EIMR INTERNATIONAL WORKSHOP
22nd February 2016
Edinburgh, Scotland
Environmental Interactions of Marine Renewable Technologies

Expert Workshop Report: Biofouling

Raeanne Miller and Jennifer Loxton

Hosted by the University of the Highlands and Islands, OES Annex IV, ICIT Heriot Watt, ORJIP, and Marine Scotland, together with the MERIKA project.

Marine Scotland, 1 Victoria Quay, Edinburgh, Scotland, EH6 6QQ

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Contents

Introduction

Environmental Interactions of Marine Renewable Technologies (EIMR) is an international conference held at different sites across the Scottish Highlands and Islands region. It serves as a major forum for global researchers to come together to present their latest research, results and ideas; and to strengthen relations between the emerging marine renewables industry, research laboratories, and universities.

As part of this on-going work, EIMR hosted a series of parallel, one-day, invite-only workshops on the 22nd February 2016 at Victoria Quay, Marine Scotland, Edinburgh. The workshops aimed to bring together science and science stakeholders to explore critical questions for monitoring and mitigation around marine renewable energy (MRE) devices and arrays in three areas: biofouling, collision risk, and societal impact.

This particular workshop aimed to address a series of linked ecologically and industrially relevant questions around marine growth, or biofouling, on marine renewable energy devices. It focussed on first identifying key topics of relevance, which was followed by a prioritisation exercise aimed at elaborating next steps needed to address any knowledge gaps.

The aim of this report is to summarise the workshop activities and outputs for workshop attendees and a wider audience.

Workshop overview

The EIMR expert workshop on biofouling was chaired by Raeanne Miller (Scottish Association for Marine Science) and Jennifer Loxton (Environmental Research Institute). The day's activities were split into four main sessions encompassing both plenary and discussion elements:

- Setting a baseline: representatives from marine science, engineering, and industry shared their perspectives on biofouling in a series of short 'rapid fire' presentations
- Break out session 1: identifying common issues around marine growth and their drivers
- Break out session 2: prioritising issues and identifying knowledge gaps
- Break out session 3: agreeing on priorities, making a plan, and next steps

An agenda for the day can be found at the end of this report.

Plenary: Setting a baseline

Summary of presentations: an ecological perspective on biofouling

Biofouling: can we improve on 'best guess'? Adrian Macleod (SRSL)

Adrian Macleod provided a summary of biofouling from an ecological perspective, addressing two questions: 'Why might we be interested in biofouling on marine renewable energy devices?'; and 'What can ecologists do to inform engineering decisions?'. In a recent study carried out in collaboration with the Offshore Renewable Energy Catapult and PML Applications, key biofouling concerns were highlighted following an industry consultation. Outputs of this survey indicated that biofouling thickness and roughness were cited by respondents as most likely to affect MRE device efficiency, though Adrian also identified a great deal of industry uncertainty around device design tolerances with respect to marine growth. Finally, Adrian identified a series of challenges to be addressed in order to effectively measure, monitor, and map biofouling on renewable energy devices, with the eventual aim of enabling location-specific prediction of marine growth.

Biofouling Solutions for Marine Renewables: Knowledge Network Development. Joanne Porter (Heriot Watt)

Joanne Porter presented work carried out as part of an ongoing collaboration between Heriot Watt University, EMEC, the Orkney Islands Council, and the Trust for Conservation Volunteers. Biofouling was identified as a key concern to industries working in the marine environment, particularly in light of the hydrodynamic and mechanical consequences of biofouling organisms on moving structures. Joanne described how she and her team worked closely with test site personnel and developers to gather data, share knowledge, and formulate expertise on specific aspects of biofouling relevant to the MRE industry. This resulted in a biofouling monitoring programme and knowledge network being initiated at EMEC, with potential to build and develop future collaborations, for example at the FORCE test centre in Canada.

Biosecurity implications of the marine renewable energy industry. Chris Nall (Environmental Research Institute)

Chris Nall introduced the concept of non-native species, and highlighted that most UK non-native species are biofouling species and are often associated with marine growth on artificial structures. Different types of non-native species which have been found inhabiting MRE devices were described, as well as potential pathways for their transfer. These pathways included the 'stepping stone effect', where artificial structures provide a dispersal corridor for non-native species; the wet movement of devices, where fouled devices are wet towed between locations; and the cleaning of devices. In summary, Chris highlighted evolving UK legislation and regulation around invasive species which included MS LOT requirements that 'the risk of transferring invasive non-native species to and from the site is kept to a minimum by ensuring appropriate bio-fouling management practices are implemented'.

Methods to study biofouling at European renewable energy test sites. Jennifer Loxton (Environmental Research Institute)

Jennifer Loxton described a series of techniques currently used to evaluate and study biofouling at MRE test sites across Europe. As part of her work in the MERIKA project, Jennifer described the use of scrape sampling techniques to develop species lists and to roughly inform fouling biomass and antifouling strategies in collaboration with the Portuguese test centre, WavEC. Settlement panels were also highlighted as a useful tool in studying biofouling in and around renewable energy sites. Jennifer described how settlement panels could be used to develop species lists, provide quantitative measures of biomass, understand differential settlement and growth patterns on and off devices, and inform antifouling strategies. By spring 2016, Jennifer's aim is to have panels installed on floating and bottom mounted wave, tidal, and floating wind devices and/or lease sites and test sites in the Azores, Portugal, Ireland, and the UK.

Summary of presentations: industry and engineering perspectives on biofouling

Marine Growth. Ben Waldron (DNV)

Ben Waldron described the role of DNV GL as a global classification, certification, technical assurance, and advisory company, before moving on to describe how DNV GL certifies equipment, services, and projects in the renewable energy industry. To date, two documents have been released specifically dealing with tidal energy turbines and arrays: the service specification, which details the process; and the tidal turbine standard, which provides the technical requirements. Ben highlighted sections within these documents which address marine growth, specifically noting the marine growth profiles which are currently used to guide design and certification, but that where possible; site specific measurements should be used. In summary, Ben identified several areas for development in the field, including the association of non-native species with ballasting/de-ballasting of devices, and the need for devices and components to be treated individually with regards to fouling: e.g., there is not a 'one-size fits all' solution.

Setting a baseline: industry perspective on biofouling. Calum Kenny (Albatern)

Calum Kenny described Albatern's experience of biofouling, particularly with regards to their WaveNET device, made up of individual units called 'Squids'. Following deployments near the Isle of Muck (May-July 2014) and in Loch Kishorn (Aug-Nov 2015), Calum described the marine growth that had accumulated while the devices were in the water. Devices experienced biofouling over the course of both deployments, though not in the same manner, or to the same degree. Marine growth quickly re-established following cleaning of one Squid, while growth rates increased during times of no service. Albatern's key concerns with regards to biofouling included settlement on piston shafts and potential damage to seals and friction of joints of pumping modules.

AkzoNobel Performance Coatings: Leading through sustainable innovation. Richard Ramsden (Akzo Nobel)

Richard Ramsden gave a presentation detailing Akzo Nobel's experience with developing and applying coatings for the marine renewable energy sector. After illustrating the potential fouling which could affect MRE devices, Richard discussed existing tools which Akzo Nobel uses to predict biofouling and assess performance. These included a broad global model for biofouling prediction based on global datasets (9km^2) and a track record of coating performance in the form of regular inspections over time. Developments needed to complement these tools included high resolution, area-specific biofouling models, models with high taxonomic resolution, and new sensor technology to validate these models.

Marine growth mapping and monitoring: biofouling sensor feasibility. Tom Vance (PML Applications)

Tom Vance discussed the outputs of a recent study commissioned by the Offshore Renewable Energy Catapult to determine the feasibility of developing a sensor for real-time monitoring of marine growth on submerged structures. Such a sensor could help users to optimise biofouling management, to monitor the presence or absence of non-native species, and to differentiate between loss of device efficiency resulting from mechanical faults of biofouling. A literature review suggested that the renewable energy had specific requirements for such a sensor around fouling of the instrument itself, instrument robustness and service intervals, which were different from other marine industries. Tom suggested that while no single sensor technology was suitable for the marine renewable energy market, they were examining a business case for the wider marine industry, to be taken forward with collaborative partners and suitable funding.

Break out session 1: identifying common issues around marine growth and their drivers

Breakout session one focussed on identifying as many issues or concerns around biofouling as possible, using a 'think, pair, share' technique. Delegates first spent several minutes individually identifying issues and concerns, recording them on separate post-it notes. Delegates were then asked to discuss what they identified with the person next to them, in a pair, examining similarities and recording any new issues identified. Finally, delegates discussed the identified topics as a group around a table, and arranged them in a 'mind map' format, harvesting ideas from the resulting map.

The group identified 119 ideas across fourteen different categories (Figure 1). The most common categories were invasive species risk, knowledge exchange, and the operational impacts of biofouling. Concerns identified around invasive species risk included the effectiveness of antifouling against non-native or invasive species and the role played by harbours as sources of contamination. Topics highlighted around knowledge exchange focussed on the pathways for information transfer and knowledge generation between scientists, engineers, regulators, and industry representatives, as well as between the marine renewable energy industry and the wider marine industry. Corrosion, device loading, and efficiency, meanwhile, were among the list of highlighted concerns around the operational impacts of biofouling on wave and tidal energy devices.

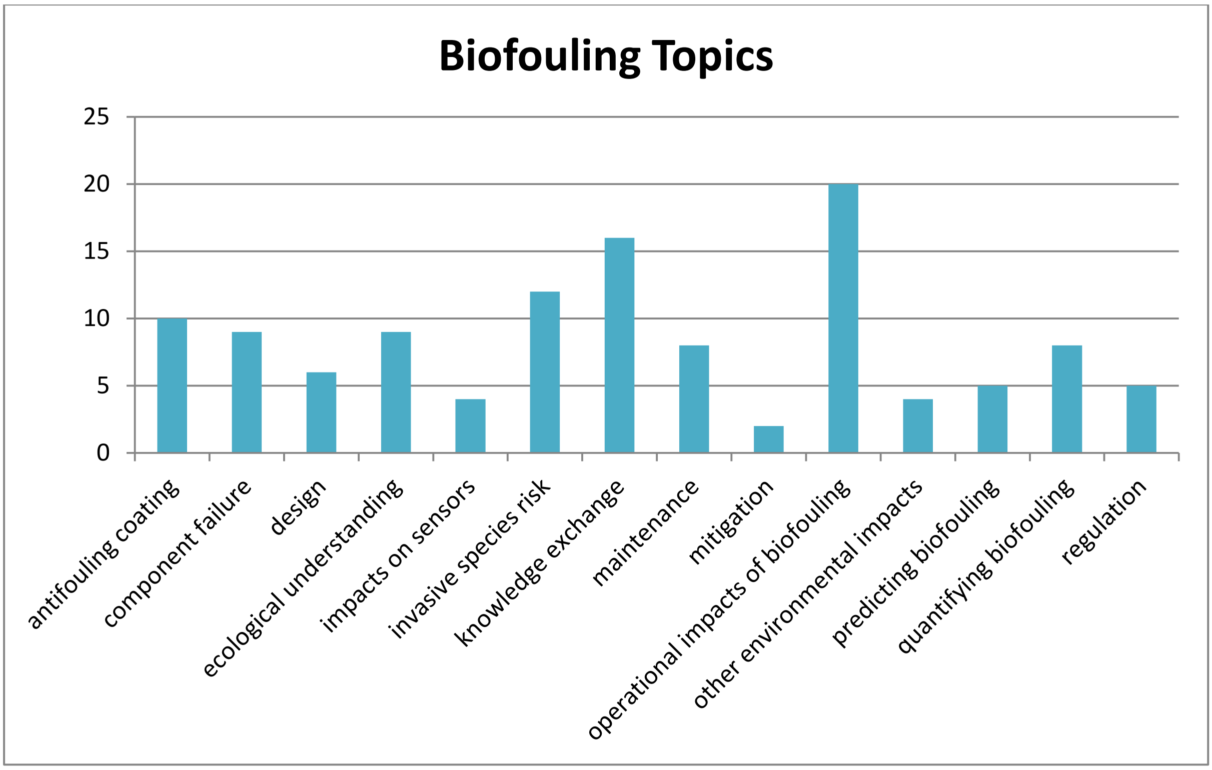

Figure 1: Topics of biofouling concerns and issues identified in break out session 1.

Individual issues were then grouped, and taken forward to a prioritisation exercise in break out session 2.

Break out session 2: prioritising issues and identifying knowledge gaps

Break out session 2 focussed on prioritising the issues and concerns identified in session 1 by scoring them with regards to financial, operational, and environmental risk in small groups, and then by assigning them a position along a priority spectrum as a large group (Figure 2).

In response to the task at hand, it was noted by the group that all of the above risks were interrelated, and very difficult to tease apart. For example, operational risks posed by reductions in turbine or wave device efficiency resulting from heavy biofouling also represented a financial risk associated with reduced power production. The interlinked nature of these risks is an important consideration to take forward and reflect on for future consultations, workshops, and projects in this field.

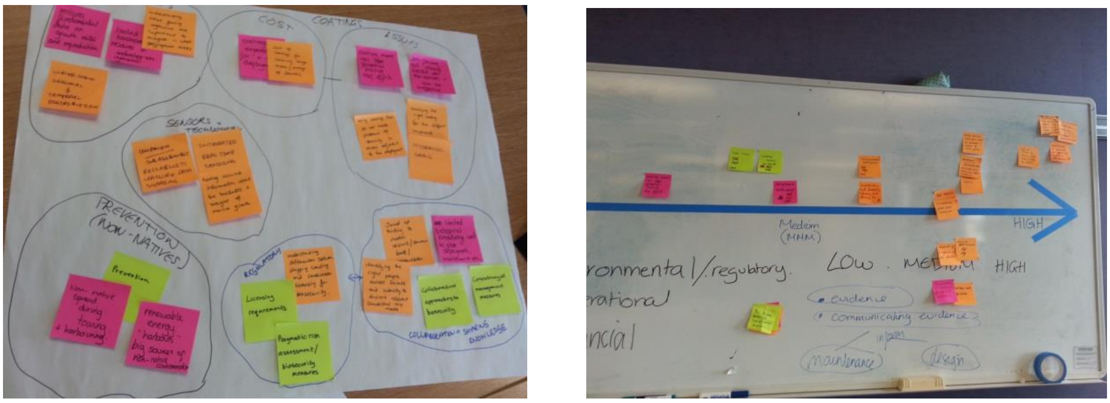

Figure 2: Scoring biofouling concerns with regards to operational, financial, and environmental risk (left), and prioritising issues as a whole group (right).

Four priority areas emerged from this exercise: understanding the ecological evidence base around biofouling held by environmental scientists and the industry; effective communication of this evidence base between disciplines which have different priorities and concerns; using the existing evidence base to inform device design in the early stages of development; and using existing evidence to inform device maintenance planning. The group structured these priorities visually, representing the flow of information between each area (Figure 3), and ultimately reflecting that all of these areas are important to ensure well-performing and reliable devices.

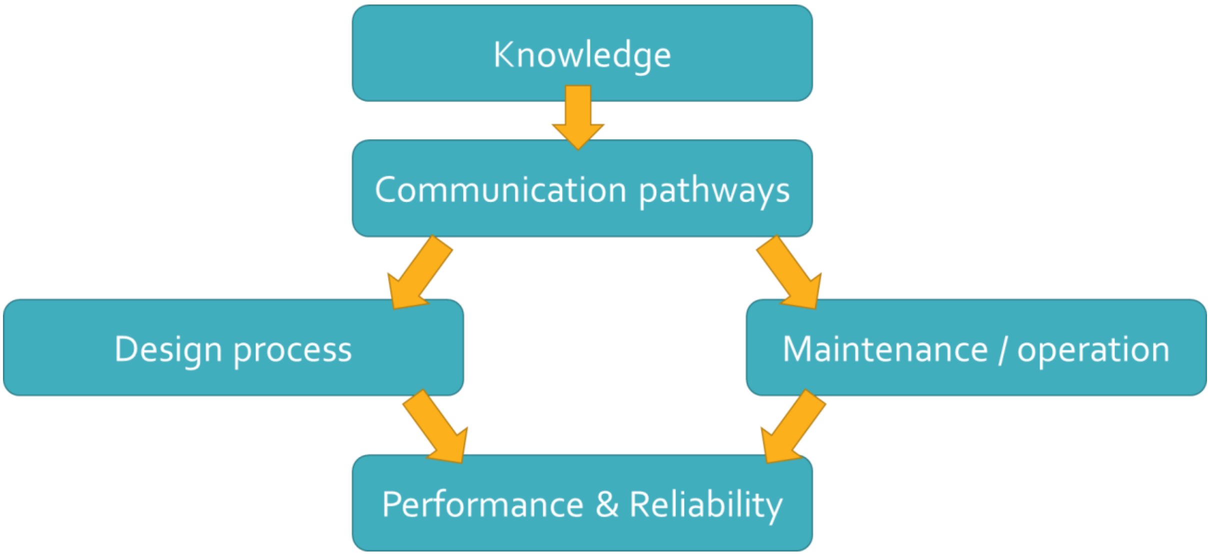

Figure 3: Visualisation of priority issues and information flow identified and agreed in break out session 2.

Break out session 3: agreeing on priorities, making a plan, and next steps

In the final session of the day, delegates joined a group of their choice to discuss and identify knowledge gaps, next steps and 'quick wins' in each area, summarised below:

Ecological understanding of biofouling species

The group discussing the ecology of biofouling identified that at present there is a reasonable list of species which are considered to be a part of biofouling assemblages, and that in more accessible environments researchers have a fairly good understanding of biofouling community makeup. This might include biofouling of man-made structures in shallow or benign environments. However, substantial knowledge gaps exist for structures in high-energy environments and in deeper, less accessible waters. Furthermore, while species lists for biofouling are continuously improving, there is currently a lack of understanding around the geographical variability in fouling types, growth rates, and assemblage makeup. Many biofouling species are historically poorly studied, and fundamental biological information essential to predicting biofouling makeup, preferential settlement, connectivity, and growth rates is lacking.

Ideally, addressing these knowledge gaps in developed and/or well-understood areas could help to feed into predictive models of biofouling for future deployments in new locations. With this in mind, the group identified a handful of 'quick wins' which could instantly evolve the knowledge base in this area. For example, piggy-backing on existing wave and tidal energy developments to gather data on environmental characteristics (temperature, salinity, current velocity, depth, ocean colour, etc) in tandem with biofouling using existing site infrastructure and procedures would immediately begin to provide a more complete picture of biofouling and its environmental drivers. This might involve the deployment of carefully selected sensors to increase the resolution of environmental data. In tandem, the group identified that biologists and ecologists working in this area should consider ways to disseminate their existing knowledge to the wider marine industry, translating ecological research in the form of industry briefings, infographics, and where appropriate, technical reports.

With a view to advancing the area in the medium term, this group discussed developing a suite of smart panel arrays or boards which could be deployed at test sites and at sites designated for development during the environmental scoping stage to evaluate and establish biofouling community makeup and its drivers in a standardised way, which would be easy to deploy and would comprise industry-relevant materials and surfaces. In the longer term, it was agreed that these quick wins could only be facilitated by developing further collaborations and pathways for communication between marine scientists and marine renewable energy developers. Members of this group agreed that a formal network might be of use when sharing expertise and discussing the state of the art.

Intelligent design of renewable energy devices

This group identified several specific knowledge gaps which could improve the design process and efficiency of tidal turbines and wave energy devices. Differences were highlighted between fixed and floating structures. While design tolerances for biofouling are well understood and routinely incorporated into the design fixed structures, much less information exists about specific moving parts and components, for example tidal turbine blades. Similarly, the impacts of biofouling-associated drag are a further area of uncertainty for floating structures. The group identified areas where ecologists and engineers could work together to address specific knowledge gaps, including the relationship between the speed of fouling and turbine blade shape and protective coatings, and the relationship between timing of installation and biofouling community development. A key area of interest was using ecologically-information to 'design out' biofouling issues for niche areas of the structure.

Quick wins identified by this group included developing a system for 'go-to' biology support to help engineers think about potential biofouling issue, as well as the development of a tool kit of biofouling related considerations to implement at the design phase. This tool kit might then be linked in with maintenance strategy implementation and standard methodologies for sampling biofouling. In service testing of biofouling was identified as a longer-term opportunity, where monitoring and maintenance data from deployed devices could be fed back into the design process.

Informed maintenance of renewable energy devices

This group identified that the marine renewable energy industry generally are not aware of what biofouling might occur on their devices, and that they aren't able to quantify when it would occur or become a serious concern, nor can they estimate how heavy or rough it might be. These factors were highlighted as areas where additional knowledge could inform the development of efficient maintenance routines with regards to biofouling, with the potential to reduce overall project costs. The group also recognized that the seasonality and geographical patterns of biofouling makeup and severity vary. If this seasonal variability was understood, it could be used to guide the timing of installation and maintenance of devices, with the potential to reduce costs.

An immediate 'quick win' identified by this group in enabling data sharing across the industry around biofouling. This might take the form of an anonymized database, allowing contributors insight into potential biofouling risks faced by industry colleagues in return for sharing their own information. This might allow for the industry as a whole to better plan maintenance procedures as a result of past learning. It was also identified that other marine industries have developed useful tools for predicting the growth of biofouling, for example, on ships, and that these models could potentially be adapted to inform marine renewable energy device maintenance.

This group also identified the need for a system of 'go to' biology support in this area, which might take the form of a knowledge pooling initiative. Members would pool funds, in order to gain benefit from the common knowledge it produced, and these funds could be used to support academics in answering fundamental biological questions about biofouling species, to feed back into the network.

Two longer term initiatives were also identified by this group to facilitate informed maintenance with regards to biofouling: the development of a real-time biofouling sensor and undertaking a biofouling baselining project. For the former, sensor outputs could be combined with device efficiency data to enable prescriptive maintenance. The latter baselining project might build on work underway at Heriot Watt, by experimentally assessing potential biofouling at potential development sites in advance of deployments, using resulting biological datasets to inform developers of possible biofouling species and/or characteristics to optimise maintenance regimes.

Knowledge exchange, research translation, and communication

Knowledge exchange, research translation, and communication were highlighted as essential areas for improvement throughout the day and across virtually all workshop attendees. This was deemed of such priority that it was discussed as a specific topic in this session.

The group's discussion centred on understanding the motivations and needs of each stakeholder group around biofouling. To date, the absence of effective knowledge exchange across these groups may have stemmed from the diversity of viewpoints and issues expressed by each group, combined with a lack of common understanding to bridge these differences. For example, representatives from Marine Scotland expressed that their concerns and interest in the topic stemmed very much from existing environmental legislation and regulations, including the International Maritime Organisation regulations and the Wildlife and Natural Environment (Scotland) Act 2011, which have requirements for the control of non-native species. Meanwhile, industry representatives were cognizant that they need to meet the requirements of this legislation, but their interest in biofouling was more strongly related to performance and reliability of their devices, in relation to reducing the overall cost of generating energy. Meanwhile, type approval and certification organisations wanted to ensure that their requirements and guidelines for biofouling were appropriate and accurate, while the academic community was much more interested in applying their existing environmental knowledge and understanding to develop workstreams which both increase the environmental knowledge base while influencing the optimum design, location, and regulation or marine developments.

While no 'quick wins' were specifically identified in this area, this workshop was cited as a good first step by bringing together multiple disciplines and allowing attendees to begin to understand each other's perspectives. There was agreement that a next step might involve identifying or developing a forum or working group for sharing information, though the format of this 'network' was yet to be decided. Potential avenues for such a network included collaboration with the Offshore Renewable Energy Catapult in the UK, and the international Annex IV initiative run by Ocean Energy Systems. Focusses for closer multidisciplinary collaboration might include:

- Structured means for industry education on biofouling risks, and impacts on operational costs mediated through device performance and maintenance
- Mapping biofouling progression geographically and temporally
- Development of a sensor for detecting / measuring biofouling
- Development of new data collection methods using technology (e.g. AUVs) or developer-targeted guidelines

Quick wins and longer-term goals from all groups are summarised in an agenda for biofouling research and innovation (table 1).

Table 1. Agenda for biofouling research and innovation.		
TOPICS	QUICK WINS	LONGER-TERM GOALS
Ecological understanding of biofouling species	• Collect environmental data by deploying sensors and using test site infrastructure at existing MRE developments. • Improve knowledge dissemination to industry • Develop a network to share expertise	• Improved collaboration and communication with scientists/ developers • Develop smart settlement panel arrays/board for quantifying biofouling.
Informed maintenance	• Sharing biofouling "dirty secrets" across the industry e.g. in an anonymous database • Determine an optimised maintenance model by using biological data to predict biofouling growth and settlement.	• Establish a knowledge pooling initiative e.g. "borrow a biologist". • Conduct a biofouling baseline project to quantify biofouling at potential MRE sites. • Develop a real-time biofouling sensor to trigger maintenance.
Informed/ intelligent design	• Develop "go to" biology support • Tool-kit of biofouling related considerations for the design phase • Standard methodology for sampling biofouling	• In-service testing of biofouling.

Summary

In the workshop, a novel approach was adopted to give participants the opportunity to learn from each other's experiences and to collate concerns and impacts of biofouling in the marine renewable energy (MRE) industry. Discussions took place at the cutting edge of research, development and deployment, involving participants from the MRE industry, anti-fouling industry, academic institutions and regulatory bodies. The key outcomes of the discussions are summarised in table 2.

Table 2. Key outcomes
Biofouling is a **concern for all stakeholders** across the marine renewable energy (MRE) industry.
Although it was noted that biofouling and marine growth may have positive ecological outcomes, the main discussion in the workshop focussed on **understanding and mitigating potential negative environmental and industrial impacts**
Workshop participants identified **119 concerns or issues** associated with biofouling in the MRE industry
Concerns and issues were grouped into **14 topics**: antifouling coatings, component failure, design, ecological understanding, impacts on sensors, invasive species risk, knowledge exchange, maintenance, mitigation, operational impacts of biofouling, other environmental impacts, predicting biofouling, quantifying biofouling and regulation.
Concerns and issues were prioritised to identify four key areas: gaps in **ecological/biological knowledge**, poor **communication pathways**, limited application of biofouling knowledge to inform **maintenance and operation processes** and MRE **device and component designs**.
These priority areas form an **agenda for future biofouling research associated with MRE** which will help to focus resources and initiate collaborative projects in the future.

Concerns and impacts were risk assessed and prioritised to identify 4 key areas:

- There are still gaps in fundamental **biological knowledge** for some biofouling species
- **Communication and knowledge exchange** could be improved between MRE stakeholders, particularly industry and academia.
- **Maintenance methodologies and schedules** are often not utilising biofouling knowledge
- MRE **device and component designs** currently only use "broad-brush" conservative estimates of biofouling.

These key areas form a cross-disciplinary agenda for future biofouling research associated with MRE which will help to focus resources and initiate collaborative projects in the future. The organisers will contribute the next steps as documented in table 3 to help initiate this progress.

Table 3. Next Steps
This **report** of the workshop will be circulated to all workshop participants and beyond
A **forum** will be created to enable discussion and help bridge communication gaps
Jennifer Loxton and Raeanne Miller will propose a further biofouling specialised session/ workshop at the **EIMR conference 2017** to build on the outputs of this workshop
A **peer reviewed article** will be prepared presenting the outputs of this workshop alongside additional data on biofouling impacts. This paper will aim to set an agenda for biofouling research associated with marine renewable energy developments.

It is clear that understanding and minimising biofouling impacts on MRE infrastructure is vital to the successful development of a reliable and cost effective MRE industry which can viably compete with traditional methods of energy generation. As the emerging MRE sector continues to grow and mature, collaborative and future-orientated biofouling research has many roles to play.

Appendix 1: Workshop attendees

Name	Organization	Email
Raeanne Miller	Scottish Association for Marine Science	Raeanne.Miller@sams.ac.uk
Jennifer Loxton	Environmental Research Institute	Jennifer.loxton@uhi.ac.uk
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Tom Vance	PML Applications	thva@pml.ac.uk
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Appendix 2: Workshop Agenda

9:30 – 10:00	**Arrival & registration**. Coffee & teas provided.
10:00 – 10:15	**Joint plenary and introduction to the day**. For all attendees across all workshops (collision, biofouling, and societal impacts)
10:15 – 11:00	**Setting a baseline: an ecological perspective on biofouling**. Adrian Macleod (SRSL) and Dr. Raeanne Miller (SAMS) Joanne Porter (Heriot Watt) Chris Nall (Environmental Research Institute) Jennifer Loxton (Environmental Research Institute) Q&A and Discussion
11:00-11:45	**Setting a baseline: Industry and engineering perspectives on biofouling** Ben Waldron (DNV) Calum Kenny (Albatern) Richard Ramsden (Akzo Nobel) Tom Vance (PML Applications) Q&A and Discussion
11:45 – 12:30	**Break out session 1:** identifying common issues around marine growth & their drivers
12:30 – 13:00	**Lunch**
13:00-13:45	**Break out session 2:** prioritising issues and identifying knowledge gaps
13:45-14:30	**Break out session 3:** agreeing on priorities, making a plan, and next steps (small groups, according to interest)
14:30- 14:45	**Summary, conclusions, and future opportunities**
14:45-15:00	**Joint Plenary and conclusion for the day.** For all attendees across all workshops (collision, biofouling, and societal impacts

Appendix 3: Issues and topics of interest identified in breakout session one.

Issues	Topics
cost of coatings for covering large areas and arrays of devices	antifouling coating
best fouling prevention solution for specific device or component	antifouling coating
cavitation-resistant coatings	antifouling coating
cost/benefit analysis	antifouling coating
component-specific coatings	antifouling coating
coating development to target specific materials and most commons species	antifouling coating
coatings too expensive for in/out deployments	antifouling coating
using coatings that do not cause toxicity problems adjacent to deployment	antifouling coating
developing the right coating for different components	antifouling coating
pragmatic risk assessment / biosecurity measures	antifouling coating
Hydraulic seals	component failure
corrosion impact on device	component failure
interface areas (internal/external)	component failure
prevention of anode fouling	component failure
ORE catapult provides a marine energy component analysis service	component failure
physical damage and prevention of fouling of moving components	component failure
reliability	component failure
seal integrity	component failure
corrosion	component failure
design protection of seawater cooling intakes	design
design protection of pump pistons	design
design protection of seals	design
design protection of tool interfaces	design
design for biofouling	design
site-specific approach	design
artificial reef & changes to natural ecology	ecological understanding
reef-effects around renwable energy devices: ecology perspective of biofouling	ecological understanding
Artificial reef effects	ecological understanding
understand seasonal and temporal distribution	ecological understanding
most common species life traits and ecological effects	ecological understanding
biofouling communities mapping (spatial variability)	ecological understanding
missing fundamental data on growth-rates and reproduction	ecological understanding
limited taxonomic resource (people with skills)	ecological understanding
environmental impacts +/- of biofouling	ecological understanding
Components: sub -assembly, reliability, and failure data sharing	impacts on sensors
protecting sensor heads from biofouling	impacts on sensors
sensor accuracy	impacts on sensors
impact of biofouling on sensors	impacts on sensors
translocation of invasive species risk assessment	invasive species risk
biosecurity compliance	invasive species risk
collaborative approaches to biosecurity	invasive species risk

Issues	Topics
non-native species	invasive species risk
invasive species	invasive species risk
biosecurity planning - what are the best tools	invasive species risk
consensus on non-native species	invasive species risk
antifouling not always tested on non-natives	invasive species risk
non-native spread during towing and harbouring	invasive species risk
renewable energy harbours are big sources of INNS contamination	invasive species risk
non-natives	invasive species risk
non-native sp - is ORE the problem or the messenger	invasive species risk
research groups join forces with ORE Catapult	knowledge exchange
technology developer education programme	knowledge exchange
positive managing?	knowledge exchange
how science can support development of EIAs, process, and biosecurity	knowledge exchange
location?	knowledge exchange
develop industry-friendly codes of practice	knowledge exchange
joined-up thinking to involve leisure/commercial boats and renewables	knowledge exchange
limited biological knowledge used to plan deployments & maintenance	knowledge exchange
identifying the right people across science and industry to ensure relevant connecitons are made	knowledge exchange
consistency of management measures	knowledge exchange
perspective - relative impacts of ORE vs shipping	knowledge exchange
current solutions in other sectors, e.g. inland waterways	knowledge exchange
read across from marine shipping	knowledge exchange
re-appropriation of data or models	knowledge exchange
drawing on existing research / work	knowledge exchange
education - coatings, devices, implications of the above and characterisation	knowledge exchange
strategies to minimize and predict maintenance	maintenance
in-water cleaning and repair	maintenance
safety, e.g. diving maintenance	maintenance
little and often cleaning approach	maintenance
maintainability	maintenance
maintaenance scheduling	maintenance
compatability of maintenance and coating type/selection	maintenance
accurate asset maintenance predictions & investment	maintenance
novel prevention, detection, and mitigation	mitigation
prevention	mitigation
sensor integrity	operational impacts of biofouling
understanding and characterising efficiency and efficiency loss	operational impacts of biofouling
hydrodynamic efficiency	operational impacts of biofouling
load impact	operational impacts of biofouling
loading	operational impacts of

Issues	Topics
	biofouling
biofouling effects on technology	operational impacts of biofouling
impact on operational costs	operational impacts of biofouling
retrieval/installations	operational impacts of biofouling
loading, drag, and roughness	operational impacts of biofouling
efficiency	operational impacts of biofouling
does biofouling of mooring reduce corrosion margin	operational impacts of biofouling
corrosion	operational impacts of biofouling
structural loading	operational impacts of biofouling
impact of fouling on performance	operational impacts of biofouling
biofouling impact characterisation	operational impacts of biofouling
performance	operational impacts of biofouling
modes of action in efficiency impedance	operational impacts of biofouling
demonstrating reliability for investors	operational impacts of biofouling
biocorrosion	operational impacts of biofouling
indications of longevity of devices - what level of efficiency is too low	operational impacts of biofouling
coatings = loss of positive reef effects	other environmental impacts
reef effect	other environmental impacts
chemical pollution of anti-fouling	other environmental impacts
pollution from organic waste from cleaning	other environmental impacts
understanding what fouling organisms are important to mitigate in what geographic areas	predicting biofouling
what types of biofouling are going to be most problematic	predicting biofouling
use of satellite applications to gather data and monitor growth	predicting biofouling
predictive modelling	predicting biofouling
indications of longevity of sensors	predicting biofouling
having accurate information about thickness and weight of marine growth	quantifying biofouling
integrated real-time sensing	quantifying biofouling
real-time or near real-time biofouling assessment	quantifying biofouling
how can auvs support biofouling monitoring and clean-up	quantifying biofouling
economic impacts positive and negative of biofouling	quantifying biofouling
rapid biofouling extent analysis	quantifying biofouling

Issues	Topics
biofouling characterisation - chemical/physical/environmental	quantifying biofouling
efficiency effects	quantifying biofouling
licensing and permits	regulation
understanding differences between shipping licensing and renwables licensing for biosecurity	regulation
communication of requirement for considering biofouling	regulation
type approval (certification) DNV	regulation
compliance with legislation	regulation