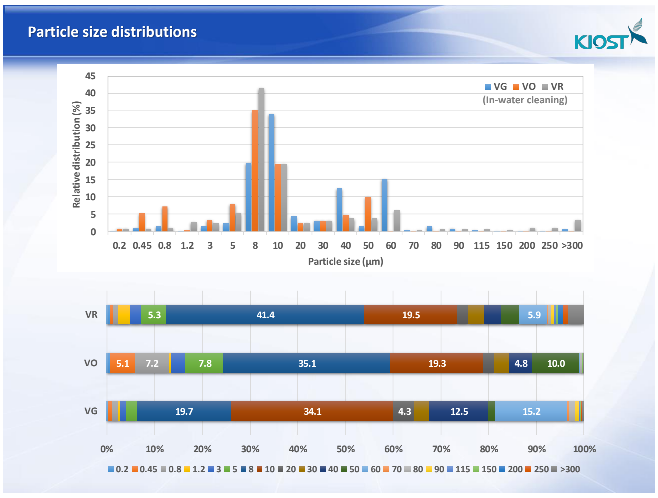
Materials and methods_Haul-out hydroblasting

Results – Total suspended solids

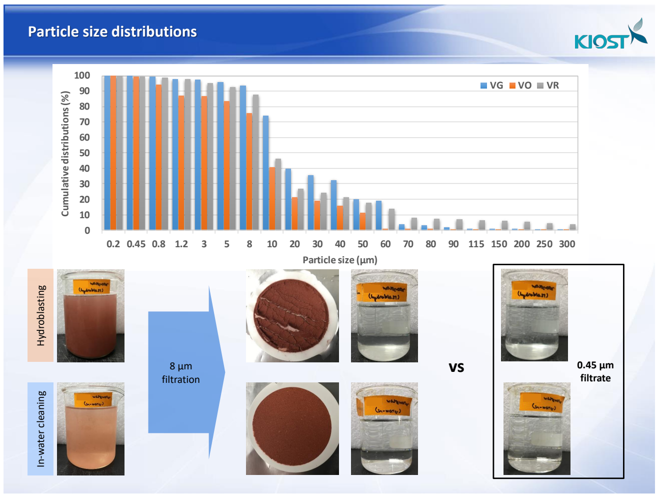


	VG	VO	VR	VG	VO	VR	
Total volume (L)	192,500	22,500	6,000	226	199	209	Total sample (L)
				1.5	1.5	1.5	Area cleaned (m²)
				3850	450	120	Hull area (m²)
Total emission (kg)	297	20.6	2.0	145	5.8	2.1	Total emission (kg)

Particle size distributions

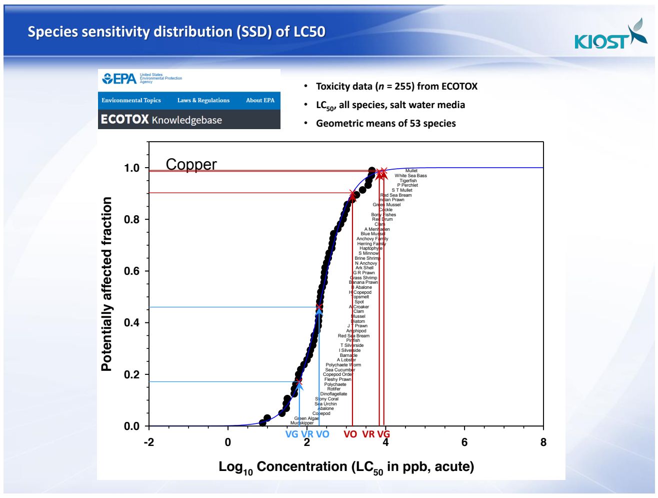


Particle size distributions

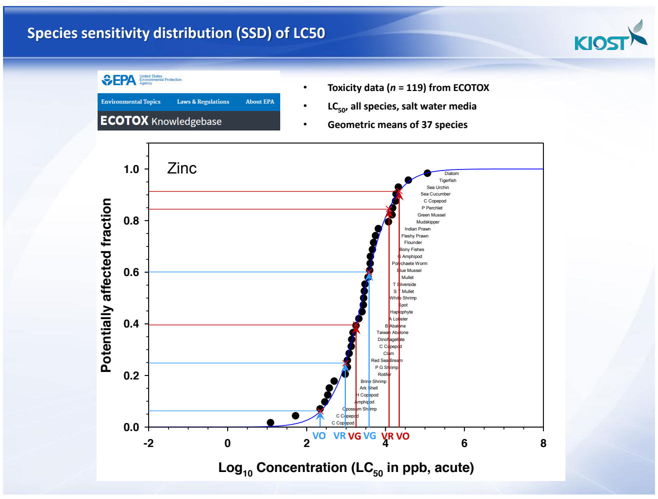


Metal concentrations - dissolved

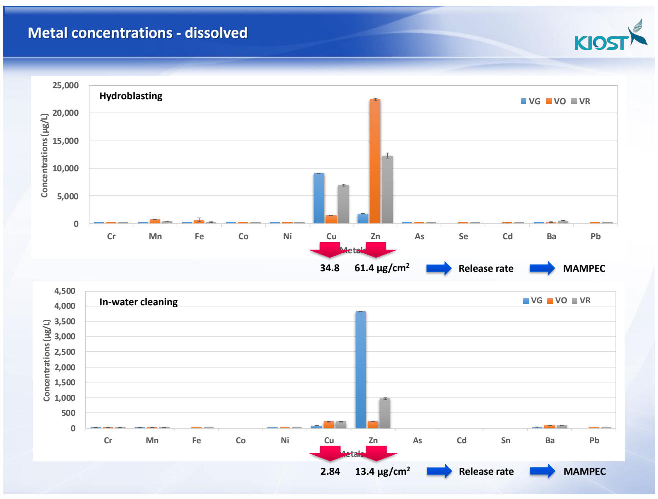
Species sensitivity distribution (SSD) of LC50



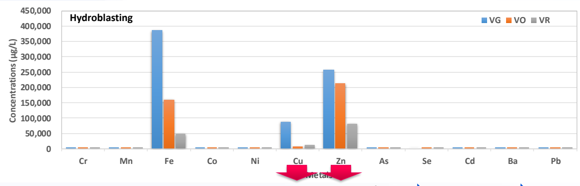
Species sensitivity distribution (SSD) of LC50



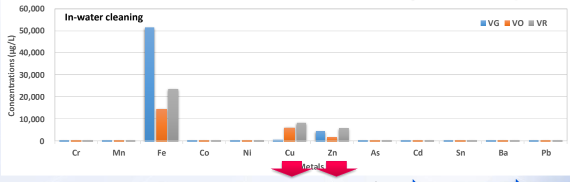
Metal concentrations - dissolved



Total metal concentrations – dissolved + particulate

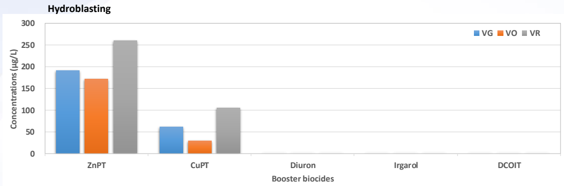


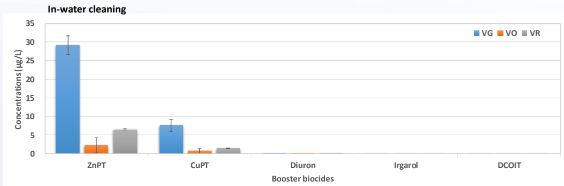
57.5 404 µg/cm² → Release rate → MAMPEC



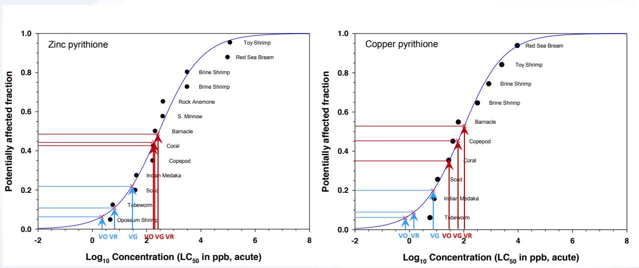
115 79.6 µg/cm² → Release rate → MAMPEC

Booster biocides



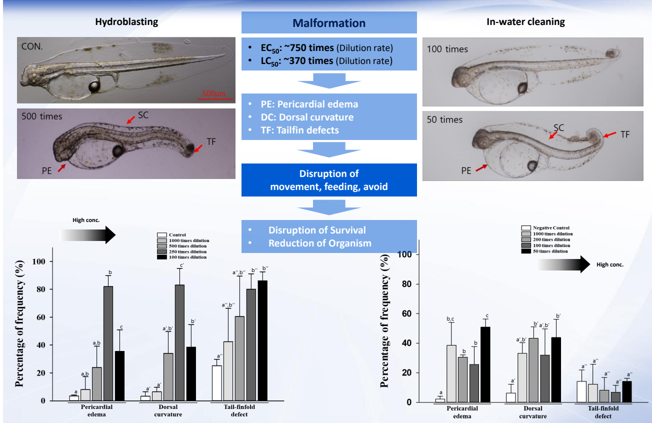


Species sensitivity distribution (SSD) of LC50



EPA ECOTOX Knowledgebase

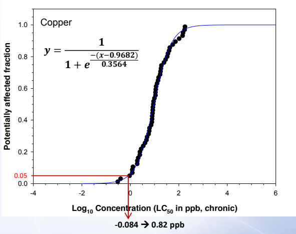
Toxicity - Morphogenesis



Risk Assessment (Cu - preliminary)

Hazard assessment (Representation of PNEC)

- ✓ LC_{50} data (n = 255) from ECOTOX
- ✓ Geometric means of the species (*n* = 53)
- ✓ Conversion of acute values to chronic
- ✓ Species Sensitivity Distribution (SSD) and HC_5 calculation
  - HC_5: Hazardous Concentration for 5% of species, 0.82 ppb Cu from SSD
- ✓ PNEC = HC_5 / AF = 0.82 / 1 = 0.82 (ppb)
  - PNEC: Predicted No Effect Concentration
  - AF: Assessment Factor = 1

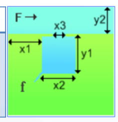


Risk Assessment (Cu - preliminary)

Exposure assessment (Calculation of PEC; predicted environmental concentration)

- ✓ Calculation of PEC by MAMPEC 3.1 (Marine Antifoulant Model to Predict Environmental Concentrations)
- ✓ Environment: OECD-EU Commercial harbor
- ✓ Compound: Copper
- ✓ Emission: OECD-EU Commercial harbor

Hydrodynamics	Water characteristics	Layout & General
Tidal period 12.41 hr Tidal difference 1.5 m Max density difference tide 0.4 g/m³ Flow velocity (F) 1 m/s	SPM concentration 35 mg/L POC concentration 1 mg/L DOC concentration 2 mg/L Chlorophyll 3 µg/L Salinity 34 Temperature 15°C pH 7.5	x1 1000 m, x2 5000 m, x3 2500 m y1 1000 m, y2 500 m Depth 15 m Latitude 50°NH Cloud coverage 5 class

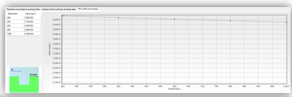


Sediment	Calculated Exchange volumes	Compound	Emission
Depth mixed layer 0.2 m Sediment density 1000 kg/m³ Net sedimentation velocity 1 m/d Fraction organic carbon 2.85E-2	Tidal 7.5E+6 m³/tide Horizontal 9.166E+6 m³/tide Density induced 3.452E+7 m³/tide Total 5.119E+7 m³/tide 68.25 %/tide	Copper, 63.546 g/mol Solubility at 20°C 0.001 g/m³ K_d 58.2 m³/kg Zinc, 65.39 g/mol Solubility at 20°C 1.00 g/m³ K_d 126 m³/kg	**Release rate (dissolved) during hull cleaning: 35 µg/cm²/day** Ship: length class 100-150 m, surface area 3231 m², one hull cleaning per day

Risk Assessment (Cu - preliminary)

✓ PEC (Predicted Environmental Concentration)

Run name	Hydroblasting - Cu
Environment	OECD-EU Commercial harbour
Compound	Copper -- (imported 2018-06-16)
Emission	OECD-EU Commercial Harbour
Load	1125.0342 g/d



Predicted concentrations at steady state | Analysis of fate and fluxes at steady state | PEC profile surroundings

Harbour

	Total conc.	Freely dissolved	Suspended matter	Sediment after 1 Year	Sediment after 2 Years	Sediment after 5 Years	Sediment after 10 Years
Maximum concentration	3.82E-002 ug/l	1.26E-002 ug/l	7.33E-001 μg/g dw	4.53E-002 μg/g dw	8.79E-002 μg/g dw	2.00E-001 μg/g dw	3.46E-001 μg/g dw
95 % concentration	3.79E-002 ug/l	1.25E-002 ug/l	7.27E-001 μg/g dw	4.50E-002 μg/g dw	8.72E-002 μg/g dw	1.99E-001 μg/g dw	3.43E-001 μg/g dw
Average concentration	2.05E-002 ug/l	6.76E-003 ug/l	3.94E-001 μg/g dw	2.44E-002 μg/g dw	4.72E-002 μg/g dw	1.08E-001 μg/g dw	1.86E-001 μg/g dw
Median concentration	2.05E-002 ug/l	6.74E-003 ug/l	3.92E-001 μg/g dw	2.43E-002 μg/g dw	4.70E-002 μg/g dw	1.07E-001 μg/g dw	1.85E-001 μg/g dw
Minimum concentration	2.35E-003 ug/l	7.75E-004 ug/l	4.51E-002 μg/g dw	2.79E-003 μg/g dw	5.41E-003 μg/g dw	1.23E-002 μg/g dw	2.13E-002 μg/g dw

Surroundings

	Total conc.	Freely dissolved	Suspended matter	Sediment after 1 Year	Sediment after 2 Years	Sediment after 5 Years	Sediment after 10 Years
Maximum concentration	2.80E-003 ug/l	9.20E-004 ug/l	5.36E-002 μg/g dw	3.31E-003 μg/g dw	6.42E-003 μg/g dw	1.46E-002 μg/g dw	2.53E-002 μg/g dw
95 % concentration	2.72E-003 ug/l	8.97E-004 ug/l	5.22E-002 μg/g dw	3.23E-003 μg/g dw	6.26E-003 μg/g dw	1.43E-002 μg/g dw	2.46E-002 μg/g dw
Average concentration	8.63E-004 ug/l	2.84E-004 ug/l	1.65E-002 μg/g dw	1.02E-003 μg/g dw	1.98E-003 μg/g dw	4.52E-003 μg/g dw	7.81E-003 μg/g dw
Median concentration	4.25E-004 ug/l	1.40E-004 ug/l	8.14E-003 μg/g dw	5.04E-004 μg/g dw	9.77E-004 μg/g dw	2.23E-003 μg/g dw	3.84E-003 μg/g dw
Minimum concentration	4.69E-013 ug/l	1.55E-013 ug/l	9.00E-012 μg/g dw	5.57E-013 μg/g dw	1.08E-012 μg/g dw	2.46E-012 μg/g dw	4.25E-012 μg/g dw

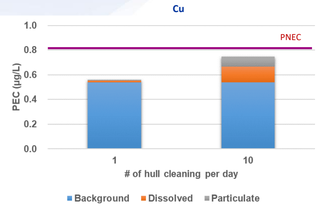
Predicted concentrations at steady state | Analysis of fate and fluxes at steady state | PEC profile surroundings

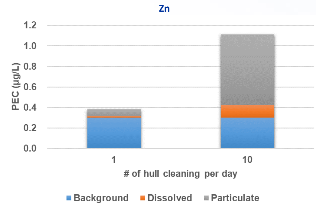
Harbour

Description	Flux	Percentage
Emission	1.13E+003 g/d	100.00 %
- Hydrodynamic Exchange	1.06E+003 g/d	93.86 %
- Hydrolysis	0.00E+000 g/d	0.00 %
- Photolysis	0.00E+000 g/d	0.00 %
- Biodegradation	0.00E+000 g/d	0.00 %
- Sedimentation	6.90E+001 g/d	6.14 %
- Volatilisation	0.00E+000 g/d	0.00 %

Risk Assessment – PEC (predicted environmental concentration)

✓ Hydroblasting





※ Background: OECD-EU default emission scenario

PEC / PNEC = 0.75 / 0.82 = 0.91 < 1

PEC / PNEC = 1.11 / 4.97 = 0.22 < 1

RCR (risk characterization ratios) = Σ PEC / PNEC = 0.91 + 0.22 + …… > 1

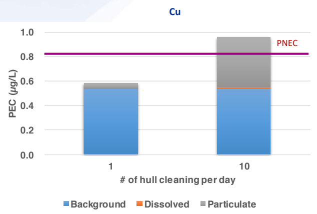
Risk characterization

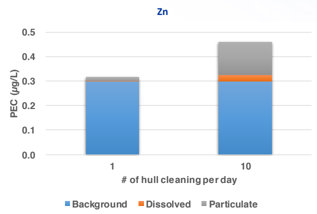
✓ PEC / PNEC ≥ 1: possible risk to the marine environment

✓ PEC / PNEC < 1: low risk to the marine environment

Risk Assessment – PEC (predicted environmental concentration)

✓ In-water cleaning





※ Background: OECD-EU default emission scenario

PEC / PNEC = 0.95 / 0.82 = 1.16

PEC / PNEC = 0.46 / 4.97 = 0.09

RCR (risk characterization ratios) = Σ PEC / PNEC = 1.16 + 0.09 + …… > 1

Summary and conclusions

- Wastewater generated during hull cleaning was highly contaminated with metals and booster biocides at toxic levels of concern.
- Particle size distributions: generally, 8 – 10 μm size fraction consists of the majority of the particles.
- A single hull cleaning seems not to clearly damage marine environment but the number of cleaning should be regulated based on the risk assessment, considering background concentrations, vessel size, and release rate from the cleanings…….
- It is expected that wastewater discharged into the water column without further treatment will affect the marine environment depending on the strength of hull cleaning activities.

Limitations and challenges

- Just a number of case studies. More systematic approach and extensive studies are needed to clearly understand the risk brought by hull cleaning activities.
- There are so many factors, variables, and variabilities to be considered (paint types, ages, conditions, fouling conditions, cleaning method/tool, environmental factors, etc).
- Uncertainty of input data. More accurate numbers and factors are needed to better estimate environmental concentrations and risks.

Acknowledgements

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KOREA INSTITUTE OF OCEAN SCIENCE & TECHNOLOGY

Captains and crews of Vessel VG, VO, & VR

Research Team
Risk Assessment Research Center, KIOST
Ballast Water Research Center, KIOST


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Dr. Mario Tamburri received a Bachelor's degree from University of California Santa Barbara, a Master's degree fromUniversity of Alabama, and a Ph.D. from the University of South Carolina in biology and marine science. His basic science research focuses on how chemical cues regulate basic biological and ecological processes of aquatic organisms, including larval settlement. Dr. Tamburri has worked inenvironments ranging from estuaries to the deep sea. Recently, he has focused much of his work on new innovations to address environmental problems from climate change toinvasive species.

Dr. Tamburri is now a Professor at theChesapeake Biological Laboratory, University of Maryland Center for Environmental Science, and Director two environmental innovation programs, the Alliance for Coastal Technologies (ACT) and the Maritime Environmental Resource Center (MERC). ACT is a NOAA- and EPA-funded effort dedicated to fostering the development and adoption of effectiveand reliable sensors andplatforms for studying and monitoring coastal, ocean and freshwater environments. Similarly, MERC is a State of Maryland and US Maritime Administration initiative that provides test facilities, expertise, information, technologies, and decision tools to address key environmental issues facing the international maritime industry. Dr. Tamburri has published nearly 100 peer- reviewed publications, technical reports and book chapters and has severed on multiple national and international scientific committees, including: an Ocean Studies Board on Ocean Infrastructure at the National Academies; a working group member of the US EPA Science Advisory Board, International Council for the Exploration of the Sea (ICES) and International Organization for Standardization (ISO); and a founding member of Global TestNet.

Exploring vessel in-water cleaning as a source of ocean microplastics

In-water removal of vessel biofouling has long been employed to increase ship in-service efficiencies and new innovations in clean and capture technologies show promise to both address vessel operational needs and biosecurity risks. While it has long been recognized that in-water vessel cleaning must avoid or minimize the release of coating biocides (e.g., copper and zinc) to the environment, to date, the release of microplastics has received little attention. Ocean microplastic pollution is a significant international environmental concern, yet a large proportion of anticorrosive and antifouling marine coatings employ microplastics as binders. These binding agents (e.g., cellulose ester, thermoplastic alkyl resins, and polyurethane) often represent approximately 40% of the coatings and it is estimated that over 450 ktons of microplastics per year are used in marine coatings worldwide. While microplastics are released from commercial ships and recreational boats during normal operations and use, the expansion of in-water cleaning to minimize the potential for transporting invasive species may also have the unintended consequence of increasing ocean microplastics pollution. In-water cleaning operations are also typically conducted in ports or nearshore anchorage areas, resulting in potentially more serious localized microplastic pollution (compared to the slow, distributed wearing of coatings). Our presentation will focus on a description of the problem and our new experimental approach to assessing the potential release of microplastics as a result of vessel in-water biofouling cleaning.

Exploring In-Water Cleaning as a Source of Ocean Microplastics

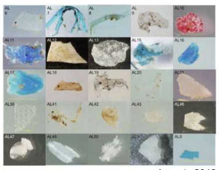
Mario Tamburri – UMCES, ACT and MERC
Greg Ziegler – UMD WREC
Katherine Davis – UMCES, ACT and MERC
Lance Yonkos – UMD

Ocean Plastics Pollution

- Plastics are one or more high molecular mass polymers formed in manufacture of the polymer or fabrication into a product (MARPOL, MEPC74.WP10)
- Widely recognized significant global environment concern
- Between 4 and 12 million metric tons of plastic enter the ocean each year
- Plastics can include or absorb toxic compounds and are entering the food web of marine systems
- Slow breakdown, on the scale of hundreds to thousands of years
- Discharging plastics from ships into the sea is prohibited under MARPOL, IMO and Administrations are considering further actions

Ocean Microplastics

- Particles < 5 mm (generally accepted)
- Greater biological availability
- Two main ways microplastics are formed and enter the ocean
  - Secondary: degradation (mechanical, photo and/or biological) of larger pieces into smaller fragments
  - Primary: manufactured pellets/ microbeads for personal care products (terrestrial), fibers (terrestrial) and <u>coating binding agents (marine)</u>



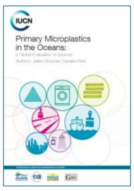
Laverty 2018

In-Water Cleaning and Microplastics

- Current vessel hull husbandry based on antifouling coatings (biocide and non-stick/fouling release) and in-water cleaning
- ~ 40% of most marine coatings are microplastics as binding agents (e.g., cellulose ester, thermoplastic alkyl resins, and polyurethane) with over 450 ktons per year of microplastics used worldwide
- The polymeric backbone as binding agents of biocidal coatings are designed to release biocide by dissolution/erosion (free-association paints), hydrolysis reaction with seawater (self-polishing coatings) or a combination (hybrid)

In-Water Cleaning and Microplastics

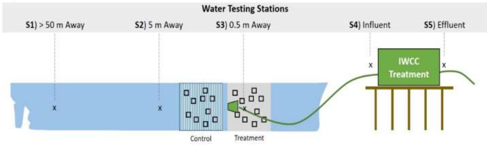
- IUCN (2017) reports that marine coatings account for 3.7% of releases of primary microplastics in the world oceans
- IMO (2019 and others) report 6 to 7% of marine coating lost directly to the sea during lifetime of a vessel and little is know about in-water cleaning impacts
- Scianni and Georglades (2019) describe the in-water cleaning continuum from removal to prevention of biofouling, using divers or ROVs, applying brushes or water jets, and some with debris capture and treatment
- While microplastics are released from vessel during normal operations, which may be a relatively small direct source of microplastics, the expansion of in-water cleaning may significantly increase localized microplastics pollution



In-Water Cleaning and Microplastics

- Evaluations of in-water cleaning systems
  - How well do they clean?
  - How well do they reduce biosecurity risks?
  - How well do they reduce <u>water quality risks</u>?

Water Quality Sampling for Evaluations of In-Water Systems



- Copper, zinc, or biocide of concern
- TSS and PSD
- <u>Microplastics</u>

Water Quality Sampling for Evaluations of In-Water Systems

- Continuous, time-integrated sampling during cleaning
- Discrete, replicate sampling one day before, one hour before, one hour after and one day after for variability in ambient background conditions
- Additional samples of local <u>surface waters</u> and <u>sediments</u>
- Sample volumes of minimum 4 liters, in glass containers

Quantifying and Characterizing Microplastics

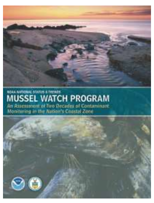
- Yonkos et al. 2014; Masura et al. 2015
- Microplastics sample processing:
  - Water samples are filtered to concentrate the solid material
  - Captured material is dried and treated to digest and eliminate biota and particulate organic matter
  - Density separation (floatation) is used to isolate plastic from other inorganic solids
- Microplastics sample analyses:
  - Particle sizes and shapes (fragments, fibers, films, etc) can be quantified microscopically and concentrations reported as microplastics per volume (water) or mass (sediment)
  - The molecular composition of plastic polymers can be determined using a variety of methods (e.g., C:H:N analysis, gas chromatography and mass spectrometry, Raman spectroscopy, and Fourier-transform infrared spectroscopy)

Quantifying and Characterizing Microplastics

- For evaluations of in-water cleaning systems, we propose:
  1. Documentation of coating type(s) and associated microplastics (coordination with vessel and coating companies)
  2. Water and sediment samples will be filtered to ≤ 50 µm
  3. Captured solid material will be digested by wet peroxide treatment (≤ 30% H_2O_2)
  4. Density separation will be used to separate plastics from other inorganic solids by immersion in a hypersaline brine solution (density 1.3 mg/mL) or $ZnCl_2$ solution (density 1.7 mg/mL)
  5. Plastic shapes will be determined by microscopic assessment and size distribution will be characterized by digital microscopy using ImageJ software
  6. Molecular composition of plastic polymers will be determined by micro-Raman or micro-FTIS spectroscopy and compared to know coating binding agents

Long-Term In-Water Cleaning Monitoring

- Periodic measure of ambient water quality in locations of in-water cleaning activities to monitor for possible increases of coating biocides and microplastics (likely permitting requirement)
- Establish Mussel Watch Program in locations with and without in-water cleaning operations to monitor of bioaccumulations of coating biocides and microplastics (e.g., NOAA's National Center for Coastal Ocean Science)



Summary

- Ocean plastic pollution is a critical global environmental concern
- While microplastics release from marine coatings makes up a small percentage of the total plastics entering the oceans, it is still as significant source
- In-water cleaning is a rare example of new innovations to address a significant market need (*reduce ship fuel consumption*) that can also directly help address a critical global environmental need (*prevention of invasive species*)
- In-water cleaning itself must also not cause harm to the environment
- Rigorous, standardized and independent testing of in-water cleaning systems is needed to ensure environmental safety and should include direct measure of microplastics releases in areas of operation

Acknowledgements

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  - Mario Tamburri, ACT/MERC/CBL
  - Matt First, US NRL
  - Greg Ruiz, SERC
  - Chris Scianni, CSLC
  - Ian Davidson, SERC
  - Jules Kuo, Hawaii DLNR
  - Plus technical staff, QA/QC, analytical services, etc.
- **Technical Advisory Committee:**
  - William Hertel, US NSWCC
  - Eugene Georgiades, MPI New Zealand
  - Graeme Inglis, NIWAR New Zealand
  - Carolyn Junemann, MARAD
  - David Elias, RWQCB San Francisco
  - Regina Bergner, USCG
  - Myron Honda, Hawaii DLNR
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  - Jesús Cisneros-Aguirre, University of Las Palmas, Spain
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  - Maryland Port Administration (MD DOT)
  - US Maritime Administration (MARAD)
  - California State Lands Commission (CSLC)

MARTY DEVENEY
Subprogram Leader, Marine Biosecurity
SARDI Aquatic Sciences, Australia

Marty Deveney is Subprogram Leader, Marine Biosecurity at SARDI Aquatic Sciences. He has been working in marine biosecurity for over 20 years, and has, since 2007, been running one of the few labs worldwide that integrates marine invasive species and disease biosecurity. His group has developed novel environmental testing technologies for detection of pests and pathogens, and has led the technical components of responses to aquatic pest incursions and disease outbreaks.

Vessel biofouling as a route for transmission of pathogens

Marty R. Deveney[1], Kathryn H. Wiltshire[1], Jessica J. Buss[1,2], Y N. Lieu[1,2], James O. Harris[2], Peter G. Mohr[3], Nicholas J.G. Moody[3], Matthew S. Bansemer[4], Shane D. Roberts[4], Kevin A. Ellard[5].

[1]South Australian Research and Development Institute (SARDI) Aquatic Sciences, SA [2]College of Science and Engineering, Flinders University, SA
[3]CSIRO Australian Animal Health Laboratory, Geelong, VIC
[4]PIRSA Fisheries and Aquaculture, SA
[5]Department of Primary Industries, Parks, Water and Environment, TAS

The contribution of biofouling communities on vessels as vectors for aquatic diseases has long been suspected but few data are available to understand relative risk. Some important shellfish pathogens have broad, discontinuous ranges that are not linked oceanographically and have no mechanism other than shipping that could parsimoniously be responsible for their distribution. The recent detections of OsHV-1 microvariant and *Bonamia ostreae* in the Southern Hemisphere suggest strongly that vessel biofouling can translocate diseases, particularly in areas where vessels, susceptible hosts and human activities such as fishing and aquaculture are co-located.

Following detections of OsHV-1 microvariant in the Port of Hobart prior to outbreaks in commercial oyster farms in Tasmania, in biofouling from a construction barge towed from Sydney Harbour to Port Adelaide and of *Bonamia* in biofouling from several vessels, we surveyed biofouling for these pathogens. Detections were common and prevalence and intensity indicate that biofouling is carrying infectious loads of these important pathogens.

SARDI

Vessel biofouling as a route of transmission for pathogens

Marty Deveney
ANZPAC Workshop on Biofouling Management for Sustainable Shipping
4 October 2019, Melbourne Conference and Exhibition Centre

On every new thing there lies already the shadow of annihilation

W.G. Sebald 'The Rings of Saturn'

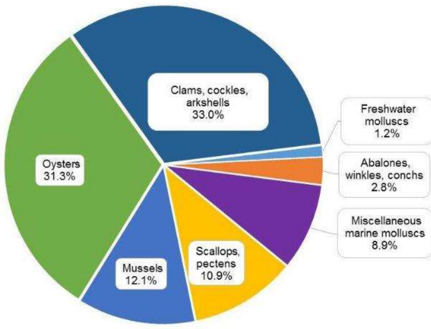
Molluscs

- Economically, socially (nutritionally), environmentally important
- Huge production – 15.2 million T/year (2014)
- Massive value - $5 billion/year (2012)
- Important for subsistence
- Historical social significance

Taxa

(FAO 2014)

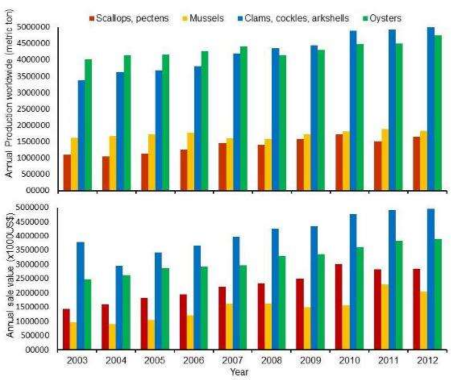
Diverse
Intertidal, subtidal
Inshore, offshore
Sustainable
Potential for expansion



Production and value

(FAO 2012)

15.2M tonnes (2014)

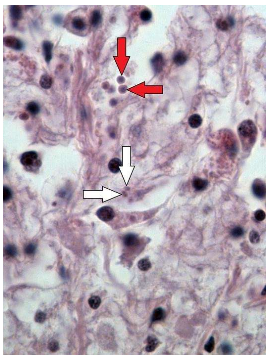


Delicious

Brian Jones

Mollusc diseases

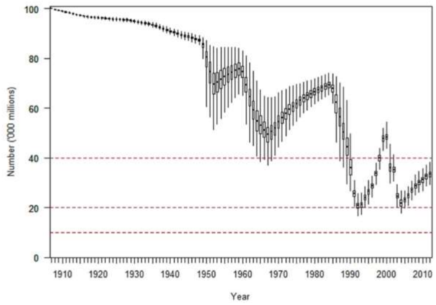
- Control recruitment wild populations
- Limit aquaculture production
- Socially pervasive
- *Bonamia*
  - *B. ostreae* in European, Pacific oysters
  - *B. exitiosa* in Bluff, Ariak, Suminoe, Argentine, Stentine, Sydney rock, Pacific oysters
  - *B. perspora* in Stentine oysters
  - *Bonamia* spp. in other hosts



Henry Lane

Bonamia exitiosa in NZ

- Bluff oyster fishery stable at ~100M/year to 1950
- 1950 on - population controlled by *B.exitiosa*
- Recruitment inverse density dependant
- High density areas suffer *B. exitiosa* mortality



Bonamia ostreae in Europe

- Production *O. edulis* ~100,000t 1970
- 1970s *B. ostreae* outbreaks
- Switch to Pacific oysters
- No production recovery ~40 years

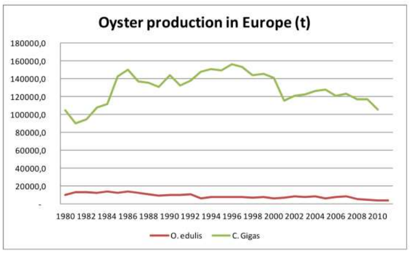


Figure 1. Production of oysters (European Flat oyster and Pacific oyster) in Europe, from 1980 to 2010.

oysterecovery.eu

Bonamia spp. distribution Engelsma et al. 2014

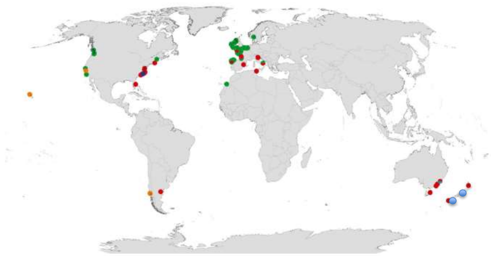
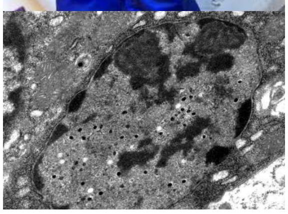


Fig. 5. Geographical distribution of *Bonamia* species based on published literature and disease reports of the OIE World Animal Health Information Database (see Table S1 in the Supplement at www.int-res.com/articles/suppl/d110p005_supp.pdf): *B. ostreae* (green), *B. exitiosa* and species of the *B. exitiosa* clade (red), *Bonamia* sp. from *Ostrea chilensis* in Chile, *O. lurida* in California and *O. sandvicensis* in Hawaii (orange), *B. perspora* (dark blue) and the microcell in *Saccostrea glomerata* (light blue)

OsHV-1

Colleen Burge

- Malacoherpesvirus
- Asia, Europe, NZ, Australia, USA
- Reference strain – hatchery mortality
- Microvariant(s) – summer mortality in spat, juveniles and oysters
- 50%+ losses where it occurs
- Notifiable in Australia
- Outbreaks NSW 2010, 2013; TAS 2016
- Substantial threat to $30M SA oyster industry



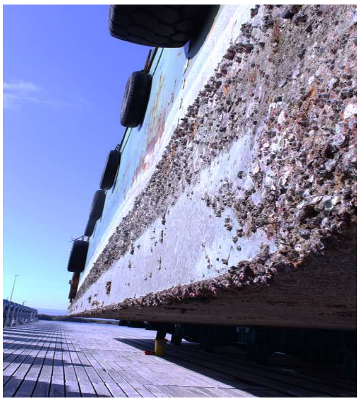
Tristan Renault

Port River

- Urban waterway near Adelaide
- Commercial port
- Highly contaminated
- Well surveyed flora and fauna
- Feral Pacific oysters

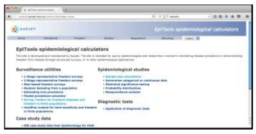
Barge arrival

- NSW to Port Adelaide July 2016
- ~5,000 Pacific oysters
- 1/56 OsHV-1 microvariant +
- 1.8% (0.01-2.9%) prevalence
- ~100 infected oysters



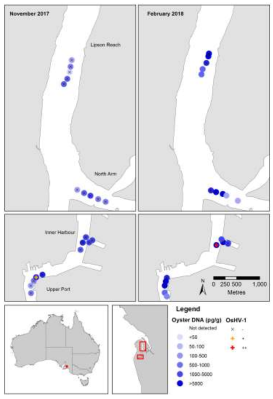
Post-barge arrival

- Oyster surveys
- 95% confidence <1% prevalence
- 600 samples 4800 tests
- No OsHV-1 detected 2016



OsHV-1 environmental surveillance

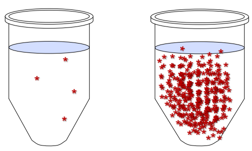
- Hobart/Derwent River port samples January 2016
- Tested after February 2016 OsHV-1 outbreak
- 3 confirmed positives from 30 samples
- Assess utility of environmental surveillance



- Adelaide remained negative from 2016 to the end of 2017
- But then . . .
- One environmental sample indeterminate (1/2 tests positive) re-tested negative (0/4)
- 600+ oyster samples 2400+ tests negative
- Possibilities:
  - Non-OsHV-1 target
  - Test malfunction
  - Dead virus
  - Contamination?

That dreaded sample

- SARDI eDNA extraction produces 150 µL DNA
- OsHV-1 assay uses 2 µL per test
- First re-test negative
- Continued to re-test
- Every sixth 2 µL subsamples tests positive (CT~38)

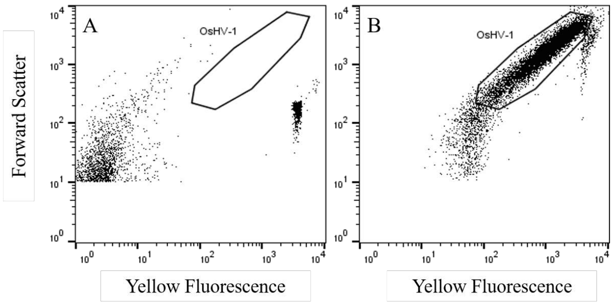


February 2018 – OsHV-1microvariant outbreak in Pacific oysters

Sample Date	Detections	Samples	Oyster prevalence	Vessel oyster prevalence	Bulk biofouling prevalence
21-Feb-18	16	25	64.0%	26%	5%
02-Mar-18	143	208	68.8%	25%	3%
24-Apr-18	16	32	50.0%	19%	3%
28-May-18	17	32	53.1%	18%	ND
26-Jun-18	12	31	38.7%	12%	ND
14-Aug-18	12	32	37.5%	14%	ND
12-Sep-18	11	37	29.7%	11%	ND
23-Oct-18	6	46	13.0%	ND	ND
26-Nov-18	13	33	39.4%	21%	3%
20-Dec-18	23	32	71.9%	34%	5%
22-Jan-19	7	36	19.4%	8%	5%

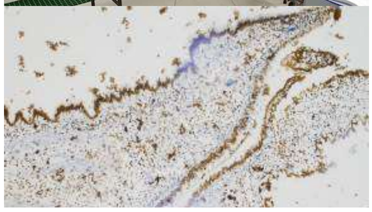
Bayesian LCM Martenot and Jenkins tests 'or' rule

OsHV-1 flow cytometry (water)



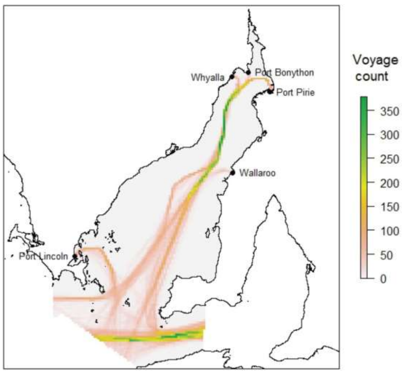
Transmission

- Infection model
- Cohabitat biofouling Pacific oysters with naive Pacific oyster spat
- Raise temperature
- Biofouling oysters transmit OsHV-1 >50% if CT<30, 5-30% if CT >30



Shipping model

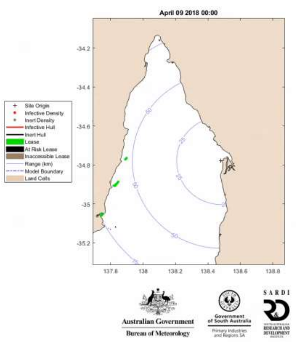
- Voyage count
- Voyage distance
- Voyage origin
- Infection
- Season
- Infectivity
- Port Adelaide 1.5-25 years to infection from emergence



Risk or inevitability?

- Pacific oysters on 90+% of Port Adelaide moored vessels
- Pacific oysters common in domestic and international biofouling
- Distance from farms to ports
- Dis/continuity of farmed and feral Pacific oyster populations
- Environmental suitability for disease
- Secondary transport

Currents



Conclusions

- Pathogens are common in biofouling
- Biofouling transmits aquatic animal diseases and is the best fit to describe a range of pathogen distributions
- These diseases pose an ongoing threat to uninfected industries
- Infected biofouling oysters can transmit pathogens

Thanks

- Future Oysters CRC-P, FRDC, DAWR
- Sarah Culloty, Sharon Lynch (University College Cork, Ireland)
- DoA / The National System / NIMPIS, Ingo Ernst, Peter Stoutjestijk, Brett Herbert, James Forwood, Susie Kropman, Tim Carew et al.
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- MISA, Staff at SARDI Aquatic Sciences (Marine Ecosystems) and SARDI Crop Science (Molecular Diagnostics)
- Biosecurity SA, Flinders Ports, AMLR and KI NRM Boards
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- Mark Farnsworth
- Cawthron Institute, Susie Wood
- CSIRO Mark Crane
- Joshua Mackie
- AMSA, AMSA
- ABC Four Corners

When biosecurity works, nothing happens

TIM CAREW
Science Officer
Australian Government Department of Agriculture, Australia

Timothy Carew completed a Bachelor of Environmental Science (Marine Biology) in 2016 before working as an aquaculture technician at Southern Ocean Mariculture, an abalone farm in south west Victoria. From there he joined the Department of Agriculture as a graduate in 2017. He worked in the areas of Marine Biosecurity, Fisheries Management and Plant Biosecurity before settling in his current role in the Marine Biosecurity Unit.

In the Marine Biosecurity Unit Tim has been working on policy for ballast water, biofouling and in-water cleaning as well as project management to support the decision-making framework that underpins key policy documents.

Understanding environmental detection of aquatic pathogens to inform vessel management policy in Australia

The Australian Department of Agriculture (the Department) is responsible for regulating ballast water on internationally arriving and domestically operating vessels. The Department is now working towards establishing regulations for biofouling on internationally arriving vessels, to ensure the biosecurity risk associated with these vessels is comprehensively managed.

Biofouling and ballast water present a risk of spreading aquatic diseases which can have devastating effects on local businesses and the environment. It is however very difficult to obtain the information required to make the informed management decisions required to reduce this risk. To make these informed decisions a reliable method for determining if an aquatic pathogen is present in the environment is required.

The Department has funded a project to develop robust and repeatable methods for environmental DNA detection of pathogens in the marine environment. The aim of the project is to develop the required tools for determining the presence/absence of aquatic pathogens in the environment, this information can inform management decisions regarding the transmission of aquatic animal disease via ballast water and biofouling.

The initial stage of this project was to determine the diagnostic sensitivity and specificity of quantitative PCR tests for white spot syndrome virus and Ostreid herpesvirus-1 in environmental samples. The Department aims to use this capability going forward to determine if an aquatic disease is present in a port environment and inform risk ratings for domestic ballast water transfer as appropriate.

The Departments approach to implementing this tool to inform risk-based management decisions to prevent the spreading of aquatic animal diseases will be discussed.

Australian Government
Department of Agriculture

Understanding environmental detections of aquatic pathogens to inform vessel management policy in Australia

Timothy Carew
4 October 2019

Biosecurity risk of ballast water and biofouling

Vessel arrivals

AMSA Port State Control Australia – 2018 Report
- During the 2018 calendar year there were:
  - 29,094 ship arrivals by 5,900 foreign-flagged ships
- Bulk carriers accounted for 49.3% of ship arrivals
- The average gross tonnage per visit was 51,808 GT
- The average age of vessels was 10 years.

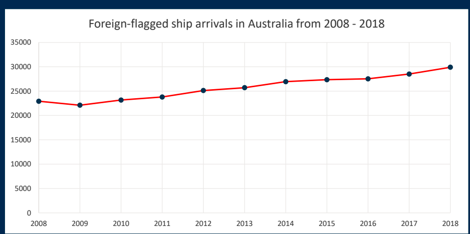
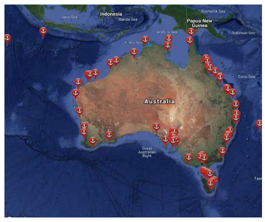


Figure 1: Foreign-flagged ship arrivals in Australia based on Australian Maritime Safety Authority Port State Control data

What's the risk?

Increase in shipping movements, change in shipping patterns
- Major vector for marine pest & disease introductions – ballast water and biofouling



What are we doing about it?

Biosecurity Act 2015

International Convention for the Control and Management of Ships' Ballast Water and Sediments

Biofouling Management Requirements for Internationally arriving vessels

Ballast water management requirements

Why do we need to do port surveillance?

Management options:
- Ballast water treatment
- Ballast water exchanges

  or
- Risk-based exemption domestically

The Australian Ballast Water Risk Assessment (BWRA)
- Environmental matching risk assessment
- Species' biogeographical risk assessment
- Species-specific risk assessment
- 7 species used

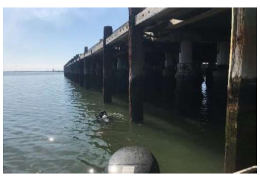


Photo source: Jacobs Group (Australia) Pty Ltd.

Australian Sourced Ballast Application Risk Based Exemption

Low Risk Voyage
- Determined by the port of uptake and discharge
- What risks have been identified in port of uptake
- Times of the year
- Don't need to manage ballast

High Risk Voyage
- Vessels must manage ballast water
- Record all ballast water managements in BWRB
- May be subject to a domestic ballast water inspection

MARS

http://www.agriculture.gov.au/biosecurity/avm/vessels/mars

Existing Research:

Risk of waterborne virus spread – review of survival of relevant fish and crustacean viruses in the aquatic environment and implications for control measures

Parasitology

The role of the mussel *Mytilus* spp. in the transmission of ostreid herpesvirus-1 microVar

cambridge.org/par

Vol. 122: 247–255, 2017 doi: 10.3354/dao03078	DISEASES OF AQUATIC ORGANISMS Dis Aquat Org	Published January 24

Detection of ostreid herpesvirus 1 microvariant DNA in aquatic invertebrate species, sediment and

Transporting Ocean Viromes: Invasion of the Aquatic Biosphere

Yiseul Kim, Tiong Gim Aw, Joan B. Rose

Published: April 7, 2016 • https://doi.org/10.1371/journal.pone.0152671

2016 White Spot Syndrome Virus Outbreak in Brisbane

- Estimated total loss of $49.5 million (Ridge Partners 2017)

Testing:

- The Department retrospectively tested environmental samples using qPCR's
- Indeterminate results

How can we be sure though?

- Sent the samples to Korea for confirmation by NGS

What can we do next?

Detection of environmental pathogens

Project aim:

Assess feasibility of existing qPCR and nPCR / cPCR assays for viral pathogen detection and confirmation for environmental samples.

Three stages:

1. Laboratory component
2. Field validation
3. Confirmatory tests and field test performance

https://www.abc.net.au/cm/rimage/8100480-16x9-small.jpg?v=2

https://images.theconversation.com/files/185175/original/file-20170907-9573-19vm7lm.JPG?ixlib=rb-1.1.0&q=45&auto=format&w=1000&fit=clip

Stage 1 – Initial Laboratory Component

Aim: Test existing environmental samples to better understand the limit of detection

- Spike environmental samples with irradiated virus
- Extract DNA from spiked samples
- Test samples using qPCR and nPCR/cPCR assays
- Determine the extraction efficiency and level of detection for each of the assays

Stage two – Field Sampling and Field Validation

Test samples from known positive and known negative sites.

- These samples will be tested using the same methods. qPCR and then cPCR and Sanger sequencing for positive results.
- This aims to determine the diagnostic specificity and sensitivity of the assays.
- Understand the viral distribution in the environment to inform survey sensitivity
- Provide confidence in the likelihood of absence of the virus provided by negative results from a given approach

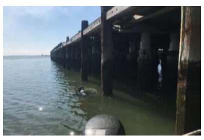


Photo source: Jacobs Group (Australia) Pty Ltd.

Stage Three – Confirmatory tests and field test performance

Aim: To provide additional higher sensitivity confirmatory tools for qPCR detections in plankton samples.

- Improve confirmatory tests
- Test high Ct qPCR positive samples using different platforms
- Refine sample techniques and survey design

How can we use this tool?

The Department needs to make regulatory decisions to minimise the spread of aquatic diseases.

- Need is to establish risk areas
- Therefore we need to:
  - Have confidence in negative results
  - Have confidence that positive result is a positive result
- Early warning system to help direct sample efforts in adult populations
- If we can confirm the presence of a disease in a port environment, then we can use the risk tables to rate voyages as high risk.
- Biofouling?

Difficulties we are facing

- Environmental samples are very different from animal tissue samples
- Plankton samples contain many different sources of DNA and therefore increases the chance of inhibition
- Developing suitable confirmation tests
- Sampling large areas

Acknowledgements:

1. CSIRO Australian Animal Health Laboratory
2. SARDI Aquatic Sciences
3. SARDI Sustainable Systems

CSIRO

Government of South Australia
Primary Industries and Regions SA

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Australian Government
Department of Agriculture

MARINE FUHRMANN
Postdoctoral research associate, School of Veterinary Science
University of Sydney, Australia

Dr Marine Fuhrmann holds a PhD in marine biology from the University of Brest in France where she worked at the French Research Institute for Exploitation of the Sea (Ifremer). She is now working as a postdoctoral research associate at the University of Sydney in the group of aquatic animal health.

Her research focuses on the Pacific Oyster Mortality Syndrome. Her research includes the study of the effect of environment on the interaction between the Pacific oyster and the Ostreid Herpesvirus *1, investigating host and virus responses, in addition to OsHV-1 transmission pathways.*

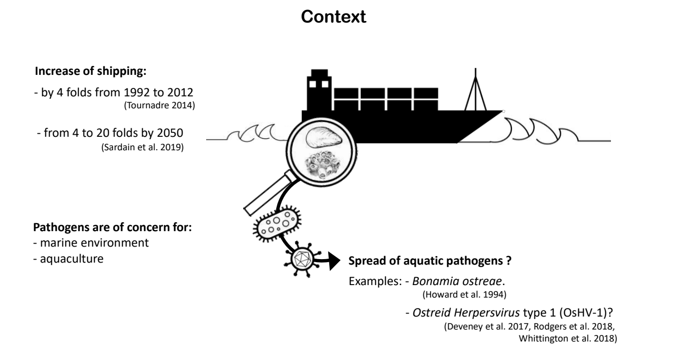
As an engineer in agronomy and a researcher in marine biology, she is interested in how science can be used to help manage aquaculture.

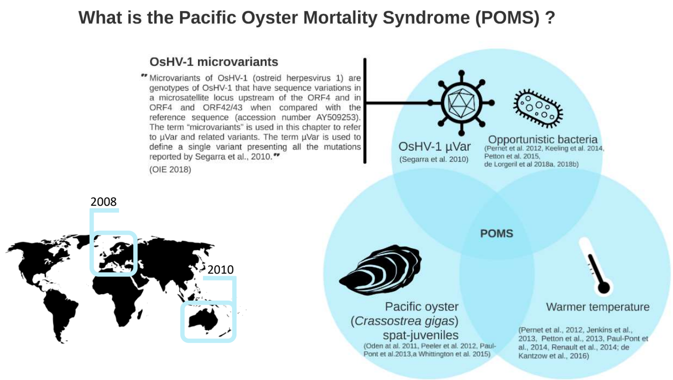
Biofouling and aquatic pathogens: The case study of the *Ostreid Herpesvirus 1*

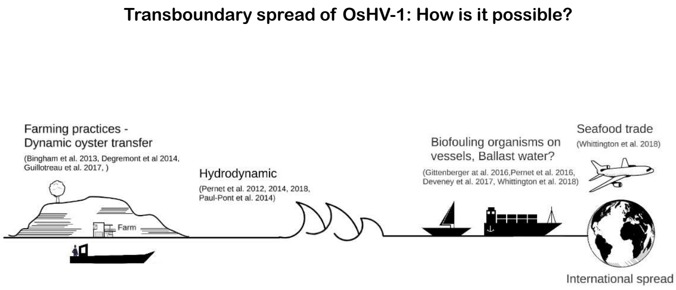
Ostreid Herpesvirus 1 (OsHV-1) has caused massive mortalities in Pacific oysters (*Crassostrea gigas*) in Europe since 2008, and in Australia and New Zealand since 2010. While movements of infected Pacific oysters associated with the aquaculture activities are a well-known mechanism of OsHV-1 spread to other growing regions, additional pathways of OsHV-1 spread have yet to be elucidated. Therefore, the Ministry for Primary Industries, New Zealand, commissioned a proof of concept project to investigate the risk of translocating OsHV-1 via biofouling organisms commonly associated with vessels and aquaculture equipment.

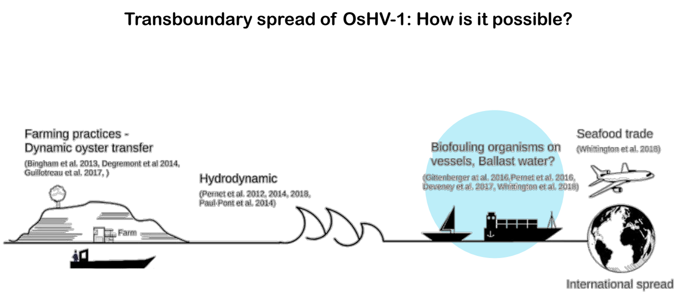
Laboratory experiments were undertaken to investigate the potential to transfer OsHV-1 from infected Pacific oysters to uninfected Pacific oysters, Sydney rock oysters (*Saccostrea glomerata*), or Mediterranean mussels (*Mytilus galloprovincialis*) via cohabitation. The potential for transmission of OsHV-1 from the exposed bivalves to naïve Pacific oysters was evaluated in subsequent cohabitation experiments. Field experiments are underway to investigate the risk of OsHV-1 transmission from a broader range of biofouling organisms than those examined in the laboratory.


Vessel biofouling and aquatic pathogens:
The case study of the Ostreid Herpesvirus 1
M. Fuhrmann* and P. Hick*
* University of Sydney, School of Veterinary Science, Faculty of Science, 425 Werombi Road, Camden, New South Wales 2570, Australia
4thANZPAC workshop
Melbourne, Vic, Australia
4 October 2019
Ministry for Primary Industries
Manatū Ahu Matua
THE UNIVERSITY OF SYDNEY


Context
Increase of shipping:
- by 4 folds from 1992 to 2012
(Tournadre 2014)
- from 4 to 20 folds by 2050
(Sardain et al. 2019)
Pathogens are of concern for:
- marine environment
- aquaculture
Spread of aquatic pathogens ?
Examples: - Bonamia ostreae.
(Howard et al. 1994)
- Ostreid Herpesvirus type 1 (OsHV-1)?
(Deveney et al. 2017, Rodgers et al. 2018, Whittington et al. 2018)


What is the Pacific Oyster Mortality Syndrome (POMS) ?
OsHV-1 microvariants
"Microvariants of OsHV-1 (ostreid herpesvirus 1) are genotypes of OsHV-1 that have sequence variations in a microsatellite locus upstream of the ORF4 and in ORF4 and ORF42/43 when compared with the reference sequence (accession number AY509253). The term "microvariants" is used in this chapter to refer to µVar and related variants. The term µVar is used to define a single variant presenting all the mutations reported by Segarra et al., 2010."
(OIE 2018)
2008
2010
OsHV-1 µVar
(Segarra et al. 2010)
Opportunistic bacteria
(Pernet et al. 2012, Keeling et al. 2014, Petton et al. 2015, de Lorgeril et al 2018a, 2018b)
POMS
Pacific oyster
(Crassostrea gigas)
spat-juveniles
(Oden at al. 2011, Peeler et al. 2012, Paul-Pont et al.2013,a Whittington et al. 2015)
Warmer temperature
(Pernet et al., 2012, Jenkins et al., 2013, Petton et al., 2013, Paul-Pont et al., 2014, Renault et al., 2014; de Kantzow et al., 2016)


Transboundary spread of OsHV-1: How is it possible?
Farming practices -
Dynamic oyster transfer
(Bingham et al. 2013, Degremont et al 2014, Guillotreau et al. 2017,)
Farm
Hydrodynamic
(Pernet et al. 2012, 2014, 2018, Paul-Pont et al. 2014)
Biofouling organisms on vessels, Ballast water?
(Gittenberger at al. 2016,Pernet et al. 2016, Deveney et al. 2017, Whittington et al. 2018)
Seafood trade
(Whittington et al. 2018)
International spread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Farm
Hydrodynamic
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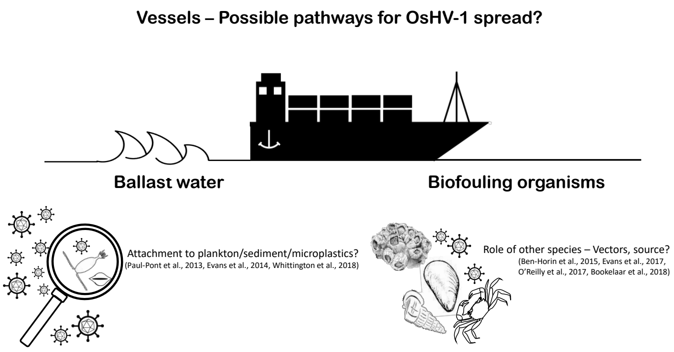
International spread


Vessels – Possible pathways for OsHV-1 spread?
Ballast water
Biofouling organisms
Attachment to plankton/sediment/microplastics?
(Paul-Pont et al., 2013, Evans et al., 2014, Whittington et al., 2018)
Role of other species – Vectors, source?
(Ben-Horin et al., 2015, Evans et al., 2017, O'Reilly et al., 2017, Bookelaar et al., 2018)

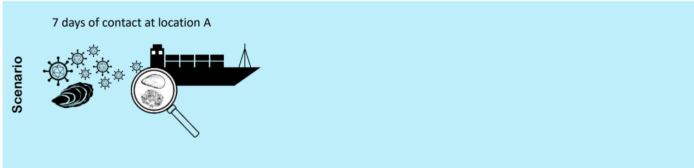
Aims of the study

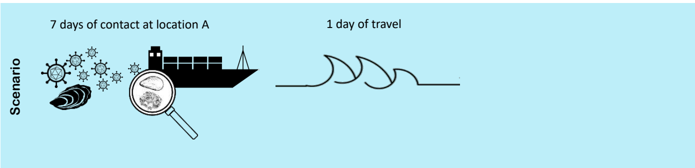
This **proof of concept research** investigates the risk of translocating OsHV-1 via biofouling organisms associated with vessels, or equipment associated with aquaculture industry.

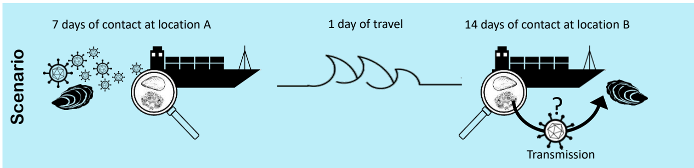
It consists of:

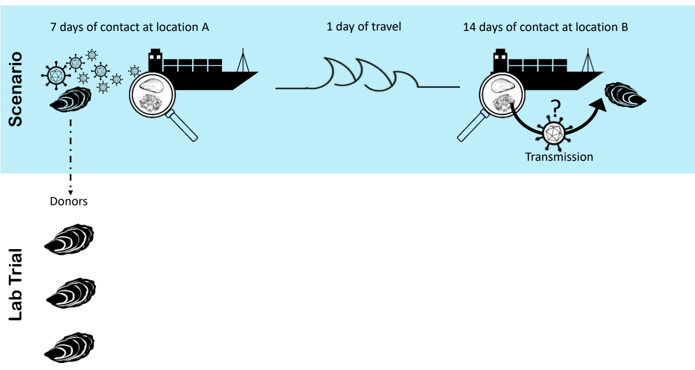
- **Experiment 1**: Laboratory testing for OsHV-1 viability in Sydney rock oysters (*Saccostrea glomerata*) and Mediterranean mussels (*Mytilus galloprovincialis*) after cohabitation with Pacific oysters (*Crassostrea gigas*) injected with OsHV-1 and subsequent potential for transmission to naïve Pacific oysters.

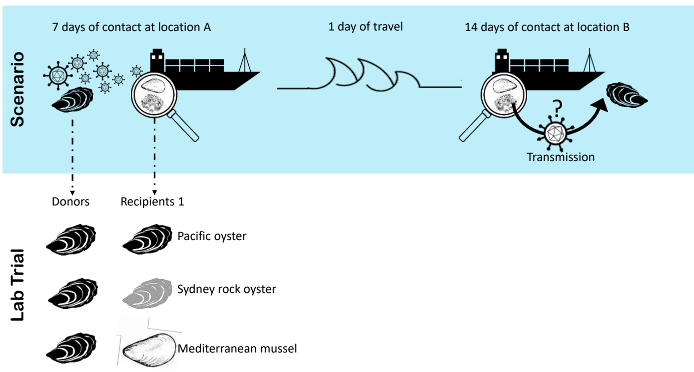
- **Experiment 2**: Field surveillance for OsHV-1 in a Pacific oyster farm from the Georges River and collection of biofouling organisms to be tested for OsHV-1 and viral viability.

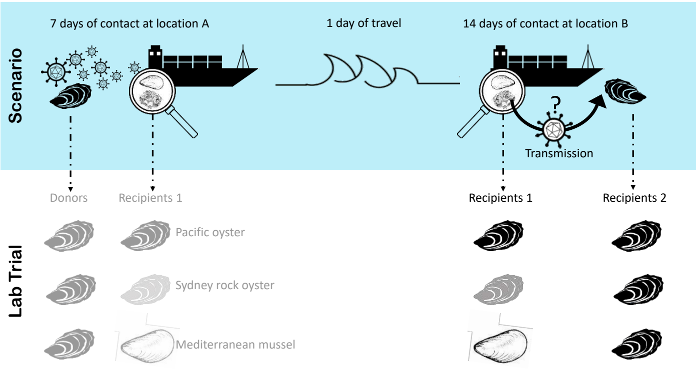


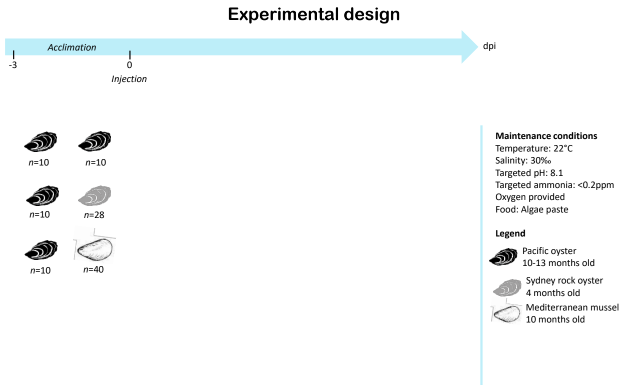


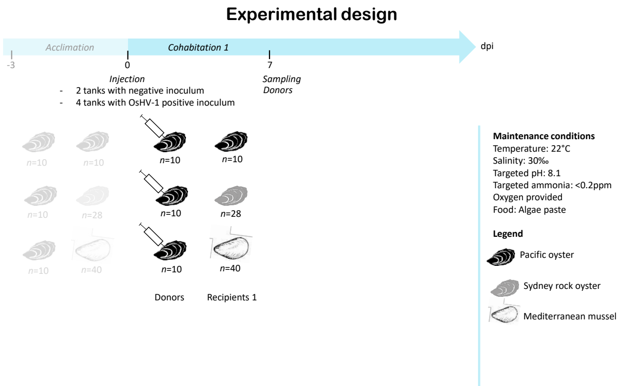


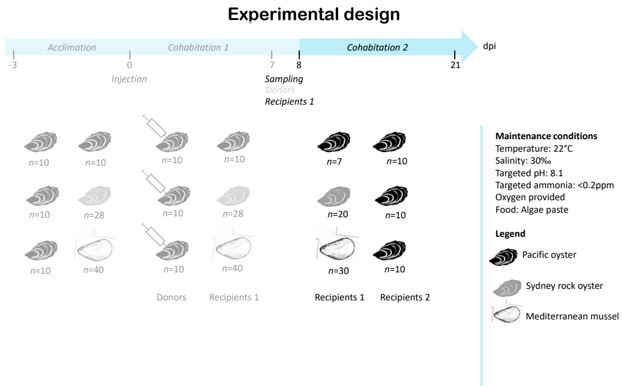


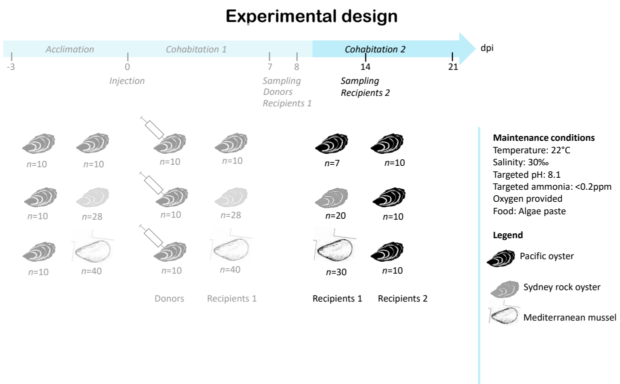



Scenario
7 days of contact at location A
1 day of travel
14 days of contact at location B
Transmission
Donors
Recipients 1
Recipients 1
Recipients 2
Lab Trial
Pacific oyster
Sydney rock oyster
Mediterranean mussel


Experimental design
Acclimation
dpi
-3
0
Injection
n=10
n=10
n=10
n=28
n=10
n=40
Maintenance conditions
Temperature: 22°C
Salinity: 30‰
Targeted pH: 8.1
Targeted ammonia: <0.2ppm
Oxygen provided
Food: Algae paste
Legend
Pacific oyster
10-13 months old
Sydney rock oyster
4 months old
Mediterranean mussel
10 months old


Experimental design
Acclimation
Cohabitation 1
dpi
-3
0
7
Injection
- 2 tanks with negative inoculum
- 4 tanks with OsHV-1 positive inoculum
Sampling
Donors
n=10
n=10
n=10
n=10
n=10
n=10
n=10
n=28
n=10
n=40
n=10
n=40
Donors
Recipients 1
Maintenance conditions
Temperature: 22°C
Salinity: 30‰
Targeted pH: 8.1
Targeted ammonia: <0.2ppm
Oxygen provided
Food: Algae paste
Legend
Pacific oyster
Sydney rock oyster
Mediterranean mussel


Experimental design
Acclimation
Cohabitation 1
Cohabitation 2
dpi
-3
0
7
8
21
Injection
Sampling
Donors
Recipients 1
n=10
n=10
n=10
n=10
n=7
n=10
n=10
n=28
n=10
n=28
n=20
n=10
n=10
n=40
n=10
n=40
n=30
n=10
Donors
Recipients 1
Recipients 1
Recipients 2
Maintenance conditions
Temperature: 22°C
Salinity: 30‰
Targeted pH: 8.1
Targeted ammonia: <0.2ppm
Oxygen provided
Food: Algae paste
Legend
Pacific oyster
Sydney rock oyster
Mediterranean mussel


Experimental design
Acclimation
Cohabitation 1
Cohabitation 2
dpi
-3
0
7
8
14
21
Injection
Sampling
Donors
Recipients 1
Sampling
Recipients 2
n=10
n=10
n=10
n=10
n=7
n=10
n=10
n=28
n=10
n=28
n=20
n=10
n=10
n=40
n=10
n=40
n=30
n=10
Donors
Recipients 1
Recipients 1
Recipients 2
Maintenance conditions
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Salinity: 30‰
Targeted pH: 8.1
Targeted ammonia: <0.2ppm
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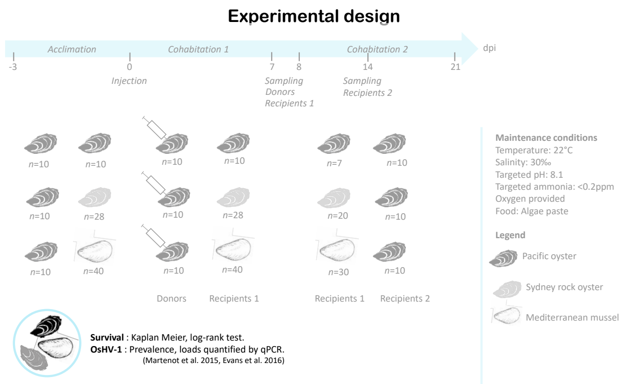
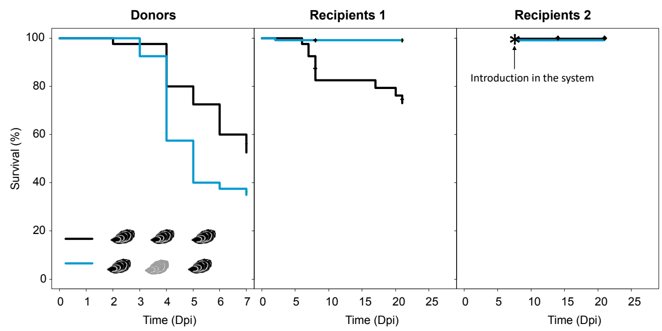
Legend
Pacific oyster
Sydney rock oyster
Mediterranean mussel


Experimental design
Acclimation
Cohabitation 1
Cohabitation 2
dpi
-3
0
7
8
14
21
Injection
Sampling
Donors
Recipients 1
Sampling
Recipients 2
n=10
n=10
n=10
n=10
n=7
n=10
n=10
n=28
n=10
n=28
n=20
n=10
n=10
n=40
n=10
n=40
n=30
n=10
Donors
Recipients 1
Recipients 1
Recipients 2
Survival : Kaplan Meier, log-rank test.
OsHV-1 : Prevalence, loads quantified by qPCR.
(Martenot et al. 2015, Evans et al. 2016)
Maintenance conditions
Temperature: 22°C
Salinity: 30‰
Targeted pH: 8.1
Targeted ammonia: <0.2ppm
Oxygen provided
Food: Algae paste
Legend
Pacific oyster
Sydney rock oyster
Mediterranean mussel

Results

Non-challenged with OsHV-1
Survival 90-100%
Samples all negative to OsHV-1 by qPCR

Results: Pacific oyster and Sydney rock oyster



Results

Figure: Results of survival and OsHV-1 loads and prevalence for the bivalves sampled at 7 dpi, 8 dpi or 14 dpi or time of death in tanks challenged with OsHV-1

Donors

Donors	Status	Mean ± SD	*n* positive	*n* total	*Prevalence*
	Alive	x	x	x	x
	Dead	$1.20x10^6$ ± $3.10 x10^6$	18	18	100
	Alive	x	x	x	x
	Dead	$3.07 x10^5$ ± $4.32 x10^5$	20	20	100

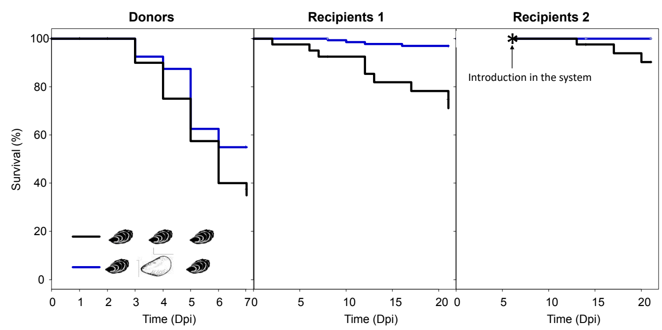
Recipients 1

Recipients 1	Status	Mean ± SD	*n* positive	*n* total	*Prevalence*
	Alive	$2.99 x10^4$ ± $5.08 x10^4$	6	7	86
	Dead	$1.67 x10^5$ ± $2.14 x10^5$	13	14	93
	Alive	0 ± 0	0	32	0
	Dead	BLOQ	1	1	100

Recipients 2

Recipients 2	Status	Mean ± SD	*n* positive	*n* total	*Prevalence*
	Alive	0 ± 0	0	12	0
	Dead	x	x	x	x
	Alive	0 ± 0	0	11	0
	Dead	x	x	x	x

Results: Pacific oyster and Mediterranean mussel



Results

Challenged with OsHV-1

Figure: Results of survival and OsHV-1 loads and prevalence for the bivalves sampled at 7 dpi, 8 dpi or 14 dpi or time of death in tanks challenged with OsHV-1

Donors

	Status	Mean ± SD	*n* positive	*n* total	*Prevalence*
	Alive	x	x	x	x
	Dead	$4.23x10^5$ ± $4.72 x10^5$	20	21	95
	Alive	$1.89x10^4$ ± $2.65x10^4$	2	2	100
	Dead	$5.69x10^5$ ± $7.92x10^5$	18	18	100

Recipients 1

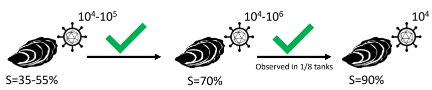
	Status	Mean ± SD	*n* positive	*n* total	*Prevalence*
	Alive	$1.57 x10^4$ ± $2.70x10^4$	7	11	64
	Dead	$1.70x10^6$ ± $4.18x10^6$	8	8	100
	Alive	0 ± 0	0	12	0
	Dead	0 ± 0	0	4	0

Recipients 2

	Status	Mean ± SD	*n* positive	*n* total	*Prevalence*
	Alive	0 ± 0	0	12	0
	Dead	$8.49x10^4$ ± $6.53x10^4$	3	3	100
	Alive	0 ± 0	0	12	0
	Dead	x	x	x	x

Results - Discussion

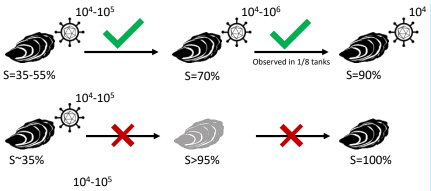
What to keep in mind for transmission of OsHV-1 in our study context?



In other studies?

Results - Discussion

What to keep in mind for transmission of OsHV-1 in our study context?

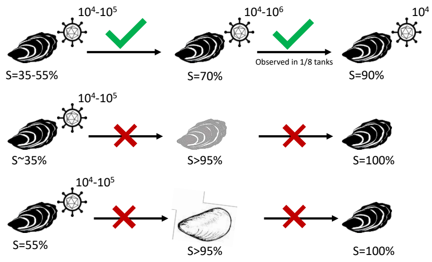


In other studies?

Detection of low levels of OsHV-1 DNA in Sydney rock oysters.
(Jenkins et al. 2013, Evans et al. 2017)

Results - Discussion

What to keep in mind for transmission of OsHV-1 in our study context?



In other studies?

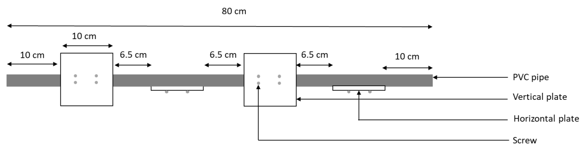
Detection of low levels of OsHV-1 DNA in Sydney rock oysters.
(Jenkins et al. 2013, Evans et al. 2017)

Interspecies transmission suggested.
(O'Reilly et al. 2017)
Detection of low levels of OsHV-1 DNA.
(Evans et al. 2016, Domeneghetti et al. 2014, O'Reilly et al. 2017)
***Mytilus galloprovincialis* is resistant to OsHV-1 due to Myticin C.**
(Novoa et al., 2016)

Study location – The Georges River, south of Sydney, NSW

Modified from Evans et al. 2016

Settlement array structures



Settlement array structures

Structures deployed in the Georges River the 30th January 2019, *n*=5 per sites.

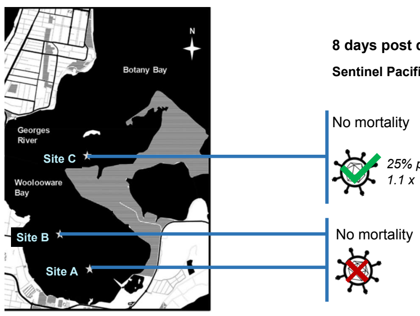
Deployment of sentinel Pacific oysters (4 months old), nearby the settlement array structures the 10th April 2019, *n*=3 socks of 500 oysters per sites.

Mortality monitoring and sampling the 18th April and 2nd May 2019.

Results

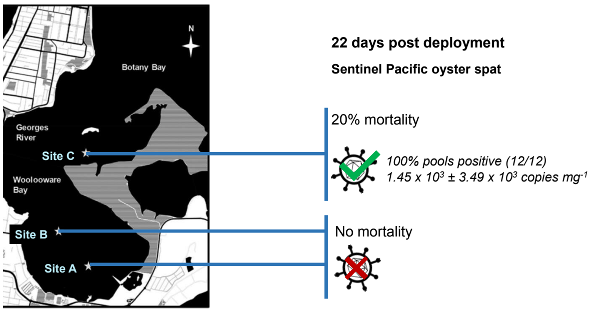
8 days post deployment

Sentinel Pacific oyster spat

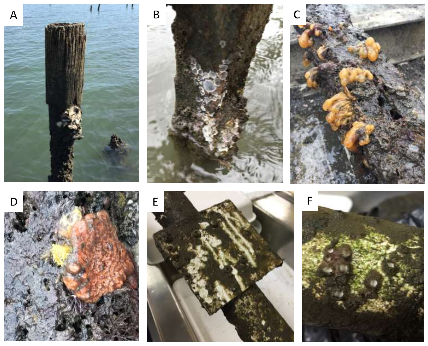


25% pools positive (4/12)
$1.1 \times 10^4 \pm 3.7 \times 10^4$ copies mg^{-1}

Results

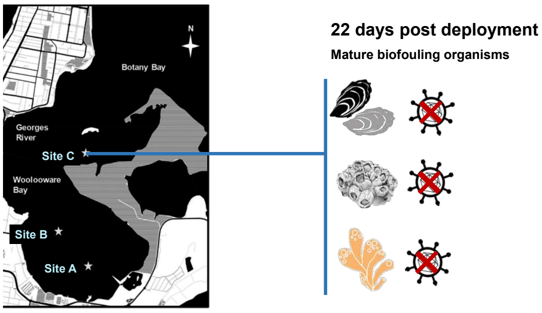


Biofouling taxa

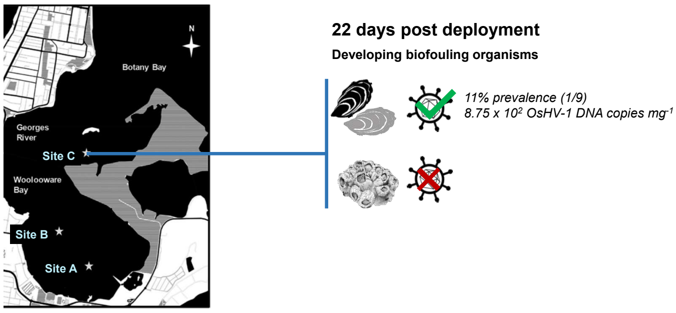


Mature (A to D) and developing (E and F) biofouling organisms collected on 2nd May 2019 from Site C, Georges River.
(A) Oysters;
(B) Barnacles;
(C and D) ascidians;
(E) baseplates of barnacles that were removed from a horizontal plates from Site C; (F) barnacles on PVC pipe holding settlement array structure from Site C.

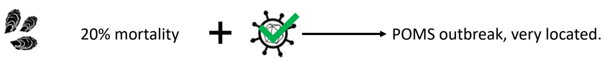
Results



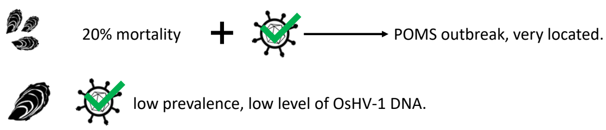
Results



Results-Discussion



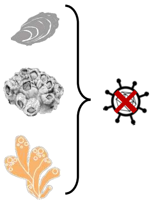
Results-Discussion



Results-Discussion

20% mortality + OsHV-1 → POMS outbreak, very located.

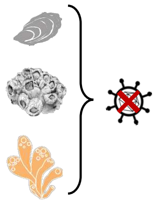
low prevalence, low level of OsHV-1 DNA.



Results-Discussion

20% mortality + OsHV-1 → POMS outbreak.

low prevalence, low level of OsHV-1 DNA.



In other studies?

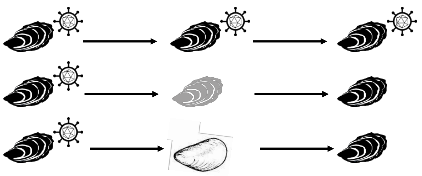
Detection of low levels of OsHV-1 DNA in Sydney rock oysters.
(Jenkins et al. 2013, Evans et al. 2017)

Detection of low levels of OsHV-1 DNA in barnacles.
(Evans et al. 2017)

No data published.

Take home message

Experiment 1
Under the scenario tested:



At risk

At low risk

At low risk

POMS is a multifactorial disease. Thus, there may be other scenarios of exposure resulting in potential translocation.

Take home message

Experiment 2

POMS outbreak observed in the Georges River in May 2019.
→ Not of a high intensity.
→ Low OsHV-1 prevalence in the surrounding Pacific oysters.
→ No detection of OsHV-1 DNA in other oyster species or other taxa.

POMS is a multifactorial disease.

What is next? To better control the infection, we will challenge developing biofouling organisms in laboratory conditions.

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PATRICK CAHILL
Team Leader
Cawthron Institute, New Zealand

Patrick Cahill is a Scientist and Team Leader in Cawthron's Coastal and Freshwater Group, with core skills in larval biology and marine chemical ecology. His research focusses on tool-development for proactive and reactive biofouling management, ranging from development of new approaches for antifouling of maritime vessels to applied pest management and biosecurity for aquaculture. This research is interdisciplinary and draws on a diverse network of collaborators in universities and industry to deliver practical outcomes for end- users.

NZ's Shellfish Aquaculture Research Platform – integrated biofouling management

Patrick Cahill, Javier Atalah, Lauren Fletcher, Ian Davidson, Shaun Cunningham, Grant Hopkins Cawthron Institute, Nelson, NZ

Biofouling is an enduring operational problem in shellfish aquaculture that can reduce productivity, impede operations, and damage infrastructure. New Zealand's shellfish aquaculture industry is supported by ongoing government investment in Cawthron Institute's 'Shellfish Aquaculture Research Platform'. The platform provides underpinning science to secure and grow the industry, and part of this work is to develop an approach for integrated biofouling management. The case study is the $NZ350 million per annum Greenshell™ mussel aquaculture industry, which has been increasingly impacted by unwanted and often invasive biofouling pests. This talk will overview the operational challenges biofouling poses in shellfish aquaculture, remedial approaches currently available to the industry, and our own work to develop an integrated framework for biofouling management. Our holistic approach to biofouling management encompasses a range of complementary and interrelated approaches:

- Ecological knowledge of the distribution, population dynamics, and impacts of 'functional groups' of pests on different stages of shellfish production to define economically appropriate action thresholds and intervention strategies.
- Realistic monitoring frameworks for industry surveillance of pest arrival and proliferation on-farm to provide baseline and continuing data required to operate and optimise intervention strategies.
- Proactive tools and treatments to prevent or avoid proliferation of harmful biofouling pests, including data-driven husbandry and spatial management approaches such as timed avoidance strategies, dispersal fire breaks, and fallowing.
- Reactive tools and treatments to apply when biofouling populations on crop reach potentially harmful levels and to decontaminate aquaculture gear before re-use or transfer within or between farms.

In this way, our goal of integrated pest management for shellfish aquaculture is not a single control method, rather a series of management evaluations, decisions, and tools. An integrated management framework underpinned by ecological knowledge will ultimately enable industry to manage biofouling risks in a cost-effective manner whilst ensuring desirable environmental outcomes.

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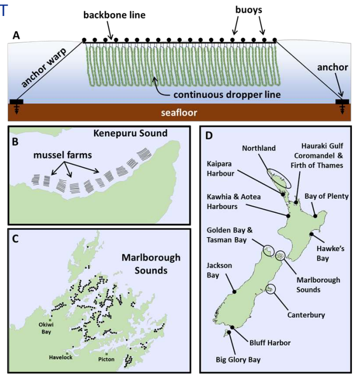
NEW ZEALAND'S SHELLFISH AQUACULTURE RESEARCH PLATFORM
INTEGRATED BIOFOULING MANAGEMENT

__PATRICK CAHILL__, JAVIER ATALAH, LAUREN FLETCHER, IAN DAVIDSON,
SHAUN CUNNINGHAM, GRANT HOPKINS

SHELLFISH AQUACULTURE – NZ CONTEXT



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SHELLFISH AQUACULTURE RESEARCH PLATFORM

'The purpose of the Strategic Science Investment Fund is to support longer-term, underpinning infrastructure and programmes of mission-led science critical to the future of New Zealand's economy, environment, and wellbeing'

Grow existing shellfish industries

Enable new shellfish aquaculture industries

Secure shellfish aquaculture production

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ON-FARM BIOFOULING RISKS AND ISSUES

- Biofouling 'marine pests' can be exotic (+) and/or native
- Impacts can be considerable but are hard to predict and manage
- Synergies of operational management and biosecurity

A+ NEW ZEALAND Sustainable AQUACULTURE

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ON-FARM BIOFOULING RISKS AND ISSUES

- Spat retention is constraining the industry and (likely) confounded by fouling
- But pests also impact later crop stages, processing, and LTO

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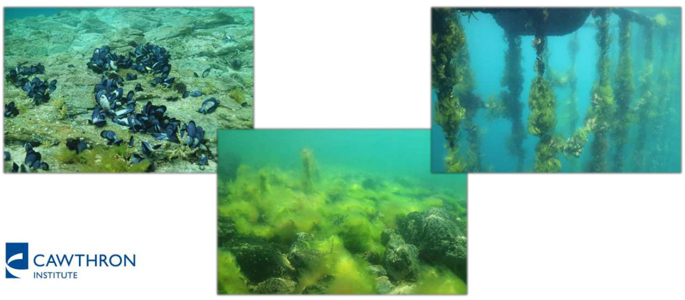
'BIOFOULING MANAGED'

'Develop tools and understanding to enable proactive management of risks to aquaculture production from biofouling'



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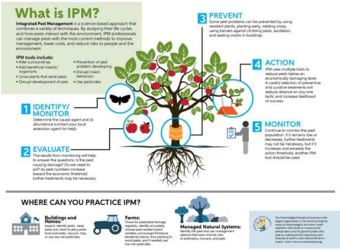
'INTEGRATED PEST MANAGEMENT'

'Use ecological knowledge of pests and the environment to inform judicious application of available control methods for optimal production outcomes'



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'BIOFOULING MANAGED'

- **Ecological knowledge** of pest distribution, population dynamics, and impacts of 'functional groups'
- **Industry monitoring** to inform management and detect problems
- **Proactive tools** to prevent or avoid proliferation
- **Reactive tools** for when pests reach harmful levels and to decontaminate gear

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ECOLOGICAL KNOWLEDGE

Stages of farming affected
Supply of spat
Crop grow out
Harvest
Processing
Product sales & marketing

Outcomes to shellfish farmers
Affect quality shellfish crop
Affect yield of shellfish crop
Impact infrastructure
Impede industry approach to harvest
Impede industry approach to processing

Pest impact categories
Rope fouling & shellfish occlusion
Shell fouling
Shell fouling & scarring
Over-settlement & displacement (spat)
Covering & reduced growth
Overtopping & displacement (crop)
Shell erosion/boring
Spat predation
Crop predation
Gear interference
Processing interference

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ECOLOGICAL KNOWLEDGE

Functional Group	Taxonomic groups	Impact type	Process stage impacted	Sentinel species
Canopy Algae	e.g. kelps and fucoids	Overtopping & displacement (crop)	Crop grow-out, crop retention, harvest, product processing	Undaria pinnatifida
Understory Algae	e.g. red, brown algae	Rope fouling & shellfish occlusion; Shellfish fouling; over-settlement & displacement (spat)	Supply of spat; crop grow-out	Colpomenia spp
Filamentous Algae	Filamentous green algae	Processing interference; Gear interference; Shell fouling	Harvest, Product processing	Cladophora
Sessile hard encrusting	barnacles, calcareous tubeworms, bryozoans	Shellfish fouling & scarring; processing interference	Product processing; product sales & marketing	Amphibalanus trigonus, Pomatocerus
Sessile soft encrusting	hydroids, colonial ascidians, sponges	Shellfish fouling; Covering & reduced growth;	Crop grow-out, product processing	Didemnum vexillum, Diplosoma
Sessile hard aggregating	mussels, bivalves	Rope fouling & shellfish occlusion; over-settlement & displacement (spat); Overtopping & displacement (crop); shellfish fouling; processing interference	Supply of spat; Crop grow-out, Harvest;	Mytilus galloprovincialis
Sessile soft aggregating	polychaetes*, solitary ascidians	Covering & reduced growth; Overtopping & displacement (crop); Gear interference Processing interference	Crop grow out; Harvest; product processing	Styela clava, Ciona intestinalis, Sabella spallanzanii
Benthic mobile predating	crabs, seastars	Spat predation Adult predation	Supply of spat; crop grow out; harvest	Asterias amurensis, Carcinus maenus
Pelagic mobile predating	fish	Spat predation Adult predation	Supply of spat; crop grow out; harvest	Spotties, snapper
Bioeroders	sponges	Shell erosion/boring; shell fouling; shell fouling & scarring	Crop grow-out;	Cliona
Macroscopic Endobiont/ Parasitic	peacrabs, bivalve-inhabiting hydroids	endobiont & reduced growth	Crop grow out; Product sales & marketing	Pea crab, Eutima

ECOLOGICAL KNOWLEDGE – DISTRIBUTION AND DYNAMICS

Field survey of crop lines and natural hard substrate habitats
- Adjacent to farm
- Distant from farm (no farms in bay)

Long and short dispersalnuisance pests:
- *Cladophora ruchingeri* (horsehair weed)
- *Didemnum vexillum* (sea squirt)
- *Colpomenia sp.* (bubble weed)
- *Undaria pinnatifida* (Asian kelp)
- *Ciona robusta* (sea squirt)
- *Mytilus galloprovincialis* (blue mussel)
- *Pylaiella sp.* (filamentous algae)
- *Codium sp.* (dead mans fingers)

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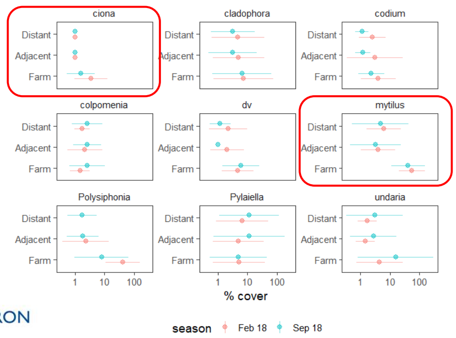
ECOLOGICAL KNOWLEDGE – DISTRIBUTION AND DYNAMICS



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ECOLOGICAL KNOWLEDGE – IMPACTS

- Identify gaps in impact assessment for functional groups
- Experimental assessments to fill gaps

Space competition – *Colpomenia* vs spat

Feeding competition – size filtering (*Sabella*/*Styela*)

Predation – flatworms vs spat and adults

Sessile/soft-bodied/aggregating – adherence not resolved by tumblers/rinsing

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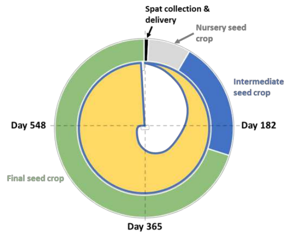
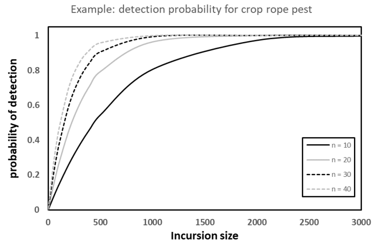
INDUSTRY MONITORING





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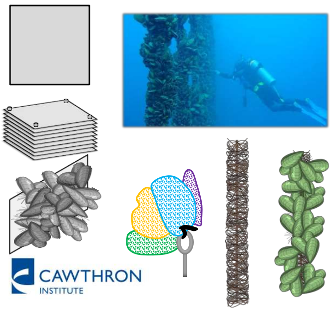
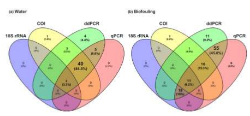
INDUSTRY MONITORING

Traditional approaches



Novel approaches



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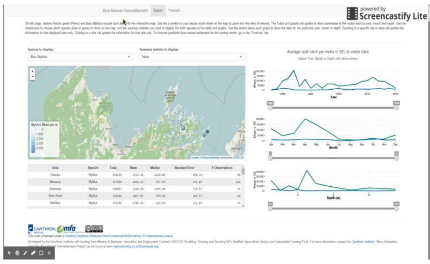
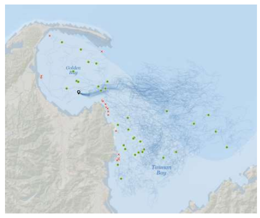
PROACTIVE TOOLS



https://cawthron.shinyapps.io/BMOP/



http://cawthron-data.upshift.co.nz/wheres-our-plastic-going/

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PROACTIVE TOOLS

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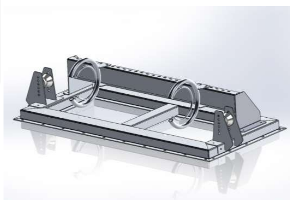
PROACTIVE TOOLS



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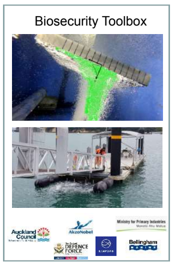

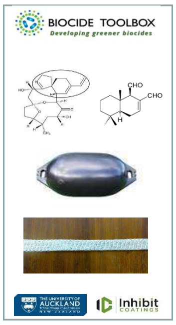

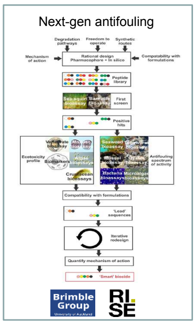

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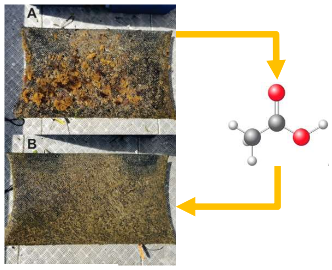
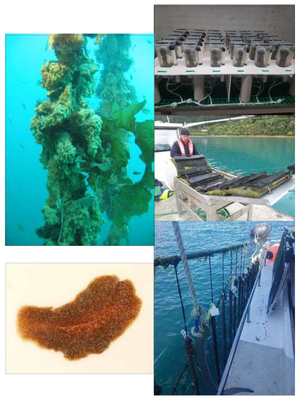
REACTIVE TOOLS





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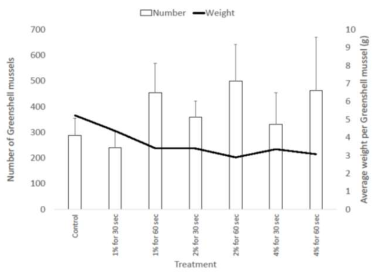
REACTIVE TOOLS



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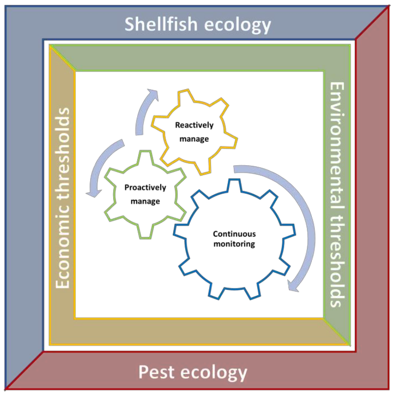
BIOFOULING MANAGED



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ACKNOWLEDGEMENTS

SANFORD

spatNZ SHELLFISH PRODUCTION & TECHNOLOGY

I AM SUSTAINABILITY. I AM OPPORTUNITY. I AM THE FUTURE.
AQUACULTURE NEW ZEALAND.

mfa MARINE FARMING ASSOCIATION

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GEOFF SWAIN
Director, Center for Corrosion and Biofouling Control
Florida Institute of Technology, USA

Dr. Geoff Swain is Professor of Oceanography and Ocean Engineering and the Director of the Center for Corrosion and Biofouling Control at the Florida Institute of Technology (FIT). He started his career at the University of Southampton, UK to develop novel methods for corrosion and biofouling control for the Royal Navy and the Department of Energy. In the early 1980's he moved to Aberdeen, Scotland where he joined a company that conducted corrosion and biofouling surveys on offshore structures in the North Sea. He joined FIT in 1984 and established the Center for Corrosion and Biofouling Control. The Center is fully staffed, has a laboratory on campus, static and dynamic seawater test facilities at Port Canaveral, two research boats and has active research grants with the Office of Naval Research and the shipping and coatings Industries. Notable accomplishments include the design of the cathodic protection system for the Living Seas at Disney World, developing an ASTM method for evaluating fouling release coatings, establishing a quality control procedure for dry docking and fouling control coatings for Royal Caribbean International, and pioneering the development of in-water grooming to maintain ship hulls in a smooth and fouling free condition. He has published over 50 refereed articles on the subject. He is a member of the National Association of Corrosion Engineers, the Society of Naval Architects and Marine Engineers, the American Society for Testing and Materials and the Marine Biological Association of the U.K.

Managing Corrosion and Biofouling of the Offshore Monopile Supports for Wind Turbines

Geoffrey Swain, Monica Maher and Kelli Hunsucker Florida Institute of Technology, Melbourne, FL, USA

In 2018 there were 4,543 grid connected offshore wind turbines representing over 17.5 Gigawatts cumulative installed capacity active in European waters of which over 70% used monopiles for their substructure and foundation (windeurope.org). The US offshore wind energy has a technical potential of over 2,000 gigawatts with a total project pipeline as of June 2018 of 25.4 gigawatts. For many of the present monopile installations there have been corrosion problems within the interiors of the structures. This research investigated the concept for the design of monopiles with perforations that enable the free circulation of seawater, corrosion control by conventional cathodic protection design and the creation of a habitat for marine life.

Partially submerged hollow steel pipes with different treatments were deployed at Port Canaveral, Florida. The results demonstrated that a cathodically protected perforated monopile structure creates an environment with more favorable corrosion mitigation and water chemistry compared to a sealed structure. Furthermore, the perforated cathodically protected pipe created a habitat for marine life and recruited a diverse population of settled and mobile organisms.

At a time when there is increasing debate about "Ocean Sprawl", there is an opportunity to manage monopiles for offshore wind turbines in a manner that enables them to provide ecosystem services in terms of fisheries, nutrient cycling and carbon fixation. However, they may also displace existing ecosystems and provide surfaces to which invasive species may spread and colonize new areas.

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Florida Institute of Technology, Melbourne FL

Managing Corrosion and Biofouling of the Offshore Monopile Supports for Wind Turbines

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Center for Corrosion and Biofouling Control
Florida Institute of Technology
Melbourne, FL

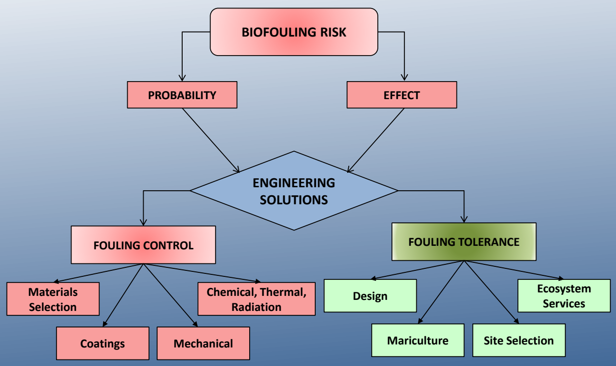
1st GEF-UNDP-IMO GloFouling R&D Forum and Exhibition on Biofouling Management
4th ANZPAC Workshop on Biofouling Management for Sustainable Shipping

Melbourne, Australia, 1-4 October 2019

Outline

- Biofouling
- Corrosion
- Hypotheses
- Experiment
- Results
- Summary

Biofouling Risk and Biofouling Management

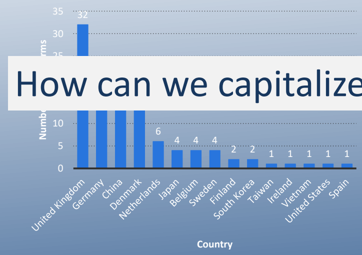


Swain, G. (2017) A guide to developing a biofouling management plan. Marine Technology Society Journal, March/April, 2017, Volume 51, Number 2, pp.105–110

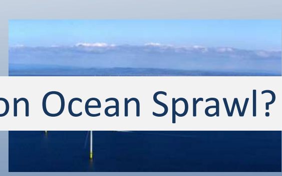
Ocean Sprawl– Offshore Wind Farms

Number of offshore wind farms worldwide as of October 2018, by country

Number of offshore wind farms worldwide by select country 2018



How can we capitalize on Ocean Sprawl?



- Walney Wind Farms
- Irish Sea, England
- 189 individual units, 1026.2 MW

Biofouling and Offshore Structures

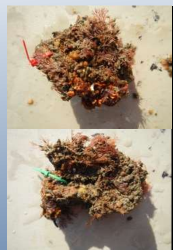
Benefits

- Artificial Reefs
- Increase Biomass
- Fish aggregates
- Aquaculture
- Habitat heterogeneity
- Ecosystem Service
  - Biomineralization
  - Carbon Sequestration
  - Food Habitat
  - Water filtration

Challenges

- Habitat Modification
  - Hydrodynamics
  - Sea Floor
  - Geology
  - Ecology
- Stepping Stone for Invasives

Ecosystem Services from Fouling



7.5 liter tanks filled with lagoon seawater.
One tank had four oyster shells fouled with: Aborescent Bryozoan, Encrusting Bryozoan, Colonial Tunicate, Sea Squirt, Calcareous Tubeworm, Sedimentary Tubeworm, Mussel, Barnacle, Amphipods

Oil Rigs and Mussel Farming

OFFSHORE OIL RIGS PROVE FERTILE FARM FOR MUSSELS ON THE COAST
By ROBERT LINDSEY, Special to the New York Times
Published: November 5, 1985

Dr. Meek perusaded Phillips Petroleum and, later, other companies to allow his company, Ecomar Inc., to clean the rigs in exchange for the mussels, with no money changing hands.

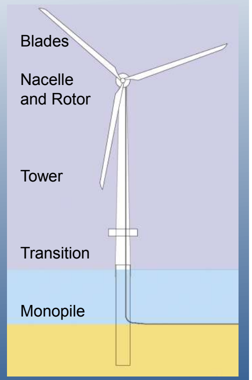
Ecomar is now selling 5,000 to 6,000 pounds of mussels weekly at about 80 cents a pound. The company harvests smaller amounts of scallops, oysters and clams from the rigs. They all ''benefit from this rich environment in the open ocean,'' Dr. Meek said.

https://bobevansphotography.com/bwg_gallery/the-mussel-company/#

Harvesting mussels from platform Hilda Removed 1996

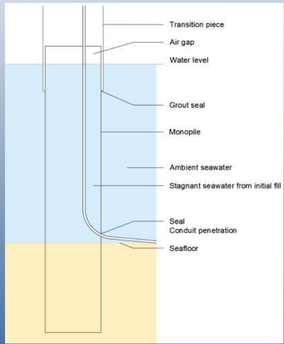
Monopile Supports

- 30m water depth
- Steel
- Wall thickness 80+mm
- 6+m diameter
- 68m long
- 38m drive in sea bed



Corrosion and Monopile Support

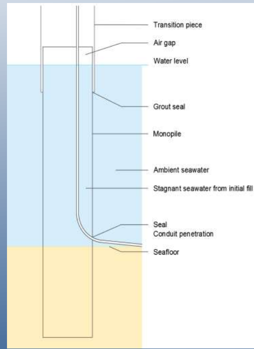
- Det Norske Veritas (DNV)
  - Offshore Standard DNV-OS-J101
- Active corrosion protection was considered unnecessary inside the monopile structures because the oxygen in the confined environment would be consumed during some initial corrosion, and then corrosion would stop once the water turned anaerobic.
- Leaks occur at conduit penetrations and grout seals, allowing oxygen ingress.
- Cathodic protection inside the confined space can affect air quality and water chemistry.



Corrosion and Monopile Support

According to Delwiche et al, based on an offshore trial in the North Sea, sacrificial anodes installed in monopile interiors cause:

- H_2S formation (hydrogen sulfide)
- Water acidification
  - attributed to aluminum sacrificial anodes
  - pH < 5
- Unique localized corrosion



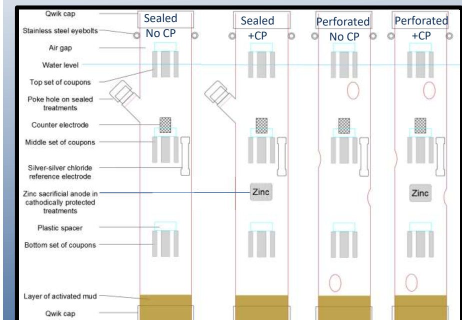
Hypotheses

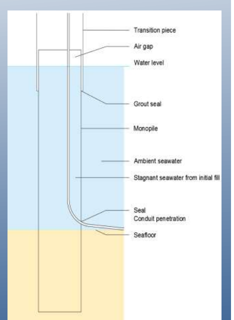
- A perforated structure will create an environment with more favorable corrosion mitigation, air quality, and water chemistry compared to the sealed structure.
- A perforated structure will create a habitat for marine life and recruit a diverse population of settled and mobile organisms.

Experimental Design

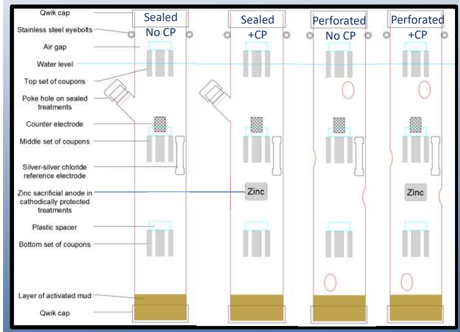
1M LONG 15CM Ø STEEL TEST PIPES

FULL SCALE 5M Ø IN 20M DEEP WATER

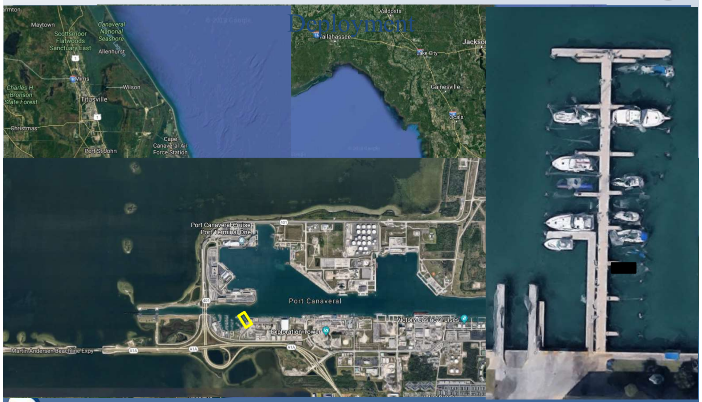




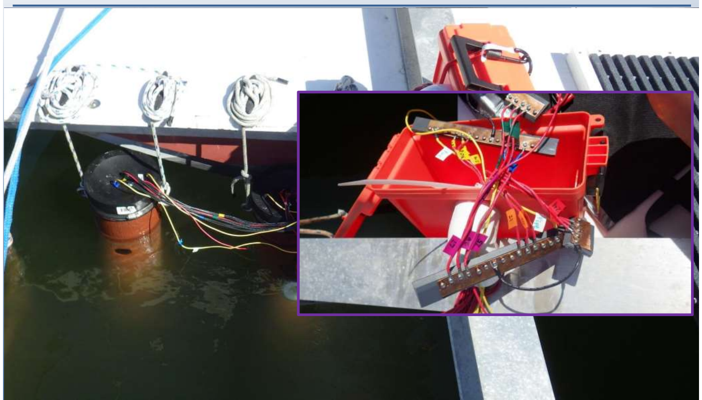
Experimental Design



Test Site



Set Up



Measurements

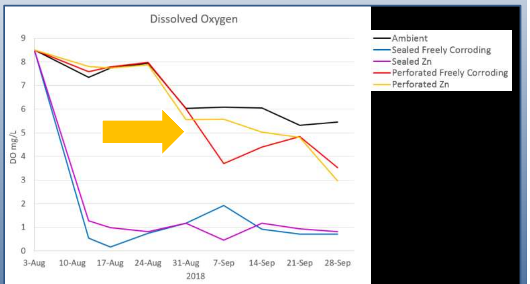
Weekly measurements

- pH with YSI probe
- Dissolved oxygen with YSI probe
- Potential of pipes and coupon set reference silver-silver chloride
- Potentiodynamic polarization with potentiostat, ramp generator, and data logger

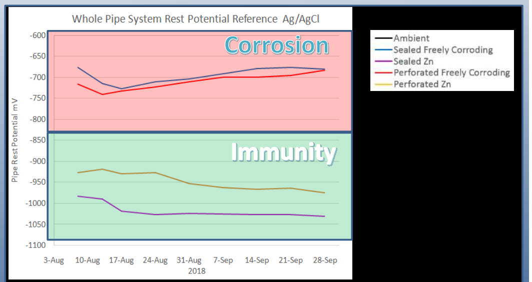
End of deployment

- Habitat observation at end of 2 month deployment
- Weight loss of steel

Water Chemistry



Potential Measurements



Condition of the Steel at the End of the Test

Sealed Pipes

- Corrosion tubercles in the splash zone
- Corrosion products on submerged surface

Orange and black corrosion tubercles in the splash zone
- iron hydroxide
- iron sulfide

Thick calcareous chalk on the submerged surface

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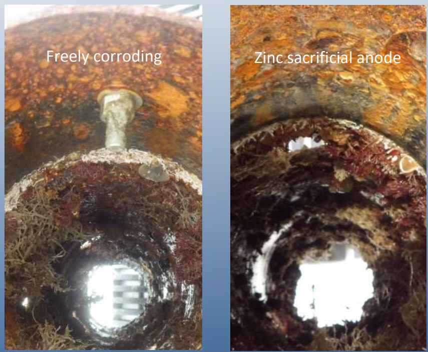
Florida Institute of Technology, Melbourne FL
Biofouling Management, Melbourne, Australia, October 2019

Perforated Pipes

- Corrosion in the splash zone
- Tubeworms at the waterline
- Corrosion and unstable biofouling cover in the submerged zone



Corrosion in the splash zone

No corrosion and diverse and stable biofouling cover in the submerged zone

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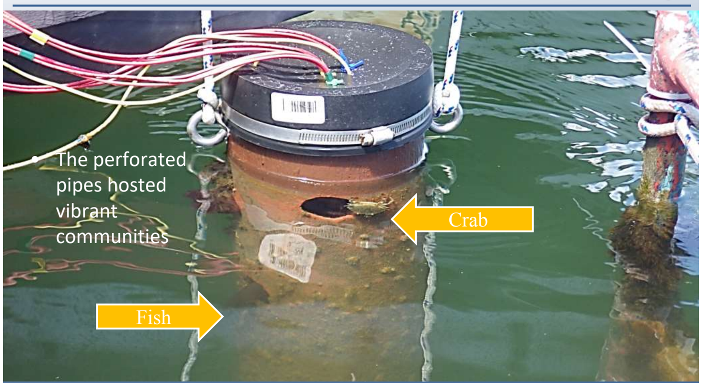
Habitat



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Perforated Freely Corroding

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Perforated Cathodically Protected

OCEANS Charleston October 2018

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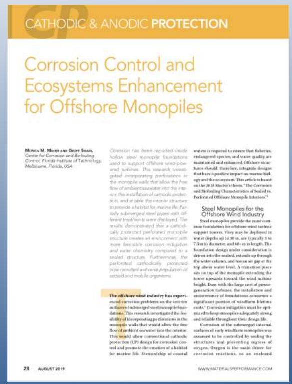
Conclusions

- Perforated monopile interior walls can more easily and predictably be protected from corrosion using cathodic protection.
- Cathodically protected perforated monopoles will enhance the ecology of a region by providing a sheltered space within which marine organisms prosper.
- Ocean Sprawl needs to be engineered and managed in a way that compliments the local ecology and provides ecosystem services

Innovation of the Year Corrosion 2019



CATHODIC & ANODIC **PROTECTION**

Corrosion Control and Ecosystems Enhancement for Offshore Monopiles

Monica M. Maher and Geoff Swain,
Center for Corrosion and Biofouling Control, Florida Institute of Technology, Melbourne, Florida, USA

Corrosion has been reported inside hollow steel monopile foundations used to support offshore wind-powered turbines. This research investigated incorporating perforations in the monopile walls that allow the free flow of ambient seawater into the interior, the installation of cathodic protection, and enable the interior structure to provide a habitat for marine life. Partially submerged steel pipes with different treatments were deployed. The results demonstrated that a cathodically protected perforated monopile structure creates an environment with more favorable corrosion mitigation and water chemistry compared to a sealed structure. Furthermore, the perforated cathodically protected pipe recruited a diverse population of settled and mobile organisms.

The offshore wind industry has experienced corrosion problems on the interior surfaces of submerged steel monopile foundations. This research investigated the feasibility of incorporating perforations in the monopile walls that would allow the free flow of ambient seawater into the interior. This would allow conventional cathodic protection (CP) design for corrosion control and promote the creation of a habitat for marine life. Stewardship of coastal waters is required to ensure that fisheries, endangered species, and water quality are maintained and enhanced. Offshore structures should, therefore, integrate designs that have a positive impact on marine biology and the ecosystem. This article is based on the 2018 Master's thesis, "The Corrosion and Biofouling Characteristics of Sealed vs. Perforated Offshore Monopile Interiors."[1]

Steel Monopiles for the Offshore Wind Industry

Steel monopiles provide the most common foundation for offshore wind turbine support towers. They may be deployed in water depths up to 30 m, are typically 5 to 7.5 m in diameter, and 60+ m in length. The foundation design under consideration is driven into the seabed, extends up through the water column, and has an air gap at the top above water level. A transition piece sits on top of the monopile extending the tower upwards toward the wind turbine height. Even with the large cost of power-generation turbines, the installation and maintenance of foundations consumes a significant portion of windfarm lifetime costs.[2] Corrosion mitigation must be optimized to keep monopiles adequately strong and reliable throughout their design life.

Corrosion of the submerged internal surfaces of early windfarm monopiles was assumed to be controlled by sealing the structures and preventing ingress of oxygen. Oxygen is the main driver for corrosion reactions, so an enclosed

28 AUGUST 2019 WWW.MATERIALSPERFORMANCE.COM

ANDREW WANT
Assistant Professor
Heriot-Watt University, United Kingdom

Dr Andrew Want is a marine ecologist with specialist expertise in biofouling and hard substrate epifaunal assemblages, including barnacles and macroalgae in high-energy habitats targeted by the Offshore Renewable Energy (ORE) sector. Andrew is currently Assistant Professor at the Orkney campus of Heriot-Watt University in Scotland. His research background in biofouling includes developing and leading the international Biofouling in Renewable Energy Environments (BioFREE) project, as well the numerous other projects such as Forensic Decommissioning of Tidal Energy Converters (FoDTEC) study.

In addition to these biofouling projects described above, he has: conducted numerous surveys of offshore energy infrastructure; worked with local fisheries in improving ecological functioning of marine infrastructure; researched genetic connectivity of isolated algal populations in the North Atlantic; and, surveyed Marine Protected Areas and priority marine features for governmental regulators. Through this research and collaborations, he has built strong connections throughout the biofouling and ORE sectors, and with marine subcontractors and regulatory bodies.

Dr. Want has extensive teaching experience at postgraduate and undergraduate level, and regularly presents at international conferences. Recent peer-reviewed papers have been published in journals including: Biofouling*;* Ocean and Coastal Management*;* Renewable and Sustainable Energy Reviews*; and,* International Journal of Marine Energy*.*

Monitoring biofouling, and testing antifouling coatings, in the offshore renewable energy industry

Andrew Want, Joanne S. Porter, Robert E. Harris
Heriot-Watt University – Orkney Campus, Stromness, Orkney, UK

Britain's seas are being targeted for deployment of offshore renewable energy (ORE) devices, i.e. wave, tidal, and offshore wind technologies, as part of UK governmental plans to decarbonise electricity generation. Biofouling affects ORE device performance by increased drag, accelerated corrosion, and additional loadings on moorings and other infrastructure. Ecological concerns exist regarding the role that these structures might play in the transfer of invasive aquatic species (IAS), as ORE deployments are happening in areas where structures have not been previously installed (e.g. extreme tidal flow areas), and where biofouling studies are uncommon.

In the BioFREE project, a collaboration between Heriot-Watt University and the European Marine Energy Centre, we designed a novel system for monitoring biofouling in any depth within the water column at high- energy wave and tidal ORE target sites. This system has been used to characterise biofouling in Orkney (UK), Chile, Japan and the USA. It also provides a platform to test anti-fouling coatings applied to materials relevant to the industry.

Results indicate that major biofouling species differ between sites owing to hydrodynamic conditions, water depth, substrate type, and deployment timing. Species exhibit contrasting patterns of seasonal reproduction, settlement, and growth. These studies did not find evidence of IAS at high-energy exposed sites. It is possible that hydrographic barriers prevent successful recruitment of IAS in these locations. However, the transfer of IAS into harbours is more likely with increased traffic of industry support vessels. Our findings inform site- specific guidance to regulating bodies and the ORE industry regarding anti-fouling strategies, including scheduling deployment and maintenance of devices and infrastructure to times when settlement of IAS is minimal or their removal least costly.

Monitoring biofouling, and testing antifouling coatings, in the offshore renewable energy industry

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ORKNEY CAMPUS

Dr. Andrew Want
04 October 2019 – Melbourne

GloFouling Partnerships

With partners: Dr. Joanne Porter, Dr. Robert Harris, and Caitlin Long

HERIOT WATT UNIVERSITY
ORKNEY CAMPUS


Dr Joanne Porter


Dr Rob Harris


Dr Mike Bell

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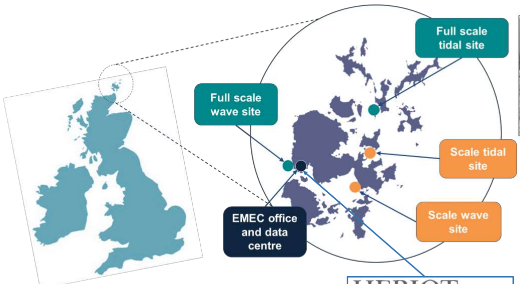

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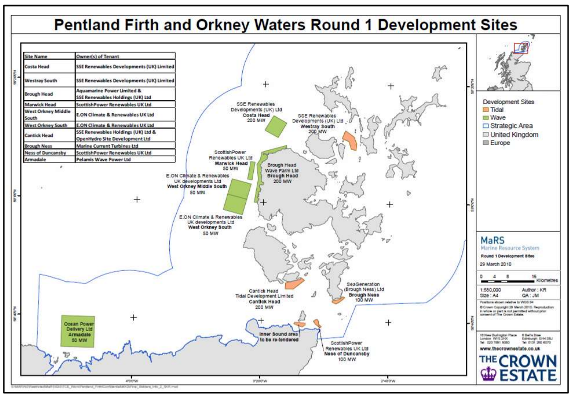
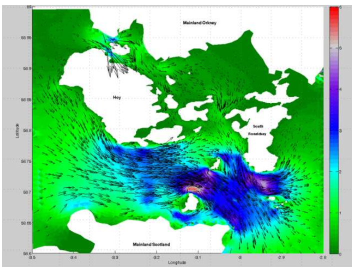


Site Name	Owner(s) of Tenant
Costa Head	SSE Renewables Developments (UK) Limited
Westray South	SSE Renewables Developments (UK) Limited
Brough Head	Aquamarine Power Limited & SSE Renewables Holdings (UK) Ltd
Marwick Head	ScottishPower Renewables UK Ltd
West Orkney Middle South	E.ON Climate & Renewables UK Ltd
West Orkney South	E.ON Climate & Renewables UK Ltd
Cantick Head	SSE Renewables Holdings (UK) Ltd & OpenHydro Site Development Ltd
Brough Ness	Marine Current Turbines Ltd
Ness of Duncansby	ScottishPower Renewables UK Ltd
Armadale	Pelamis Wave Power Ltd

Pentland Firth and Orkney Waters:

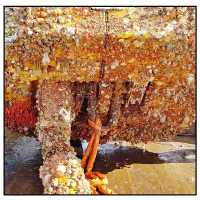
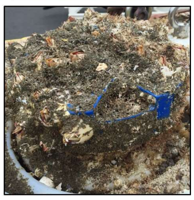


Phase 1A: 4 x 1.5 MW tidal turbines
Phase 1B: 8 x 1.5 MW tidal turbines
Phase 1C: 57 x 1.5 MW tidal turbines (85.5 MW)

What is the problem?

- Increased roughness and weight thereby impacting drag and energy capture
- Accelerating corrosion of components, i.e. subsea connectors, etc.
- Removal of fouling/antifouling strategies are costly, requiring additional operational 'down-time'



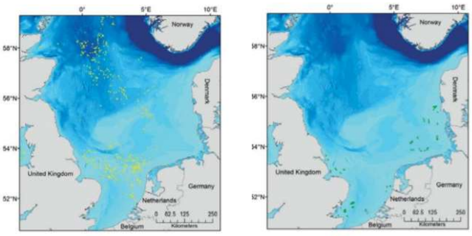
Is this a new problem?

Yes, there are several issues unique to the Offshore Renewable Energy (ORE) sector:

- Novel components/materials used in the sector
- Devices are being placed in poorly understood habitats
- Sensor accuracy is compromised leading to inaccurate determination of device performance and resource assessment

… the hydrodynamic and mechanical consequences of biofouling organisms on moving structures are of particular concern, to industry…

Providing surfaces on artificial structures in the marine environment may create 'stepping-stone' habitats for the spread of fouling communities (including non-native species)



Oil and Gas (left) and Offshore Wind (right) installations. From: Coolen *et al*. 2017

Scientists are working closely with test site personnel, device developers and engineers to gather data, share knowledge and formulate expertise on biofouling most relevant in helping develop the Offshore Renewable Energy (ORE) industry

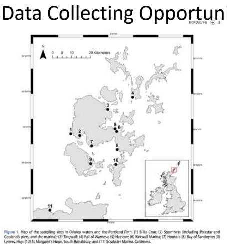
Objectives:

- Gather data from poorly-studied, high-energy habitats targeted by the ORE sector
- Develop a biofouling monitoring and testing system designed for deployment at extreme-energy wave and tidal sites
- Testing of materials used by the ORE industry and anti-fouling strategies
- Provide guidance to better manage fouling…

Guidance to better manage fouling in the ORE sector…

- Lowered Levilized Cost of Electricity generated by ORE sector;
- Biofouling management plans/protocols for ORE sector;
- Biosecurity and marine planning.

Data Collecting Opportunities:



Biofouling sampling – Waverider buoy - off Billia Croo

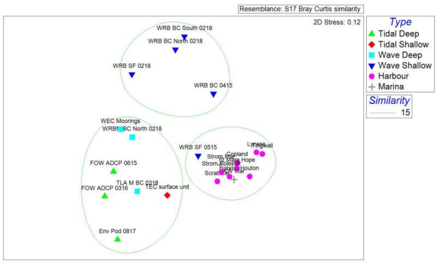
Clockwise from top left: map of survey locations in Orkney; settlement panels - EMEC infrastructure; waverider buoy survey; evidence of gregarious settlement and coating preference; test panels (Whitford Ltd.) - Stromness Harbour.

Survey Date	Device	Substrate	Site	Dominant fouling organisms		
20-Dec-17	ADCP	HDPE/steel	FW	*Anomia ephippium*	n/a	n/a
27-Feb-18	WRB	Steel	BC	*Ectopleura larynx*	*Petalonia fascia*	*Hincksia hincksia*
27-Feb-18	WRB	Steel	BC	*Hincksia hincksia*	*Petalonia fascia*	*Lomentaria clavellosa*
27-Feb-18	WRB	Steel	SF	*Petalonia fascia*	*Semibalanus balanoides*	*Jassa falcata/marmorata*
01-Apr-18	WEC moorings	Fiberglass	BC	*Chirona hameri*	*Metridium dianthus*	*Anomia ephippium*
20-May-18	WEC Cable End	Steel	BC	*Chirona hameri*	*Balanus balanus*	n/a
29-Jun-18	WEC	Steel	SF	*Balanus crenatus*	*Electra pilosa*	n/a
16-Aug-18	WEC Moorings	Mixed	SF	*Balanus crenatus*	*Balanus balanus*	*Spirobranchus triqueter*
18-Sep-18	ADCP	HDPE/steel	SF	*Spirobranchus triqueter*	*Metridium dianthus*	*Mytilus edulis*
09-Oct-18	TEC subunit	Steel	FW	*Ciona intestinalis*	*Chirona hameri*	*Ascidiella aspersa*
15-Oct-18	WRB	Steel	BC	*Semibalanus balanoides*	*Amphisbetia operculata*	*Mytilus edulis*
17-Oct-18	WRB	Steel	SF	*Chordaria flagelliformis*	*Ulva lactuca*	*Semibalanus balanoides*

Key fouling species on ORE substrates in Orkney waters include (from left): the Saddle Oyster *Anomia ephippium*; barnacles, such as *Balanus balanus*; macroalgal turf (including *Chordaria flagelliformis*, *Petalonia fascia*, and *Ulva lactuca*); and the sea anemone *Metridium dianthus*.

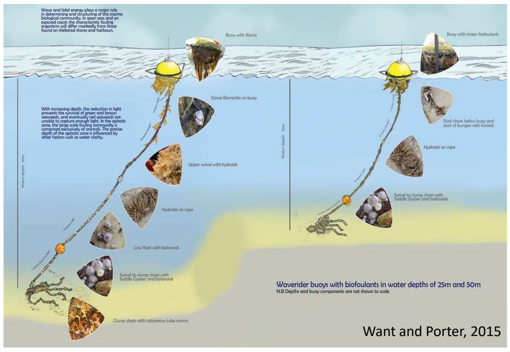
Analysis of Biofouling Survey Data:

- 200+ species recorded
- 7 NNS (in harbours/marinas)
- PRIMER software
- Bray Curtis similarity to explore differences in species between locations
- ANOSIM algorithm to see which species most responsible for the differences
- MDS plot to show differences visually in species suites, between locations



MDS plot using biofouling community data associated with various types of substratum. Ellipses represent groups identified by average-linkage cluster analysis based on Bray–Curtis similarities. The terms 'deep' and 'shallow' refer to the submerged depth of the fouled substrate rather than the bathymetric depth.

Biofouling at different depths and hydrodynamic conditions:

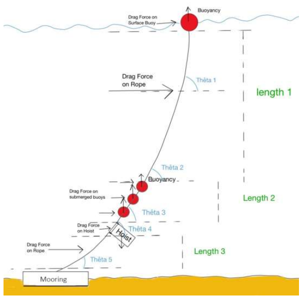


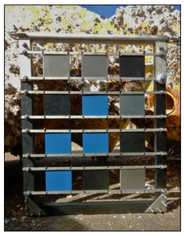
BioFREE Monitoring and Testing System:

- Monitoring of fouling organisms at different depths and energy levels
- System allows testing of different materials and anti-fouling coatings
- Allows easy deployment and retrieval for regular access
- Physically and statistically robust

System designed to:

- Minimise drag – allowing deployment in high-flow areas
- Provide buoyancy – necessary to maintain position



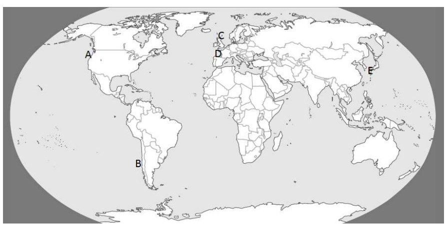


Site	Depth (m)	Height (m)
Billia Croo	45	3
Fall of Warness	40	15
Scapa Flow	25	3
Shapinsay Sound	25	5

Deployment water depth (depth) and maximum height of the frame above the seabed (height) of BioFREE frames deployed at EMEC test sites in July 2018

A: NNMREC – Oregon, USA
B: MERIC – Las Cruces, Chile*
C: EMEC – Orkney, UK
D. FEM – Bretagne, France*
E: OMST – Nagasaki, Japan

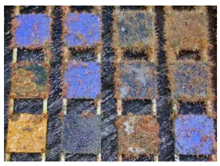
* Awaiting deployment



16-17 October 2018 (deployed mid-July)

Fall of Warness:
-High flow
-Moderate wave

Ectopleura larynx
Jassa marmorata
Celleporella hyalina



Billia Croo:
-High wave
-Moderate flow

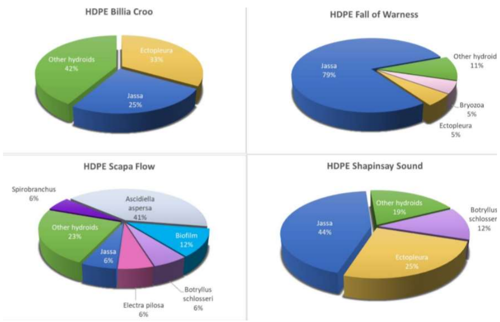
Obelia dichotoma
Anomia ephippium
Electra pilosa

Shapinsay:
-Moderate flow
-Moderate wave

Ectopleura larynx
Ascidiella aspera
Plumularia setacea

Scapa Flow:
-Moderate wave
-Low flow

Spirobranchus triqueter
Ascidiella aspera
Anomia ephippium



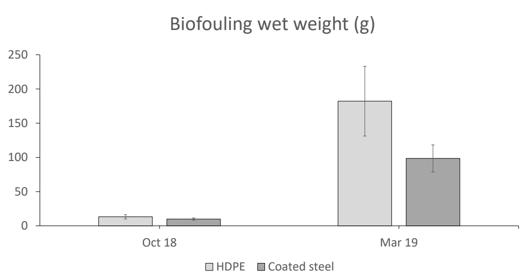
Billia Croo:
-Extreme wave
-Moderate tidal flow

Fall of Warness:
-Moderate wave
-Extreme tidal flow

Scapa Flow:
-Moderate wave
-Low tidal flow

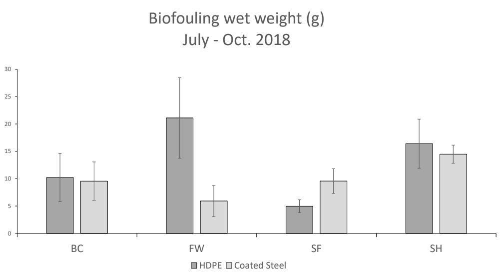
Shapinsay Sound:
-Moderate wave
-Moderate tidal flow

Substrate and Biofouling



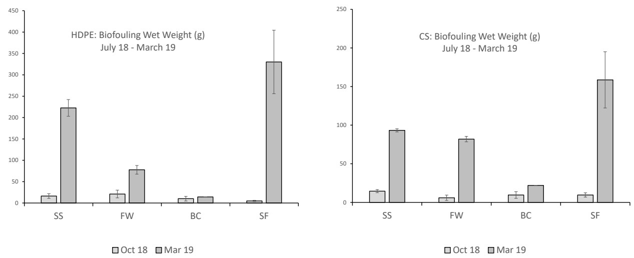
Mean wet weight (g) of biofouling on HDPE and coated steel panels (n = 8) deployed at EMEC test sites from July 2018 to March 2019 (± S.E.).

Test site and Biofouling



Mean wet weight (g) of biofouling on replicate panels deployed at EMEC test sites from mid-July to mid-October 2018. BC: Billia Croo; FW: Fall of Warness; SF: Scapa Flow; and, SH: Shapinsay Sound (± S.E.).

Growth of Biofouling



Mean wet weight (g) of biofouling on replicate panels deployed at EMEC test sites from July 2018 to March 2019. BC: Billia Croo; FW: Fall of Warness; SF: Scapa Flow; and, SS: Shapinsay Sound (± S.E.).

Seasonality and Succession
Scapa Flow

October 2018

January 2019

September 2019

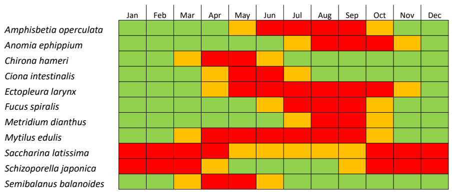
General findings/comments:

- Proven success of BioFREE monitoring and testing system which can be used to provide detailed characterisation anywhere and at any chosen placement within the water column
- ORE fouling organisms are highly specific to location
- ORE fouling varies depending on water depth and substrate type
- ORE fouling assemblages are predictable based on hydrodynamic conditions
- Orientation (relative to flow) may be an important variable in ORE fouling
- Anti-fouling coatings may be most effective at preventing fouling in high current flow conditions
- Accurate assessment of biofouling impacts is essential for maximising ORE capture, i.e. lowering electricity generating costs

Seasonality and Succession:

- Evidence gathered has provided examples of profound levels of fouling occurring over a relatively short period of time, depending on seasonality and succession
- Marked seasonality of fouling suggest that scheduling deployment and maintenance operations in a targeted manner may be an effective means to minimise fouling impacts and mitigate risk of invasive species

Waverider buoy deployed for >8 mths; fouling dominated by the barnacle *Semibalanus balanoides*.



Periods of settlement associated with major fouling organisms at MRE test sites in Orkney. Months in red indicate the highest recognised settlement season, orange months are of intermediate concern, and green months are of least concern. Table updated from Want *et al*., 2017.

Non-native Species (NNS): Orkney

- *Austrominius modestus* – Stromness Marina
- *Corella eumyota* – Kirkwall Marina
- *Schizoporella japonica* – Hatston Pier
- *Caprella mutica* – Stromness Marina
- … and others

Note: no NNS have been recorded at ORE sites in Orkney

FODTEC Forensic Decommissioning of Tidal Energy Converters

- ROV surveys
- Dive surveys
- Biofouling studies
- Structural inspection of recovered components
- Metallurgical analysis

BLACKFISH ENGINEERING DESIGN AND PRODUCT DEVELOPMENT · HERIOT WATT UNIVERSITY ORKNEY CAMPUS · ICIT · Brunel University London

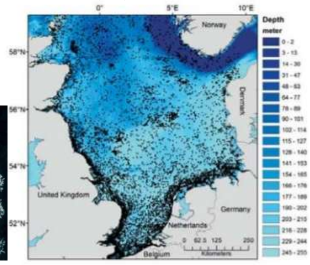
Connectivity of Hard Substrate Biofouling in the North Sea

- Using the Scottish Shelf Model (MSS/De Dominis *et al*., 2018) improved through validating data collected by monitoring and genetic studies
- Decommissioning/derogation of Oil and Gas installations; deployment of Offshore Wind Farms

- HWU Team
- Dr Michela De Dominicis (National Oceanography Centre)
- Dr. Alejandro Gallego (Marine Scotland Science)
- Dr. Andrea Waschaenbach (Natural History Museum)
- Prof. Mike Elliott (University of Hull)

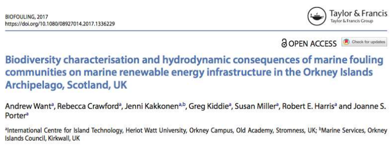
Steering Group:
-Oil and Gas Innovation Centre;
-Joint Nature Conservation Committee;
-BP;
-Aquatera Ltd.

Lophelia pertusa



North Sea wrecks. From: Coolen *et al*. 2017

Further Information:


BIOFOULING, 2017
https://doi.org/10.1080/08927014.2017.1336229

Taylor & Francis

OPEN ACCESS

Biodiversity characterisation and hydrodynamic consequences of marine fouling communities on marine renewable energy infrastructure in the Orkney Islands Archipelago, Scotland, UK

Andrew Want[a], Rebecca Crawford[a], Jenni Kakkonen[a,b], Greg Kiddie[a], Susan Miller[a], Robert E. Harris[a] and Joanne S. Porter[a]

[a]International Centre for Island Technology, Heriot Watt University, Orkney Campus, Old Academy, Stromness, UK; [b]Marine Services, Orkney Islands Council, Kirkwall, UK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Home » BioFREE (Biofouling in Renewable Energy Environments)

BioFREE (Biofouling in Renewable Energy Environments)

OES ENVIRONMENTAL the task formerly known as Annex IV

Webinar #17 in the OES-Environmental Webinar Series
March 1, 2019 at 15:00 UTC (7:00 am PT / 10:00 am ET / 3:00 pm GMT)

Event	
Title:	BioFREE (Biofouling in Renewable Energy Environments)
Location:	Online
Date:	March 1, 2019 15:00-16:30 UTC+00:00
Technology Type:	Marine Energy general

The BioFREE (Biofouling in Renewable Energy Environments) project has commenced data collection from biofouling monitoring systems deployed across international marine renewable energy (MRE) test centres. This webinar will discuss current environmental research efforts in relation to tackling biofouling.

https://tethys.pnnl.gov/events/biofree-biofouling-renewable-energy-environments

Acknowledgements:

HERIOT WATT UNIVERSITY ORKNEY CAMPUS · IMO GloFouling Partnerships · EMEC THE EUROPEAN MARINE ENERGY CENTRE LTD · NERC SCIENCE OF THE ENVIRONMENT · Interreg North-West Europe FORESEA · Whitford · Wello · Pacific Northwest NATIONAL LABORATORY · NIU · ORBITAL MARINE POWER · CORPOWER OCEAN · SIMEC ATLANTIS ENERGY · FRANCE ENERGIES MARINES · Oregon State University · MERIC marine energy research & innovation center

a.want@hw.ac.uk

CRAIG SHERMAN
Molecular ecologist
Deakin University, Australia

Craig Sherman is a molecular ecologist based at Deakin University and has experience working on a number of marine and terrestrial species. Craig's research uses a combination of ecological and molecular approaches to address fundamental and applied questions in the fields of invasive species biology, genetic adaptation, and ecosystem resilience. Craig is a collaborative researcher working with academics, industry and government agencies to find management solutions to complex environmental issues facing coastal and marine ecosystems.

The use of environmental DNA for detecting the presence and spread of invasive species

The unprecedented spread of invasive species worldwide is recognised as one of the leading threats to global biodiversity and ecosystem function, especially in inshore marine ecosystems where rates of species introductions are accelerating due to the increase in commercial shipping on a global scale. Worldwide there is an increasing demand for new innovative marine biosecurity tools allowing for early detections of new pest incursions, and timely responses that prevent species spread and proliferation. Environmental DNA (eDNA) is one such tool that provides a cost-effective and non-invasive survey method with unparalleled sensitivity for determining species presence via the detection of extracellular genetic material in environmental samples. Although the technology has the potential for assisting the Australian marine biosecurity sector, the application of eDNA tools for monitoring Australian marine pests has been limited to date. Here we report on the use of species specific TaqMan RT-qPCR assays to test for the presence of invasive marine pests in Victorian ports and coastal waters. We also test the sensitivity of eDNA assays by assessing the rates of eDNA decay and the spatial limits of eDNA detection around a known source population. Our study shows that eDNA provides a highly sensitive tool that provides high temporal and spatial resolution for the detection of invasive species.

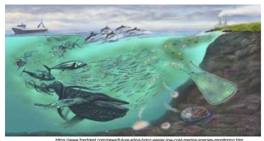
The use of eDNA for detecting the presence and spread of invasive species



Craig Sherman

Environmental DNA (eDNA)

- Detects traces of DNA shed into the environment
- Allows species detection by taking a simple environmental sample
- Emerging tool for biological monitoring

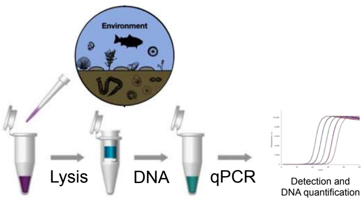


https://www.fondriest.com/news/future-edna-bring-easier-low-cost-marine-species-monitoring.htm

https://fishbio.com/field-notes/conservation/traces-left-behind

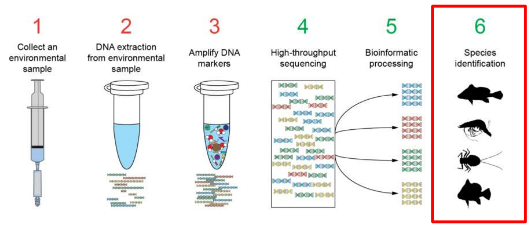
Two main eDNA approaches

- Targeted probe (qPCR or ddPCR)
  - DNA is amplified using fluorescently labelled species specific genetic probes (TaqMan®)
  - confirms species presence/absence
  - Great if you know what you are looking for!



Two main eDNA approaches

- Metabarcoding
  - Broader survey of taxonomic groups



http://www.sixthresearcher.com/amplicon-sequencing-and-high-throughput-genotyping-metagenomics/

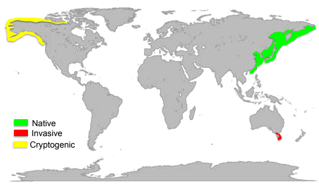
Current eDNA projects in marine biosecurity

- Identify new incursions
- Determine mechanisms of range expansion
- Assess detection limits and decay rates
- National Marine Pest Reference project


https://zeavida.com/

Northern Pacific Seastar

- Native to China, Japan, Korea and Russia

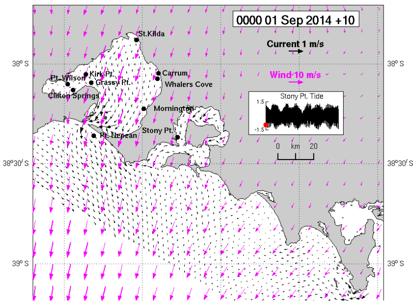



Northern Pacific Seastar

© Pang Quong

Determining source and mechanisms of range expansion

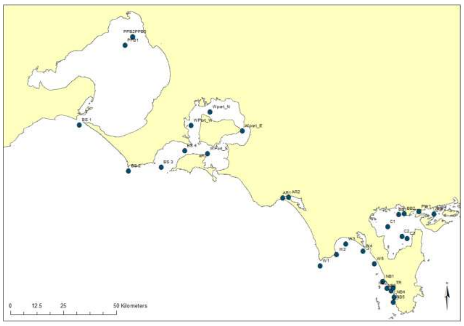
Larval dispersal model



Estimated 43 days for particles to travel from PPB to Tidal River

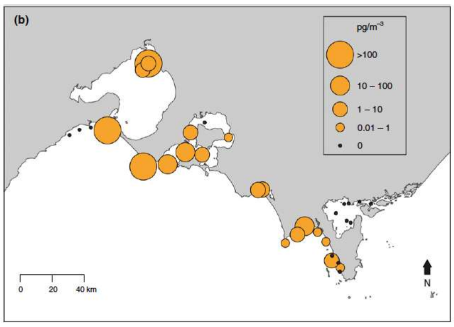
Richardson *et al.* (2016) Molecular Ecology. 25:5001-5014

eDNA sampling



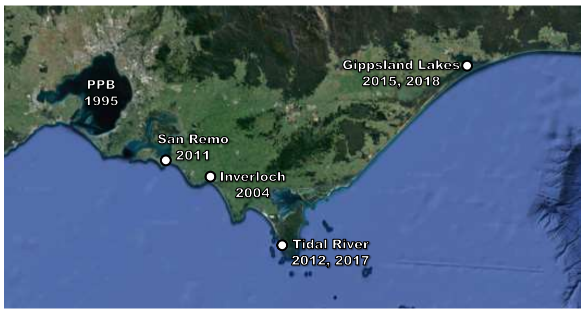
Richardson *et al.* (2016) Molecular Ecology. 25:5001-5014

eDNA sampling

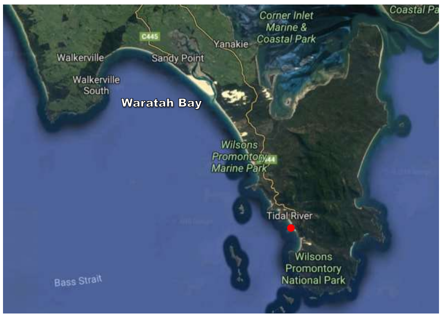


Richardson *et al.* (2016) Molecular Ecology. 25:5001-5014

Determining source and mechanisms of range expansion

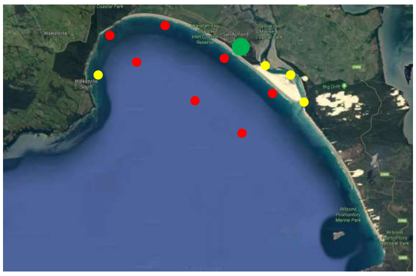


Northern Pacific Seastar returns to Wilsons Prom

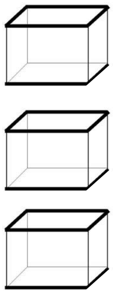


eDNA surveys: Waratah Bay

eDNA surveys: Waratah Bay

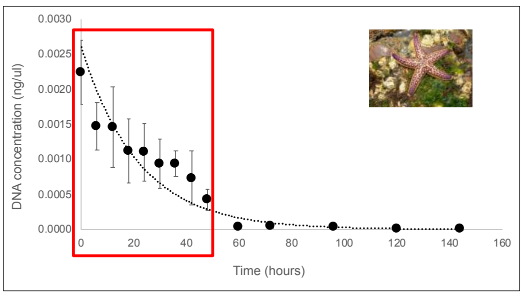


How long does eDNA persist for?



<u>Sample</u>
0 Hrs
6 Hrs
12 Hrs
18 Hrs
24 Hrs
30 Hrs
36 Hrs
42 Hrs
48 Hrs
60 Hrs
72 Hrs
96 Hrs
120 Hrs
148 Hrs
168 Hrs
336 Hrs

eDNA decay trials



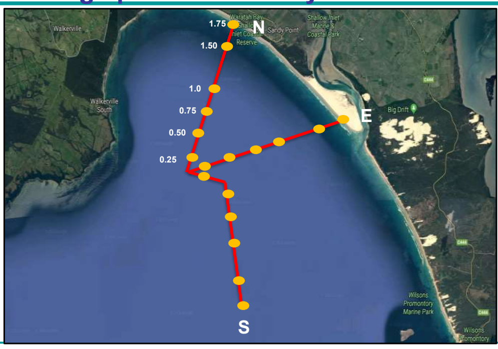
Japanese kelp – *Undaria pinnatifida*

Japanese kelp – *Undaria pinnatifida*

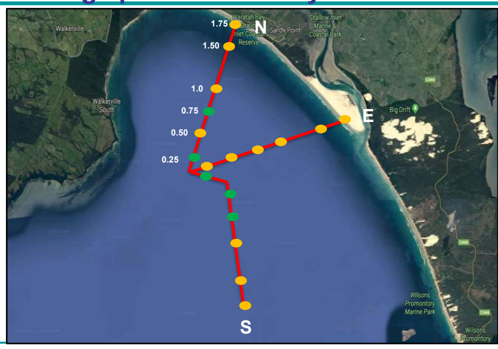
- Determine spatial and temporal detection sensitivity of the assay
- Test for species presence in selected Victorian ports and harbours

Study location – Apollo Bay Victoria

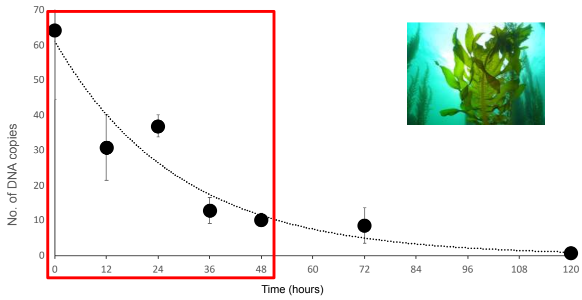
Determining spatial sensitivity



Determining spatial sensitivity



eDNA decay trials

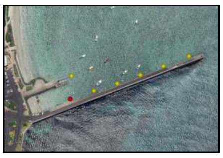


Applying assay to surveys of Victorian Ports

Victorian Ports: Portland, Warrnambool, Hastings, Port Albert, Port Franklin

Positive detections at three new locations

Portland Harbour

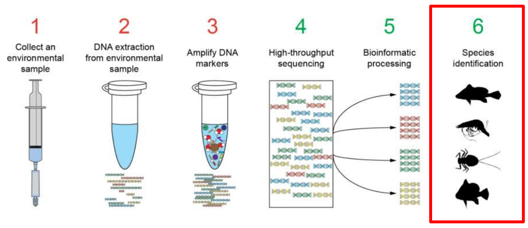


Warrnambool

Hastings

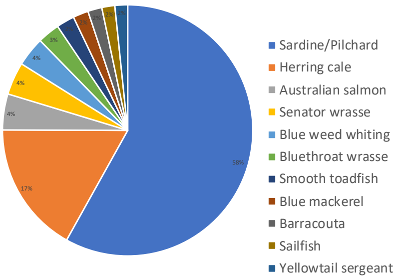
eDNA metabarcoding approaches

– Broader survey of taxonomic groups



http://www.sixthresearcher.com/amplicon-sequencing-and-high-throughput-genotyping-metagenomics/

Fish biodiversity surveys



Genomic reference resources for marine biosecurity

National Marine Pest Reference project

- Aim: Develop genomic reference resources for invasive and closely related native taxa (64 samples)
- Skimseq: Low coverage genome sequencing (61 samples)

Australian Government
Department of Agriculture

Department of Primary Industries and Regional Development
GOVERNMENT OF WESTERN AUSTRALIA

Genomic reference resources for marine biosecurity

- Recover full mitochondrial genomes
- Partial nuclear genomes

Australian Government
Department of Agriculture

Department of Primary Industries and Regional Development
GOVERNMENT OF WESTERN AUSTRALIA

Genomic reference resources for marine biosecurity

- What makes a good reference resource/database
- Robust taxonomic identification (yes we still need taxonomists)
- Sequence invasive reference samples
- Sequence native reference samples
- Need good taxonomic resolution
- Provide a publicly available resource for monitoring

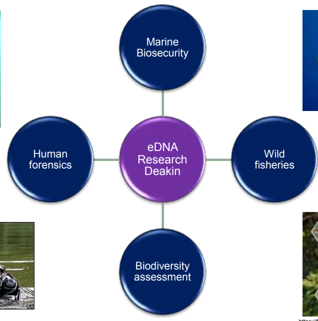
Collaborators

Adam Miller – Deakin University
Richard Stafford-Bell – Jobs, Precincts & Regions
Nathan Bott – RMIT University
Zach Clark – Student (Deakin)
Morgan Ellis – Student (Deakin)
Mark Richardson – Student (Deakin)
Brett Herbert – Department of Agriculture
Justin McDonald – Primary Industries WA
Dave Abdo – Primary Industries WA
Andrew Weeks – ENVIRO DNA
Randall Lee – EPA
Steffan Howe – Parks Vic
Jacqui Pocklinton – Parks Vic

Parks Victoria
RMIT University
Australian Government Department of Agriculture
EPA Victoria Environment Protection Authority Victoria
Victoria State Government Jobs, Precincts and Regions
Government of Western Australia Department of Primary Industries and Regional Development
EnviroDNA

eDNA research at Deakin

https://zeavida.com/



https://fishbio.com/field-notes/conservation/traces-left-behind

ROWAN FENN
CEO
rise-x.io, Australia

Rowan is a Father, a Scientist, an Optimist and an Entrepreneur. As a Father of two, Rowan is responsible for providing a better future for the next generation and the generations that follow.

As a Scientist, Rowan is fascinated by the challenge of meeting global demand of a growing population in the context of the global climate emergency. As an Optimist, Rowan believes that together we will meet, and that the answer lies in the rapid adoption of existing and emerging technologies at speed and at scale to eliminate repetitive, task orientated workflow to liberate human potential and unlock the creative capacity required to meet the climate emergency with the urgency it demands. As an Entrepreneur, he is excited by the scope and scale of the opportunity to re-invent the global industrial ecosystem. Never before has an opportunity so massive presented itself on a timeline so minute, driven by an imperative so existential.

He is the founder and CEO of rise-x technologies in Australia building the DIANA Platform for the great industrial re-invention and the co-founder and CEO of QuayChain, based in Singapore using the DIANA Platform to automate bunkering in the maritime industry. Prior to starting his companies, Rowan worked At Accenture and Deloitte in their energy strategy business, where he had the privilege of working with the world's largest and most admired companies in geographies around the world.

Introduction to BioPass, a simple, pragmatic solution designed to manage biofouling for the international shipping industry

Marine growth on the hull of ships, or biofouling, is now recognised by the IMO as a major vector for bio- invasions, presenting a risk to biogeographic regions which is equal to if not greater than the threat posed by improper treatment of ballast water.

To address this global issue. the international maritime organisation (IMO) have developed global guidelines for the control and management of ships' biofouling. The Guidelines (resolution MEPC.207(62)) are intended to provide a globally consistent approach to the management of biofouling.

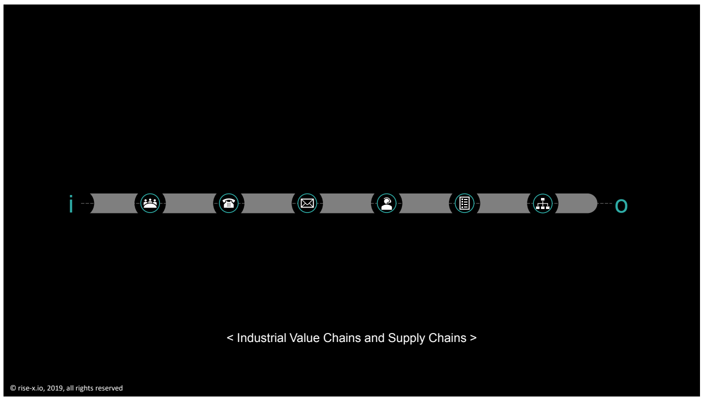
BioPass is a novel technology platform designed to support the implementation of the IMO biofouling guidelines while also enhancing stakeholder and institutional cooperation to reduce the risk bio-invasions while also reducing the costs associated with managing this risk.

BioPass is an intuitive management system designed to capture data from in water survey, inspection and hull cleaning apparatus. BioPass captures data about the condition of the ship's hull during the process of inspection or cleaning using novel IoT enabled devices to capture real time video information. Machine Learning and Artificial Intelligence (AI) identify potential invasive marine species (IMS) and eDNA testing is used to confirm and or determine the presence of invasive marine species.

Data captured during the in-water hull cleaning process is stored and maintained in a permissioned blockchain to allow Ship Owners to easily share their biofouling management plan, biofouling maintenance records and information (Collectively referred to as their BioPass) with Port Authorities across multiple jurisdictions, allowing for frictionless vessel entry under controlled conditions.

BioPass will **(a)** dramatically improve the biosecurity of global marine environments, **(b)** reducing the cost to operate for marine vessel owners and operators, **(c)** reduce the cost of compliance with incoming IMO biofouling regulations, and **(d)** reduce the cost of managing compliance for Australian and international port authorities.


BIOPASS
CleanSubSea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< Industrial Value Chains and Supply Chains >
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Non-value add activities | Friction | Redundancy | Waste
© rise-x.io, 2019, all rights reserved


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Eliminate | Automate | Virtualize | Optimise
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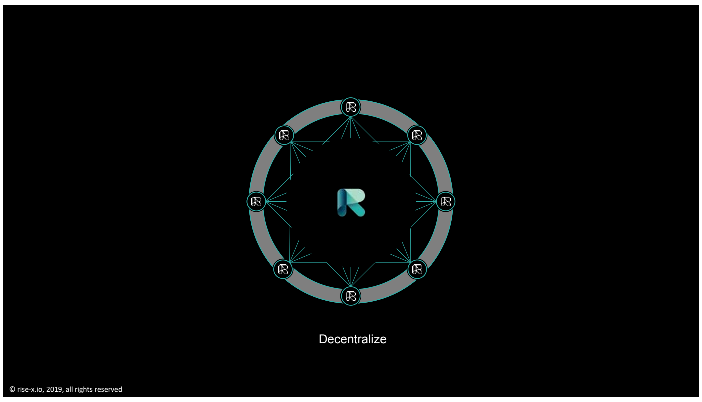
Decentralize
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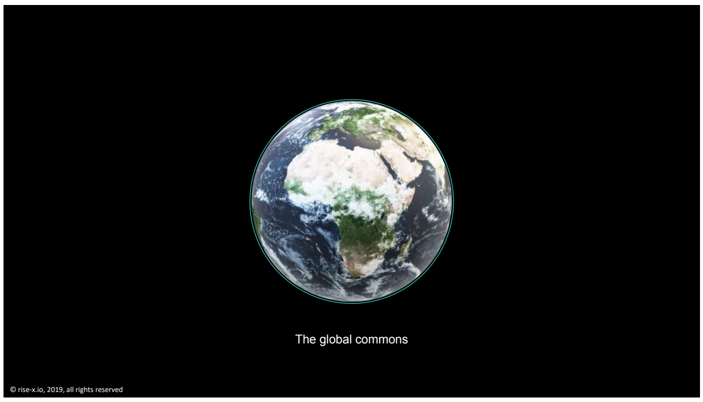
The global commons
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9.1
Billion
?
1.5
°C
1
%
The resources trilemma
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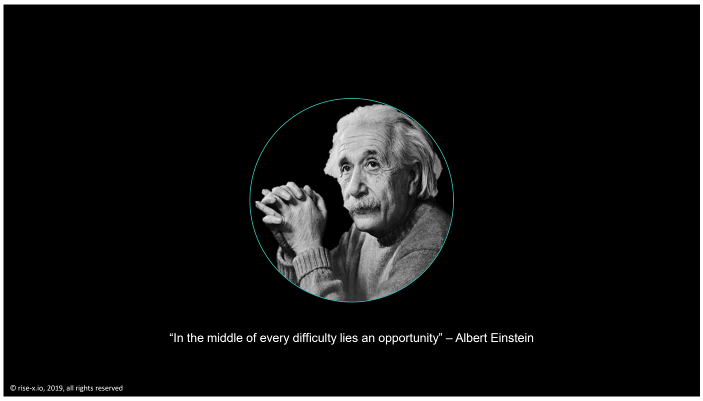
“In the middle of every difficulty lies an opportunity” – Albert Einstein
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D I A N A
DIGITAL INTELLIGENT ATOMIC NEGENTROPIC AUTONOMOUS
ECOSYSTEMS
DIANA is the digital infrastructure for an autonomous future
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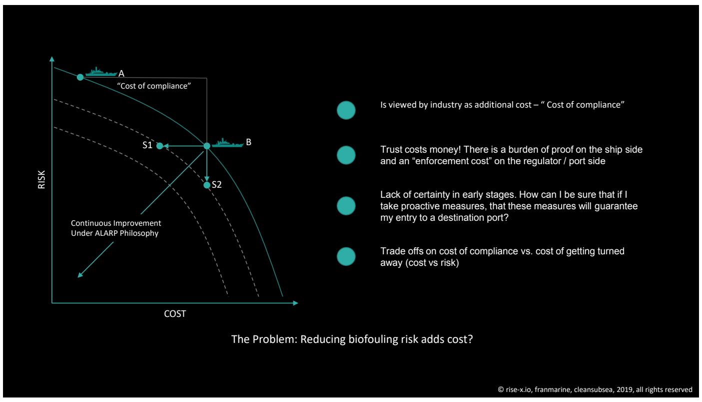
BIOPASS
CleanSubSea


A
“Cost of compliance”
B
S1
S2
RISK
COST
Continuous Improvement
Under ALARP Philosophy
Is viewed by industry as additional cost – “ Cost of compliance”
Trust costs money! There is a burden of proof on the ship side and an “enforcement cost” on the regulator / port side
Lack of certainty in early stages. How can I be sure that if I take proactive measures, that these measures will guarantee my entry to a destination port?
Trade offs on cost of compliance vs. cost of getting turned away (cost vs risk)
The Problem: Reducing biofouling risk adds cost?
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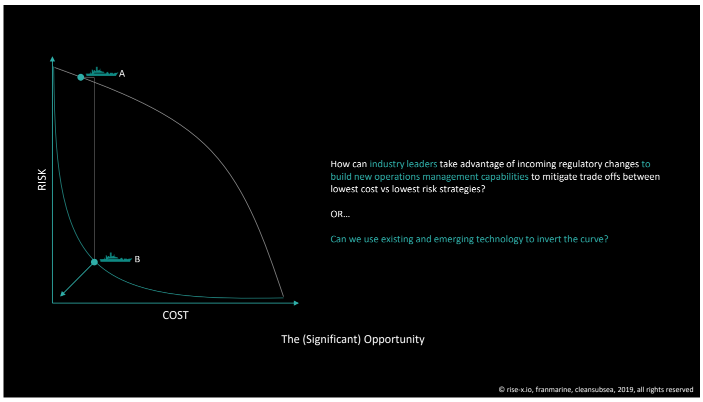
A
B
RISK
COST
How can industry leaders take advantage of incoming regulatory changes to build new operations management capabilities to mitigate trade offs between lowest cost vs lowest risk strategies?
OR…
Can we use existing and emerging technology to invert the curve?
The (Significant) Opportunity
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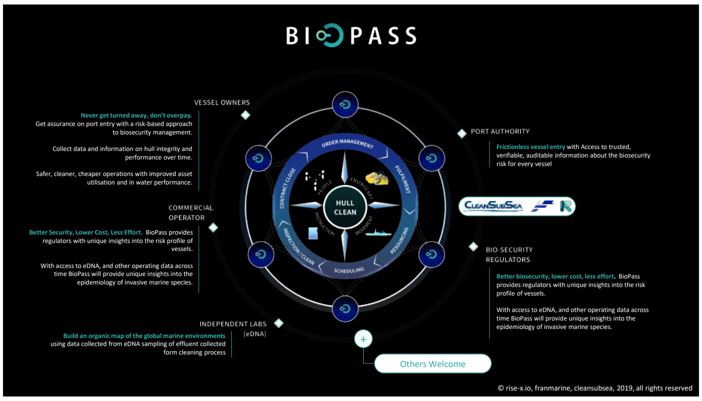
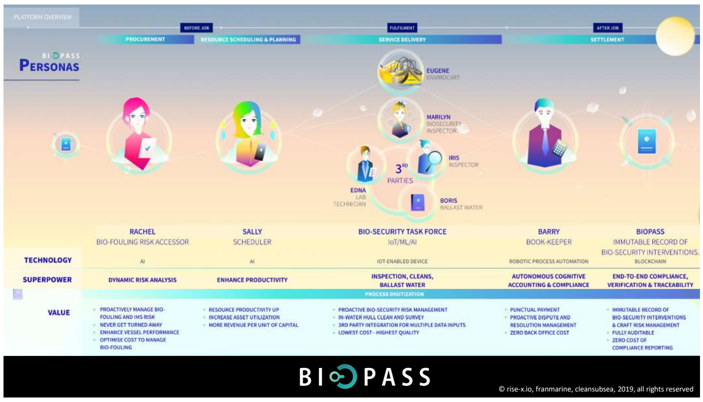




BIOPASS

Hull Performance Management. Don't overpay. never get turned away

Jan 1 2020 Pilot | Partners welcome

Next Steps

BIOPASS

rowan.fenn@rise-x.io | adam@franmarine.com.au | rory@Cleansubsea.com.au

Thank You!

Melissa Walker
Team Leader Aquatic Biosecurity Policy and Programs
NSW Department of Primary Industries, Australia

Biosecurity communications - driving behaviour change to minimise risk

M. Walker, V. Greentree
NSW Department of Primary Industries, Nelson Bay, NSW

NSW Department of Primary Industries Aquatic Biosecurity, in collaboration with Behaviour works at Monash University, conducted a social research project to identify the best ways to; communicate with our stakeholders, identify what drives their behavior and find strategies to encourage behavior change. The project was focused on the behavior we most want the recreational fishing community to adopt, ie washing boats and equipment after use and between waterways to minimize the spread of aquatic pests and diseases.

The project had four components, a literature review, a review of current communication tools, telephone interviews and a state-wide online survey.

The survey results have been analysed and a subsequent project will be delivered to implement the learnings on stakeholder behavior and preferred communication methods. The presentation will describe some of the key lessons learned in the social research project and relate these to the biosecurity outcomes required for biofouling management by small boat and vessel owners in the marine environment.

Biosecurity Communications

Behaviour change to minimise risk

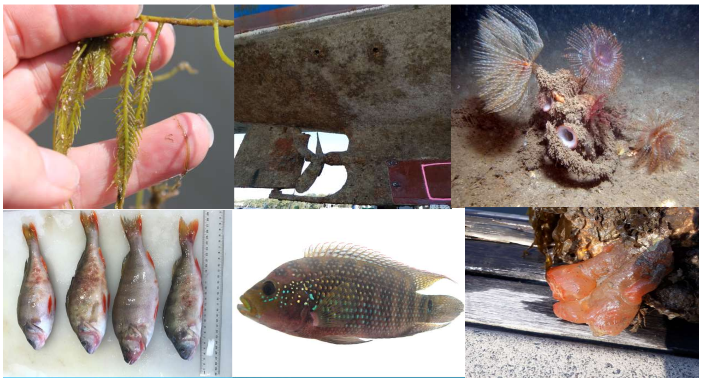
Melissa Walker NSW DPI

Acknowledgement: Vic Greentree

Communication is the key

- Getting buy-in
- Compliance
- Getting behaviour change
- Ownership

- Managing stakeholder expectations
- Build relationships
- Creating trust



Social Research Project
Behaviourworks @ Monash University

Literature review

Communication Tools review

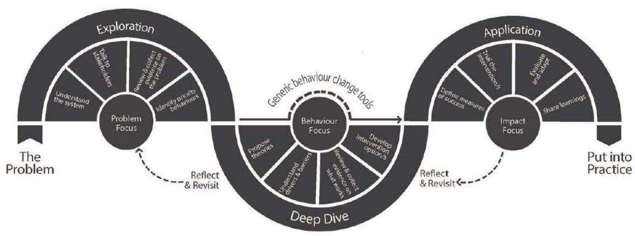
Telephone Interview

Online survey

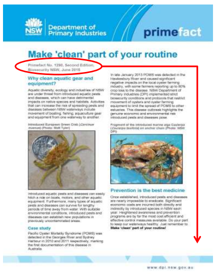
Objectives

- Identify best ways to communicate with stakeholders
- Determine behavioural drivers
- Develop strategies for behavioural change
- Identify subgroups of stakeholders and most effective communication methods

Literature Review



Communication tool review


Department of Primary Industries
primefact
Make 'clean' part of your routine

- No target audience
- Lack of incentive to pick up
- They didn't always have the important information first
- Too much text
- Information not relevant to the behaviour

General advice……

- Headings should reflect target behaviour

Know your audience: ask them about the behaviour…

15 stakeholders were contacted by Monash University and asked a series of questions in regards to their beliefs about washing down their gear

The outcomes were as follows

- People wash their gear to maintain it, not for biosecurity reasons
- Make messages simple, and behaviour easy
- No negative beliefs (no DON'T messages)
- People who have expensive gear would be more likely to wash than people renting or with cheap gear

Know your audience: Online Survey Outcomes

Four clusters of audience (426 respondents)

- Coastal Boaters and Fishers
- Inland Boaters and fishers
- Bay and inlet fishers
- Fishing enthusiast

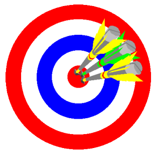
Drivers of washing down equipment

- Maintain gear
- Future fish stocks
- Stop the spread of pests and disease in oceans and waterways

Project outcome: Target your messages

- Recreational fishers and boaters respond to signs at boat ramps, retail fishing/boating outlets and information with licences
- Communications need to be targeted, relevant and concentrated on behaviours more than excessive information
- DPI needs to tailor information differently for different target groups
- Focussing on benefits to small vessel owners/fishers and their drivers

such as maintaining gear, fuel efficiency, or protecting fisheries populations

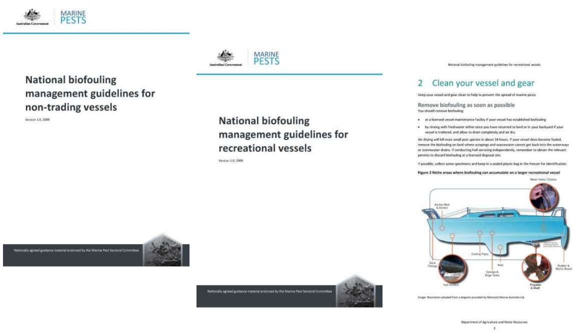



Take home messages

- What is the biosecurity behaviour we want to achieve?
- Understand your audience
- Target your messages well to achieve behaviour change

What next?

- NSW DPI – part way through a subsequent project, to develop and revise current materials to ensure messaging is improved
- Commonwealth / Australian messaging?
  - Do the national biofouling guidelines and advisory messages meet the mark?



Best practice, communicating biofouling management to non-commercial vessels

- Describe what behaviour we want
  - *Not what* not *to do*!
- Describe how it benefits stakeholders

- Need to understand behaviour drivers and barriers
  - ? Fuel efficiencies
  - ? Maintain green/clean image
  - ? Greenhouse gas
  - ? Gear lasts longer
  - ? Reduced maintenance costs

Review of current materials

- What's in… what's out…
- Language
- Relevance
- Address behavioural drivers

- What's in it for me?

Better biosecurity communications

- What is the biosecurity behaviour we want to achieve?
- Understand your audience
- Target your messages well to achieve behaviour change

Acknowledgements

Emily Rucker, Sus Perkins, Vic Greentree - NSW DPI

Bradley Jorgensen – Behaviour Works Australia -Monash University

WARD APPELTANS
Marine Biodiversity focal point
IOC-UNESCO, Belgium

Mr Ward Appeltans is the marine biodiversity focal point at UNESCO-IOC where he manages the Ocean Biogeographic Information System (OBIS) and supports the Biology and Ecosystems Panel of the Global Ocean Observing System. He graduated as a marine biologist at the Free University of Brussels, Belgium. Before he joined IOC-UNESCO in 2012, he was a project manager for nearly 10 years at the Flanders Marine Institute where he managed a.o. the World Register of Marine Species and worked for several European marine biodiversity projects.

Building stronger scientific understanding on the dynamics and pathways of marine invasive species introductions via biofouling - a case for international scientific cooperation on ocean observations, data management, capacity development and technology transfer

Ward Appeltans, Henrik Enevoldsen, Pia Haecky IOC-UNESCO, Brussels, Belgium

The GEF-UNDP-IMO GloFouling Partnerships Project includes interventions at the global, regional, national and local levels. Based on its initial focus in 12 developing countries in 7 maritime regions. Taking into consideration that the pathways for the transfer of Invasive Aquatic Species (IAS)through biofouling are not restricted to the shipping industry, but also to other ocean industries such as mariculture, ocean energy, oil/offshore, ocean instrumentation, any efforts made towards preventing the transfer of IAS through biofouling should therefore include these other industries. To achieve this holistic and harmonised approach, the IMO is partnering with the Intergovernmental Oceanographic Commission (IOC) of UNESCO, the Ocean Science body within the UN. IOC- UNESCO will be an Executing Partner of the GloFouling Partnerships Project and will take the lead in delivering activities on the non-shipping aspects, including contributions from other relevant international organizations, such as FAO, WMO, or ISA, that would play a supporting role in the review of biofouling management practices in non-shipping pathways such as aquaculture, fisheries or deep-sea mining. In parallel, and to coordinate contributions and participation from private sector companies outside the shipping industry (non-shipping pathways), the World Ocean Council (WOC) has been identified as an international, multi sectoral institution, that is placed in a good position to focus on long-term private sector engagement.

On 13 September 2019, the 10 United Nations agencies that are a member of the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) established a new GESAMP working group on biofouling with the aim to build a broader understanding on the introduction and spread of AIS via biofouling across all maritime industries as well as study the (negative) impacts of AIS on biodiversity and economy. This new GESAMP Working Group will be led by IOC-UNESCO and is co-sponsored by IMO and UNDP.

Through its Ocean Biogeographic Information System (OBIS) and in collaboration with the Global Ocean Observing System (GOOS), IOC-UNESCO also plans to develop an early-detection/early-warning monitoring system for AIS based on novel observing technologies (e.g. DNA metabarcoding).

Building stronger scientific understanding on the dynamics and pathways of marine invasive species introductions via biofouling

A case for international scientific cooperation on ocean observations, data management, capacity development and technology transfer

Ward Appeltans, Henrik Enevoldsen, Pia Haecky

GloFouling Partnerships

The IMO Secretariat, partnering with the Global Environment Facility (GEF) and the United Nations Development Programme (UNDP), launched a new project in January 2019, the GEF-UNDP-IMO GloFouling Partnerships, to develop suitable tools and provide capacity building on biofouling management in twelve developing countries and Small Island Development States.

The Intergovernmental Oceanographic Commission of UNESCO (IOC- UNESCO) has joined the three agencies to provide scientific guidance and coordinate efforts to address non-shipping pathways, in collaboration with the World Ocean Council.

Project outputs in relation to Non-Shipping pathways:

- Sustained national and regional capacity in place for reducing the introduction of IAS through biofouling
- Best practice guidance documents and tools developed
- Awareness-raising campaign designed and implemented
- Public-private partnerships developed to incentivise the development of cost-effective management and technological solutions for managing biofouling IAS
- Increased investment in biofouling management innovation, solutions and technology
- Improved information base available to countries to develop appropriate national strategies and advocacy
- Enhanced cooperation between stakeholders to ensure holistic and harmonised approach to biofouling management

GESAMP Working Group on biofouling management and nonindigenous species

APPROVED

Lead agency: IOC-UNESCO
Sponsoring agency: IMO & UNDP (GEF-UNDP-IMO GloFouling Partnerships)
Budget: USD 114,000
WG Technical Secretary: Mr. Henrik Enevoldsen (IOC-UNESCO)

Scope of work
The overall objective of the GESAMP Working Group on biofouling management and nonindigenous species is to build a broader understanding on introduction and spread of NIS via biofouling across all maritime industries

The GESAMP Working Group will provide a global overview of the impact of biofouling across all maritime industries and structures and support the initial information requirements of the GloFouling Partnerships for understanding the role of biofouling in the transfer of NIS.

GESAMP can provide valuable support and scientific advice for the growing programmes of work on marine biofouling and its role within different maritime industries as a vector for the transfer of NIS. **This information will form the basis for policy instruments and tools which deal with marine biofouling**.

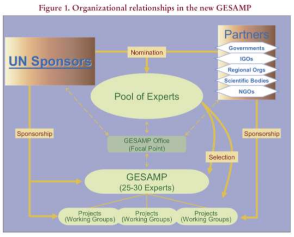
The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP)

GESAMP is an advisory body, established in 1969, that advises the United Nations (UN) system on the scientific aspects of marine environmental protection.

GESAMP is jointly sponsored by ten UN organizations.

GESAMP itself today consists of 17 experts, drawn from a wide range of relevant disciplines, who act in an independent and individual capacity. Studies and assessments are usually carried out by dedicated working groups.

Figure 1. Organizational relationships in the new GESAMP



50th Anniversary (1969-2019) GESAMP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection

GESAMP Working Group on biofouling management and nonindigenous species

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GESAMP Working Group on biofouling management and nonindigenous species

Proposed profile for Working Group members

The expertise required by the Working Group includes:

- Marine scientists and engineers with expertise in marine ecology and ecosystems, fisheries, marine biodiversity and invasive aquatic species;
- Scientists and engineers who have studied marine and/or coastal structures and their potential impacts; and
- Social scientists with expertise including environmental and/or natural resource economics.

12 Lead Partner Countries

Brazil, Ecuador, Fiji, Indonesia, Jordan, Madagascar, Mauritius, Mexico, Peru, the Philippines, Sri Lanka and Tonga.

National Strategic Action Plans for the control and management of ship's biofouling

recommendations and best-practices

GESAMP Working Group on biofouling management and NIS
-Scientific understanding of dynamics and pathways
-Impact on biodiversity and economy
-Best management practices
-Data gaps

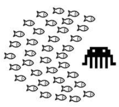
start

GloFouling Partnerships

Lead agency: IOC-UNESCO
Sponsoring agency: IMO & UNDP (GEF-UNDP-IMO GloFouling Partnerships)
Budget: USD 114,000
WG Technical Secretary: Mr. Henrik Enevoldsen (IOC-UNESCO)

Pacific Islands Marine Bioinvasions Alert Network

PacMAN



Increased capacity of Member States to use international standards and best practices to detect marine invasive species with novel technologies

Increased technical and scientific capacity of Member States in marine invasive species early warning

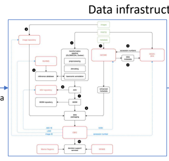
Increased capacity to use (and communicate) the information from the marine invasive species early warning system to implement national and international policies

DRAFT PROPOSAL

Disclaimer
This project is still a proposal and not yet funded. If you wish to support or contribute please get in touch with Ward Appeltans.

DRAFT PROPOSAL

Data infrastructure and bioinformatics pipeline
Data and metadata processing workflow from raw sequence reads to standardized OBIS occurrence data



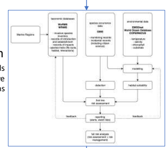
Field sampling
operational phase

Raw data

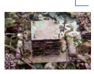
Clean data

Train scientists
in the protocols of the monitoring plan

Decision-support system
habitat suitability models
risk assessment to establish and become invasive alerting system on early-detections



Field sampling
test phase



National Monitoring Plan
- Protocols for sampling, sample processing, vouchering, imaging, and molecular analysis (barcoding and metabarcoding) of sessile and motile organisms on hard substrates
- Identify which are the species of interest

start

Stakeholder forum
Scientists - Managers

Train stakeholders
in using and communicating the results appropriately

National Invasive Species Strategy and Action Plan (NISSAP)

Habitat suitability indicator +

1. geographic distance from known occurrences
2. connectivity between ports
3. reports on the invasiveness of species in other areas

Environmental data and existing data on the distribution of species from OBIS will be used in habitat suitability models in order to assess the likelihood that a certain species can establish itself in a location of interest.

Automated first-line risk assessment

As this system is fed with live data, new detections will trigger a reevaluation of all available data to produce updated maps and indicators. The performance of the risk assessment component will be monitored continuously and improved where possible by updating the underlying algorithms and the data sources feeding into them.

dashboard application and alerting system on early-detections
-maps of invasion risk for target species
-location based species watch lists
-an indicator for the risk associated with specific shipping routes (in analogy with the OSPAR/HELCOM ballast water risk assessment tool)
-reporting mechanisms such as e-mail alerts

SPREP Pacific Environmental Portal

IUCN's Global Invasive Species Database (GISD)

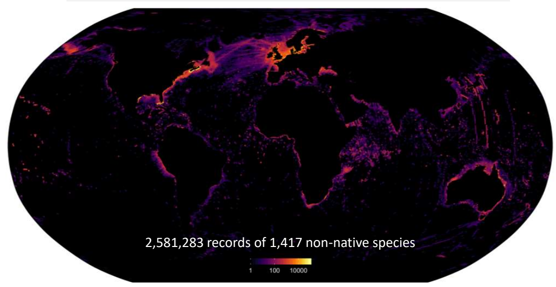
GloFouling Partnerships project portal

DRAFT PROPOSAL

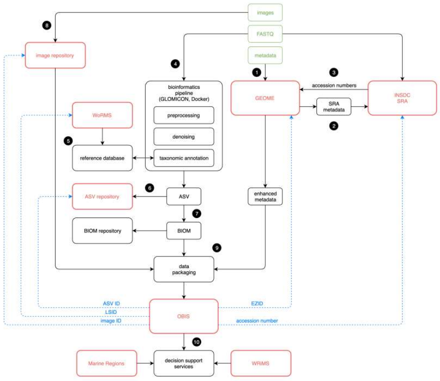
OBIS OCEAN BIOGEOGRAPHIC INFORMATION SYSTEM

HTTPS://OBIS.ORG

57,225,831	2,912	126,260
OCCURRENCES	DATASETS	SPECIES

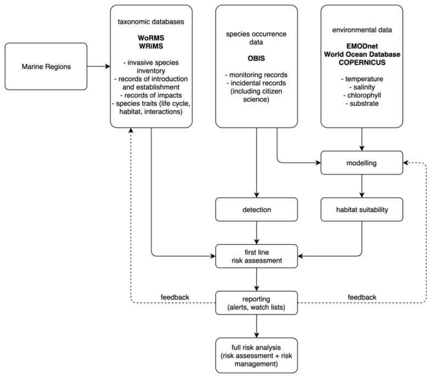


Bio-informatics pipeline



DRAFT PROPOSAL

Decision-support system



DRAFT PROPOSAL

John Lewis
Co-Chair, IMarEST Biofouling Management Special Interest Group
IMarEST, Australia

After completing honours and Masters degrees in marine botany at the University of Melbourne, John went on to spend 30 years working as a scientist in the Defence Science & Technology Organisation in Melbourne. His principal research interests at DSTO were in marine biofouling and its prevention and, prior to his departure in mid-2007, he led a team investigating new, environmentally acceptable methods of biofouling control, biofouling and marine invasive species management, environmental compliance of naval vessels, and other environmental aspects of navy operations. John now works as a private consultant with ES Link Services, primarily on biofouling impacts, antifouling technologies, invasive marine species identification and management, and ship emission indexing. He also continued his academic interests in marine botany through an honorary position in the School of Botany at the University of Melbourne and marine invertebrate taxonomy as an Honorary Associate at Museum Victoria. John is a Fellow of the Institute of Marine Engineering, Science and Technology and is Co-Chair of the IMarEST Biofouling Management Special Interest Group.

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The way forward: thoughts & discussion points

4th ANZPAC Workshop on Biofouling Management for Sustainable Shipping

1st GEF-UNDP-IMO GloFouling R&D Forum and Exhibition on Biofouling Management

THOUGHTS & DISCUSSION POINTS

John Lewis

Melbourne Conference & Exhibition Centre
Melbourne , Vic, Australia
1 – 4 October 2019

Key messages [2017]:

Focus resources for greatest benefit

Identify the significant impacts: biofouling per se, species specific

Determine management strategies to address identified risks
- IMO Biofouling Guidelines
- Fuel consumption
- Domestic spread
- Improved antifouling technology
  - Paints
  - Sea chest design
- In-water cleaning approval procedures

Impacts

ALIEN & INVASIVE SPECIES: TERMINOLOGY

An invasive alien species is:

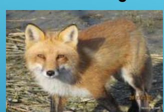
- "*a species that is established outside of its natural past or present distribution, whose introduction and/or spread threaten biological diversity*" (IUCN 2017);
- "an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health" (U.S. Executive Order 13112 1999); and
- "a species that is non-native to the ecosystem under consideration and whose introduction causes or is likely to cause economic or environmental harm or harm to human health" (Invasive Species Advisory Committee 2005)

What is an Invasive Species?




PEST ANIMALS

Damage Estimates (per year)


$227.5 million


$206 million

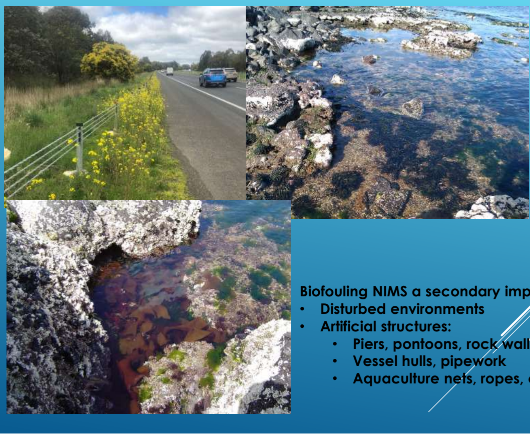

$146 million


$16 million


$11 million

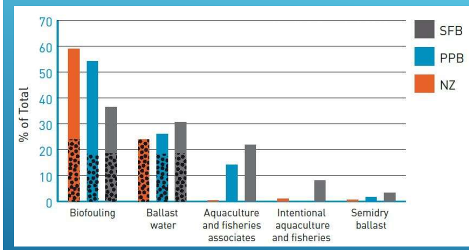
Biofouling "Invasive" Marine Species

"WEEDS & PESTS"



Biofouling NIMS a secondary impact:
- Disturbed environments
- Artificial structures:
  - Piers, pontoons, rock walls
  - Vessel hulls, pipework
  - Aquaculture nets, ropes, cages

NIMS VECTORS



ESLINK SERVICES

Perception driving policy?

Priority list of exotic environmental pests and diseases

The Chief Environmental Biosecurity Officer is pleased to release the interim priority list of exotic environmental pests and diseases for consultation (the Priority List).

The Priority List focuses on exotic pests and diseases that pose the highest risk to our environment and public spaces. This list will be used to enable activities that help prevent the entry, establishment and spread of exotic pests and diseases.

You can now read the interim list and provide feedback on its use.

Priority marine pests

Top five

- Asian green mussel (*Perna viridis*)
- Black-striped false mussel (*Mytilopsis sallei*)
- Carpet sea squirt (*Didemnum vexillum*)
- Chinese mitten crab (*Eriocheir sinensis*)
- Lady crab / Asian paddle crab (*Charybdis japonica*)

The Australian Priority Marine Pest List

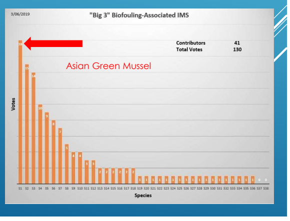
The Australian Priority Marine Pest List (APMPL) identifies 9 of Australia's significant marine pests. This list includes 3 established and 6 exotic species.

Established

Priority pests already established in some parts of Australia:
- European shore crab
- Japanese kelp
- Northern Pacific seastar

Exotic

Priority pests not known to be established in Australia:
- Asian green mussel
- Black striped false mussel
- Brown mussel
- Chinese mitten crab
- Harris' mud crab
- New Zealand green-lipped mussel



Aquaculture Pathogens & Diseases

What about? - Pacific oyster *Magellana gigas*

What about? - Solitary ascidians *Ciona* spp., *Styela clava*

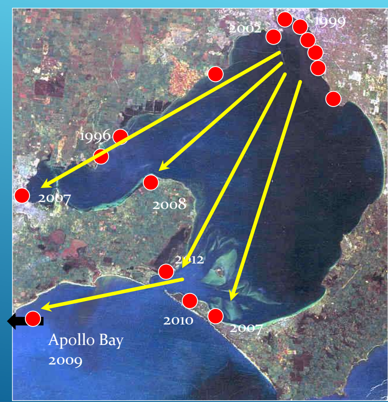
What about? - Hydroids, e.g. *Ectopleura spp*

Vessel Risk

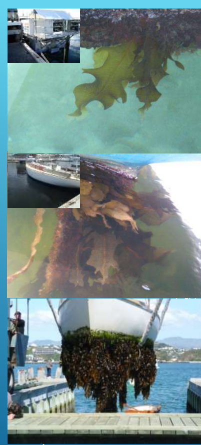
Recreational, Aquaculture, Domestic

$Time_0$

$Time_0$ + 4 mths



***Undaria pinnatifida* – Japanese kelp**



Ship Design

Sea Chest Design

MGPS Performance

International vs regional requirements

Established pests vs possibly new pests
Given the centuries of international maritime traffic, how big or small is the risk of new arrivals vs the impacts from established NIS: think Pacific oysters, oyster pathogens, ascidians, hydroids

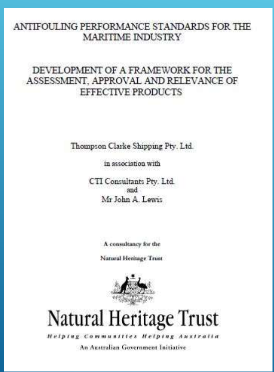
IMO biofouling guidelines
- IMS risk reduction by promoting best practice
- Removes highest risk vessels e.g. service interval exceedance
- Improve ship efficiency: fuel/cost savings, reduced GHG emissions

Clean up our own backyard:
marinas / small boats / aquaculture

Management costs:
Maritime industry: Chevron – AGM, Brazil – Cup coral
Aquaculture / ports / marinas ????

Paint application & performance

Paint application & performance


ANTIFOULING PERFORMANCE STANDARDS FOR THE MARITIME INDUSTRY

DEVELOPMENT OF A FRAMEWORK FOR THE ASSESSMENT, APPROVAL AND RELEVANCE OF EFFECTIVE PRODUCTS

Thompson Clarke Shipping Pty. Ltd.
in association with
CTI Consultants Pty. Ltd.
and
Mr John A. Lewis

A consultancy for the
Natural Heritage Trust

Natural Heritage Trust
Helping Communities Helping Australia
An Australian Government Initiative

July 2004

ANZPAC
Melbourne 2017
Biofouling Management for Sustainable Shipping

Key messages [2017]:

Focus resources for greatest benefit

Identify the significant impacts: biofouling per se, species specific

Determine management strategies to address identified risks
- IMO Biofouling Guidelines
- Fuel consumption
- Domestic spread
- Improved antifouling technology
  - Paints
  - Sea chest design
- In-water cleaning approval procedures

Knowledge/management gaps:

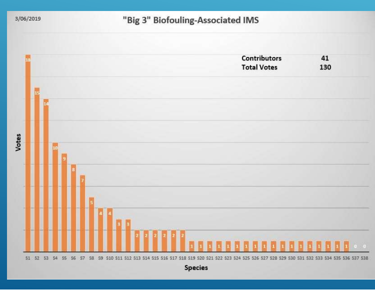
- **Impacts/risks/management cost-benefit analysis of/for "potential pests"**
- **Effective/consistent domestic/recreational vessel management**
- **Pacific oysters (feral & pathogen dispersal)**
- **Biofouling management in aquaculture**
  - **Waste capture**
- **Hull/niche design, particularly sea chests**
- **Independent assessment of MGPSs**

Help please…

Institute of Marine Engineering, Science & Technology
IMarEST

IMarEST Biofouling Management Expert Group

Issue 1: Environmental, economic and social impacts from introductions of marine non-indigenous species (NIS) associated with vessel biofouling
The BMEG will work to:
Seek and collate published evidence of environmental, economic and social impacts from introductions of marine NIS in the published literature.



4th ANZPAC Workshop on Biofouling Management for Sustainable Shipping

1st GEF-UNDP-IMO GloFouling R&D Forum and Exhibition on Biofouling Management

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CONFERENCE MATERIAL

Attendance List
- emailed to all attendees

Presentations – PDF*
- workshop website
- IMarEST Nexus – Biofouling Management

Presentations – Video*
- IMarEST TV

*Subject to presenters approval
Opt in / Not opt out

IMarEST will again be offering 12 months free affiliate membership to all workshop attendees; to join, simply go to www.imarest.org/signupdelegate and use the code BIOFOULING4.

This will sign you up for both IMarEST membership and corresponding membership of the BMSIG which means you will receive specialist news from the group and be called upon to give opinion and advice.

Gift to Speakers

Deadly Science

Our first aim is to provide science books and early reading material to remote schools in Australia. As of now we have shipped over 4000 books 70 telescopes and 80 Foldscope kits plus other resources to over 70 schools with more to come.

The Deadly Science project started after I found out that some schools I have been talking to had as few as 15 books in their library for the whole school!

We know from personal experiences that books & resources change lives, and these kids deserve nothing but the best. Deadly Science wants to make sure each of these schools has a copy of Bruce Pascoe's book "Dark Emu". It is time that people knew the real history of Australia.

Deadly Fundraiser by Corey Potter

Thank you

SPONSORS & SUPPORTERS

Thank you

ORGANISING COMMITTEE

James Chapman
Eugene Georgiades
Clare Grandison
John Lewis
Jason Monty
Alison Saunders
Richard Stafford-Bell
Angela Gillham
Sonia Gorgula
Nick Hutchins
Justin McDonald
Richard Piola
Michael Sierp
Peter Wilkinson

GloFouling Partnerships

ANZPAC
Melbourne 2019
Biofouling Management for Sustainable Shipping

Thank you

GloFouling Partnerships

John Alonso
Violeta Luque
Lilia Khodjet El Khil

Assistants

Tyler Houston
Bagus Nugroho
Bayden Findlay

Speakers

All of you

More information?

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INTERNATIONAL MARITIME ORGANIZATION

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