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A novel system for monitoring biofouling and testing antifouling and anticorrosion coatings in marine renewable energy areas

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Abstract— **As part of UK governmental plans to decarbonise electricity generation, the seas around Britain are being targeted for deployment of marine renewable energy (MRE) devices, i.e. wave, tidal, and offshore wind technologies. The success of the MRE industry is dependent upon lowering the levilized cost of electricity generation through maximising energy capture and minimising down-time. A major concern to industries working at sea is marine biofouling – the settlement and growth of organisms on submerged structures. In the MRE sector, biofouling may affect device performance by increasing drag, accelerating corrosion, and adding weight to moorings and other infrastructure. Additional concerns exist regarding the accuracy of data buoys and sensors used to assess the hydrodynamic resource and device performance. MRE deployments are taking place in areas where structures have not been previously installed (e.g. in very strong tidal flow areas) and where fouling studies are uncommon.**

The BioFREE project, part of a collaboration between the Orkney campus of Heriot-Watt University and the European Marine Energy Centre, has developed a novel system for monitoring biofouling for use in any chosen depth within the water column at high-energy wave and tidal areas. This system has been successfully deployed and retrieved and is allowing detailed characterisation of the biofouling communities from multiple locations in Orkney (UK), as well as at partner test sites in Chile, Japan and the USA. Furthermore, this system is providing a platform to test anti-fouling and anti-corrosion coatings applied to materials used in component manufacture in this industry.

Results from these studies indicate that major fouling species differ between sites owing to hydrodynamic conditions, water depth, type of substrate, and timing of deployment. Key fouling species often exhibit contrasting patterns of seasonal reproduction, settlement, and growth. This may allow site-specific guidance to the industry regarding anti-fouling strategies including scheduling of deployment and maintenance of MRE devices and infrastructure to times when the settlement of fouling organisms will be minimal or their removal will be least costly.

Keywords— **Biofouling, Corrosion, Marine Renewable Energy, Tidal, Wave.**

I. Introduction

A significant risk for industries working in the marine environment is biofouling - the settlement and growth of organisms on intertidal and subtidal structures. Impacts of marine growth on shipping are well known and have been researched from hydrodynamic [1] and economic perspectives [2], leading to development of coatings to protect hulls and promote fuel efficiency. Economic consequences of poorly managed biofouling include a reduction in performance, the costs incurred during removal and prevention of growth, and the potential need to replace corroded components. Fouling of staff access points, e.g. boat landing areas, may create safety issues [3]; heavy fouling may obscure mooring inspections as part of third party verification assessments necessary to pass regular certification [4]. In addition, fouling may interfere with cathodic protection by preferential settlement on anodes [3]; deterioration of coatings may further alter electrical conductivity of the structure [5].

In the marine renewable energy (MRE) sector, increased weight and drag from biofouling may compromise device functioning by affecting hydrodynamic performance of power delivery, and by increasing structural loading on the device or its moorings [6]-[8] (Figure 1). As the MRE sector develops, biofouling issues are being recognized that are specific to this industry. Aspects of devices that may be particularly affected by biofouling include: moving parts unique to MRE technologies [9]; novel materials used in ways that have not been trialled before in marine

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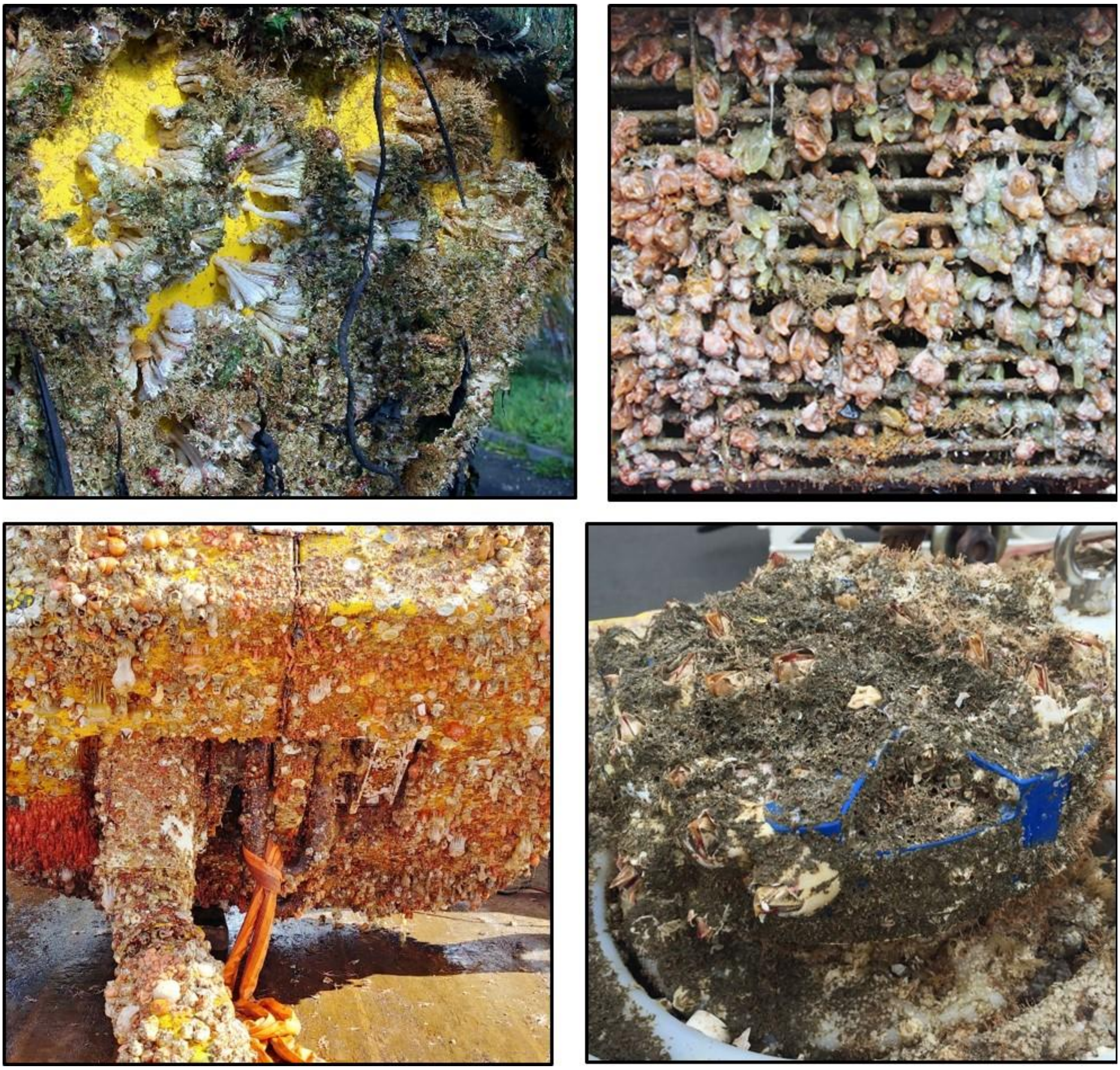

Fig. 1. Biofouling of marine renewable energy infrastructure (clockwise from top left): heavy barnacle fouling after only 8 months deployment of a Waverider buoy used to assess wave resource; tunicates dominating the fouling on a tidal device heating subunit; barnacles and hydroids on an acoustic Doppler current profiler used to assess tidal current flow; and, heavy animal-dominated fouling on an offshore 'tether-latch assembly' mooring system (Tether-latch assembly image courtesy of EMEC).

environments [10]; and, deployments taking place in areas where structures have not been previously installed and studied (e.g. in strong tidal flow areas) [11]. In addition to the effects on hydrodynamics and survivability of materials, Want *et al.* [11] described biofouling compromising the functionality of sensors (e.g. data buoys, acoustic Doppler current profilers, and cameras) used to accurately characterize energy resource and monitor device performance.

The UK Government has set the objective of delivering at least 15% of electricity from renewable sources by 2020 [12]. In Scotland, there is a more ambitious objective to produce of 50% electricity from renewable technologies by 2030 [13]. Assessment of the potential for renewable generation from marine sources has created significant interest in Orkney, which has been identified as a suitable location for large-scale deployment of wave and tidal energy converting devices [14]. The European Marine Energy Centre (EMEC) was established in 2003, to test marine renewable energy devices (MREDs) in the high-energy waters around Orkney [15]. Subsequently, in March 2010, The Crown Estate (TCE) announced leasing agreements with several developers and energy providers for the deployment of 1.6 GW of energy-generating capacity, predominantly within Orkney waters and the Pentland Firth [16]. Since its inception, EMEC has hosted over 20 developers testing 31 subsea and surface energy converters [15]. Owing to a rich local tradition of working in the sea, Orkney has well-developed infrastructure supporting the MRE industry, enhanced by the Highlands and Islands Enterprise and the local authority with the construction of additional piers and harbour structures designed to facilitate growth in this sector. In addition to testing MREDs, EMEC has deployed over £35M of marine infrastructure including subsea cables, surface buoys, moorings, and environmental sensors [15].

Previous studies on biofouling and the MRE industry: Limited published research exists on biofouling consequences in this sector owing partly to the early technology readiness level (TRL) of MREDs, and to concerns with confidentiality [17]. Published biofouling studies in this sector have included assessment of fouling on buoys [7], [18] and harbours used in the industry [19]. Studies specific to the biofouling community in Orkney waters have included: long-term monitoring of intertidal indicator species [20]; classification and quantification of fouling on a wave device [21]; and, a characterisation of the biofouling community at 11 wave, tidal, and harbour sites including MREDs, fixed infrastructure, data buoys, and sublittoral sensors [11]. In the latter study, collaboration between Heriot-Watt University (HWU) and EMEC led to the identification of key species chiefly responsible for biofouling in different habitats used by the MRE industry; and, for the first time, the change in heave response of a data buoy at the wave test site was matched with the knowledge of the specific type of biofouling community [11].

The BioFREE project and objectives: Biofouling of Renewable Energy Environments - Marine (BioFREE) is a collaborative project between HWU and EMEC with additional support from antifouling coating manufacturer Whitford Ltd. HWU's participation within this project was funded by the Natural Environment Research Council (NERC).

The overarching aim of these studies was to provide guidance to the MRE industry by addressing key knowledge gaps of fouling in these data-poor areas and through development of practical strategies to minimise impacts from biofouling. A multi-disciplinary approach combining biological expertise with engineering and hydrodynamic disciplines was utilised in the development of a biofouling monitoring and testing system designed for standardised deployment and retrieval at any depth within the water column. This system is being deployed at EMEC test sites in Orkney and internationally at partner wave and tidal sites (with varying temperature, seasonality, hydrodynamic conditions, etc.). These studies may ultimately lead to increased efficiency of energy capture and device reliability by providing more effective assessment and management of fouling organisms.

II. METHODS

Biofouling community surveys: A comprehensive record of fouling species present was collected from wave and tidal test sites in Orkney. In addition, the most dominant species were identified based on quantitative assessment of total fouling. The survey approach was based on rapid assessment survey described by Arenas *et al.* [22]. The researchers undertaking the assessment had specialist expertise in hard substrate and fouling assemblages, including barnacles, bryozoans, hydroids, and macroalgae. Photographic records were made using a digital SLR camera. When necessary, species not easily identifiable in the field were collected for identification in the laboratory, e.g. using microscopy. Samples of particular significance, e.g. rare or non-native species, were preserved in 70% ethanol for voucher material to be deposited in an appropriate repository for long-term curation.

Development and application of the BioFREE monitoring and testing system: As a key objective of the BioFREE project, a system was designed to collect fouling data from high-energy areas targeted by the MRE industry. This system was required to be physically robust to withstand extreme hydrodynamic forces, and statistically robust, to allow testing of coatings in a hierarchically-designed study [23]. Additional factors considered included material selection, cost, and ease of manufacture, deployment, and retrieval. Extensive consultation was conducted with marine operational staff and hydrodynamicists in the design of the BioFREE system with the aim to ensure survivability over long-term field tests in both tidal and wave dominant sites; particular attention was paid to determining the buoyancy and drag of the frame, buoys, and mooring lines along with the resulting system profile. This analysis along with suitably applied factors of safety helped ensure survivability of the system. System design also required that it can be replicated by various manufacturers throughout the world, emphasizing the required simplicity of the final units.

The BioFREE monitoring and testing system consists of a frame (measuring 796 mm (length); 672 mm (height); and, 25 mm (width)) populated with an array of 12 settlement panels, capable of deployment at any depth within the water column. This system is anchored to the seabed via a simple clump weight mooring system attached by swivel to the frame hoist. Subsea buoyancy above the frame is necessary to maintain vertical orientation of the array, although drag forces will considerably affect the position of the frame relative to the seabed (particular in strong tidal currents). Buoyancy is provided through frame components and subsea floats attached to a line extending to a surface buoy, necessary for relocation. A small 'recovery' buoy is attached to the surface buoy to aid in retrieval.

Following discussions with industry developers to identify materials of greatest concern, HDPE, raw steel, and steel treated with anti-biofouling and anti-corrosion coatings were selected for settlement studies. Panels measuring 124 x 124 mm were provided by Whitford Ltd; steel panels were treated with an organic thin-film protective coating designed by Whitford Ltd. Four panels of each substrate type were mounted randomly in arrays within BioFREE frames (Figure 2). Additional relevant components, identified by the industry, may be fitted to the system for further testing. Frames were recovered quarterly, all panels imaged (front and back), and select panels removed (and replaced) for further analysis to determine species identification, seasonality of settlement, fouling mass, and growth. Deployment occurred in replicate pairs at all four EMEC test sites in July 2018; first quarterly retrieval, sampling, and redeployment occurred in October 2018. Deployment depth varied between sites; maximum height of the frame above the seabed was adjusted depending on the tidal current profile at each site (Table 1).

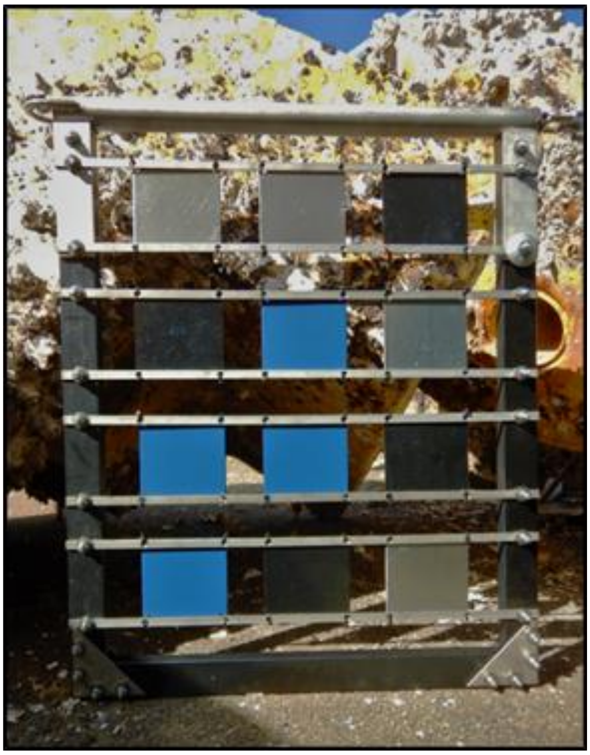

Fig. 2. BioFREE biofouling monitoring and testing frame: designed, manufactured and deployed following extensive consultation with MRE operational staff and developers, hydrodynamicists, and statisticians. Note: heavily fouled mooring structures in background.

TABLE 1
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.

Site	Depth (m)	Height (m)
Billia Croo	45	3
Fall of Warness	40	15
Scapa Flow	25	3
Shapinsay Sound	25	5

III. Results

Biofouling community surveys: In combination with earlier studies by the HWU team, over 190 fouling marine organisms have been identified in Orkney waters on artificial substrates used by the MRE industry.

BioFREE monitoring and testing system: Following deployment in mid-July, replicate BioFREE frames populated with settlement panels were successfully recovered from all four EMEC test sites on 16-17 October 2018. Synoptic images of a representative frame from each EMEC test site are presented in Figure 3. Data from international deployments are not presented. As a general observation at this time of year, overall fouling was dominated by a turf of hydroids (in particular *Ectopleura larynx*) except at the scale wave test site at Scapa Flow. This location is the most sheltered and features the lowest tidal flow rate of the four study sites. Fouling at the Scapa Flow site was dominated by the encrusting calcareous tubeworm *Spirobranchus triqueter*. The largest organism, with the highest profile, observed during the autumn recruitment season was the solitary tunicate *Ascidiella aspera*, especially conspicuous at the Shapinsay Sound site. Noticeably absent from all settlement panels were barnacles – one of the key groups of fouling organisms. This illustrates the importance of seasonality in fouling settlement; barnacle fouling is expected to dominate spring and summer seasons.

Preliminary analysis of data and results available at this time include the following: identification of dominant fouling species at each EMEC test site (Table 2); a comparison of fouling weight between HDPE and coated steel panels recovered for study in October 2018 (Figure 4); and, comparison of settlement on HDPE and coated substrates between individual test sites based on fouling weight on settlement panels recovered for study in October 2018 (Figure 5). Further analysis and data collection will continue and these findings will be made available in the near future. Results of fouling on raw steel are not presented. Oxidation of these surfaces led to extensive ‘sloughing-off’ of outer layers of raw steel settlement panels preventing accurate assessment of biofouling. In continuing studies, uncoated raw steel panels were replaced by marine grade (316) steel.

These results indicate greater settlement and growth of fouling organisms on substrates of HDPE when compared with antifoulant-coated steel. Based on wet weight of fouling, the greatest settlement and growth occurring between mid-July and mid-October 2018, was observed on HDPE panels deployed at the full-scale tidal test site at the Fall of Warness. The second greatest increase in wet weight was recorded on HDPE panels deployed at the scale tidal test site in Shapinsay Sound. These data suggest that settlement and growth of fouling organisms is positively associated with the rate of tidal flow, at least during the limited period of time observed at these four sites. The most striking contrast between wet biofouling on

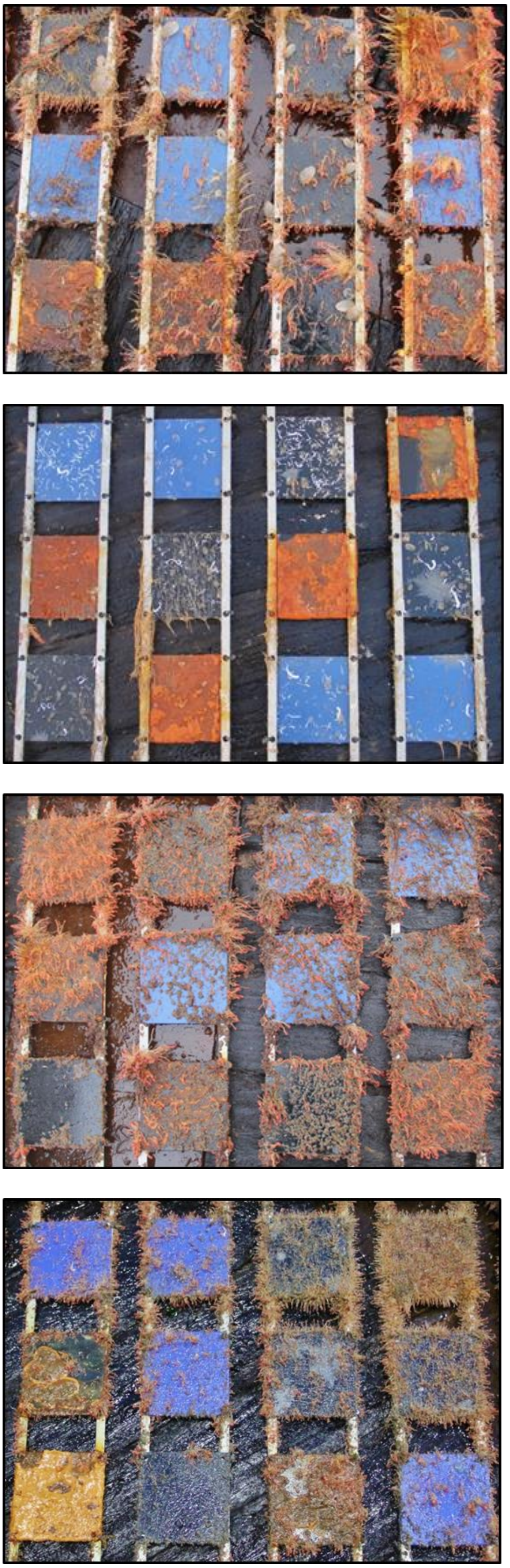

Fig. 3. Synoptic images of BioFREE settlement panels deployed at EMEC test sites between July and October 2018.From top: Shapinsay Sound, Scapa Flow, Fall of Warness, Billia Croo.

these two substrates was observed at the Fall of Warness. At this site, the mean weight from fouling on settlement panels was 21.11 g on HDPE and 5.92 g on coated steel. These results suggest that, while conditions at this site may favour settlement and growth on to HDPE panels, the efficacy of antifouling coatings is most apparent in high-tidal flows. In other words, high current flow may promote recruitment and growth, i.e. through enhanced larval and nutrient transport, but also create untenable drag forces for organisms adhering to anti-biofouling coated surfaces. It must also be stated that any conclusions be made with great caution; these preliminary results are based on limited data recorded during one 3-month season. More detailed analysis of settlement differences of key fouling species between sites and substrates has not yet been performed.

TABLE 2
PRELIMINARY RESULTS OF MOST ABUNDANT FOULING ORGANISMS FROM EMEC WAVE AND TIDAL TEST SITES (JULY TO OCTOBER 2018).

Site	**Dominant fouling organisms**		
Billia Croo	*Obelia dichotoma*	*Anomia ephippium*	*Electra pilosa*
Fall of Warness	*Ectopleura larynx*	*Jassa marmorata*	*Celleporella hyalina*
Scapa Flow	*Spirobranchus triqueter*	*Ascidiella aspera*	*Anomia ephippium*
Shapinsay Sound	*Ectopleura larynx*	*Ascidiella aspera*	*Plumaria setacea*

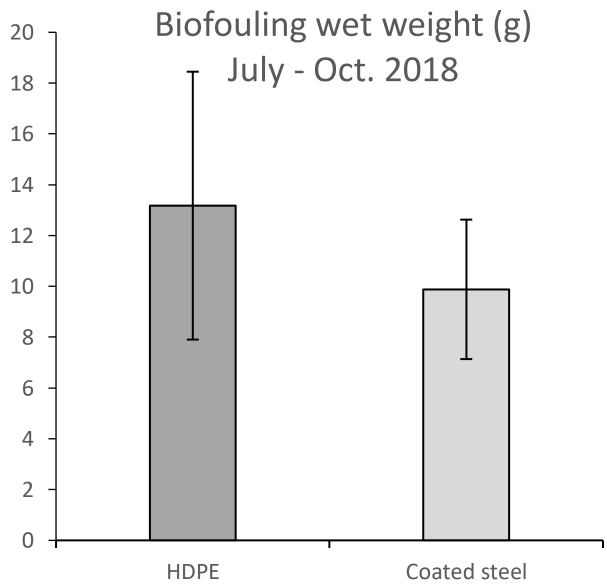

Fig. 4. Mean wet weight (g) of biofouling from HDPE and coated steel panels (n = 8) deployed at EMEC test sites from mid-July to mid-October 2018 (± S.E.).

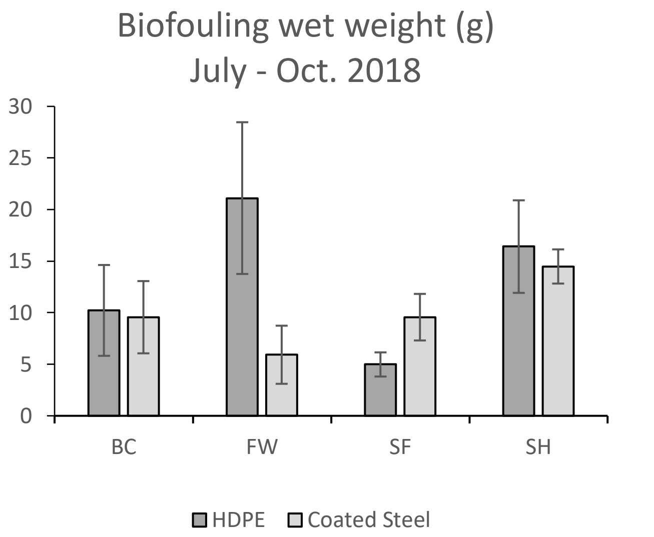

Fig. 5. Mean wet weight (g) of biofouling from replicate panels (2) deployed at EMEC test sites from mid-July to mid-October 2018. BC: Billia Croo; FW: Fall of Warness; SF: Scapa Flow; and, SH: Shapinsay Sound (± S.E.).

IV. DISCUSSION

Following deployment in the challenging hydrodynamic conditions found at MRE test sites, this system has been proven to be effective in capturing critical biofouling data and capable of survival in these highly-energetic environments. Unlike previous biofouling studies on MREDS and other offshore structures which rely on limited in situ opportunities to examine fouling, i.e. on surface deployments or seabed moorings, the BioFREE system captures fouling data from any chosen depth within the water column. This allows characterisation of the biofouling community in areas of greatest relevance to specific technology deployments. Furthermore, rather than depending on opportunistic surveys based on device operations and maintenance scheduling, the BioFREE system can be independently deployed and retrieved to allow greater control of timing, necessary for scientific rigour in seasonal and long-term studies.

Gathering of data using the BioFREE system, and complementary surveys and experimental research on MREDs during this project, has provided evidence supporting several important findings. These include:

- Fouling organisms are highly specific to location;
- Fouling varies depending on water depth and substrate type;
- Fouling assemblages are predictable based on hydrodynamic conditions;
- Anti-fouling coatings may be most effective at preventing fouling in high current flow conditions;
- Marked seasonality of fouling suggest that scheduling deployment and maintenance operations in a targeted manner may be an effective means to minimise fouling impacts.

Considerable caution must be applied when interpreting these results. Preliminary findings discussed here represent limited studies during the late-summer to early-autumn season when rates of settlement and growth are expected to decline. The main fouling species during this period may not be representative of the overall key foulants whose impacts are most profound upon device performance and survivability. Completion of data collection over at least an annual cycle of all settlement seasons is necessary to better understand issues of seasonality and successional changes in fouling communities [24].

Managing extreme drag encountered in high-tidal flows has played a major role in design of the BioFREE system. By necessity, the panel array is a as large as possible without exceeding the buoyancy capacity provided by system components; in less challenging areas, greater capacity for testing and replication would be possible. Modelling of drag and buoyancy has provided estimations of frame position relative to the seabed at different tidal velocities. These models suggest that the BioFREE system is capable of survival in tidal flows exceeding 4 m/s. Factoring in a safety margin of 2.0 and deployment in waters below 3 m/s helped ensure survival of the system in this study. In this case, sufficient safety margins also lower marine operational costs by making it unnecessary to capture detailed recordings of the seabed prior to deployment. Future studies will include data loggers to record depth data necessary to plot precisely the position of the frame throughout the tidal cycle.

No detailed analysis has yet been conducted on the effects that panel position within the BioFREE array may have on fouling settlement and growth. While the system has been designed to be as symmetrical as possible, it is possible that differences in fouling might be observed when comparing the front and back of individual panels. Additional analysis is necessary to test the presence of an 'edge' effect which might be a factor in fouling comparisons between panels located in the centre versus the periphery of the frame. Furthermore, it is possible that position relative to the frame hoist may be a factor owing to the potential of the system to 'flutter', especially in higher tidal flow conditions. While these additional and necessary analyses are not yet possible owing to limited data currently available, there is no preliminary evidence of differences in fouling on BioFREE systems based on panel position.

Dissimilarities in biofouling assemblages result from many environmental variables but most obviously between geographic location, depth of device deployment, and hydrodynamic characteristics of the deployment site. Additional variables include substrate type, orientation to shade, nutrient levels, oxygenation, and distance from shore or other hard substrates [25-27].

Based on the current studies and previous research in Orkney [11; 28], some general statements regarding fouling at the EMEC test sites can be made. Surface devices and buoys will often feature considerable fouling from several macroalgal species, including larger kelps such as *Laminaria hyperborea*, and, in more wave exposed areas, *Alaria esculenta*. Several animals are key foulants on intertidal and shallow sublittoral structures at these test sites including: the barnacle, *Semibalanus balanoides*; the blue mussel, *Mytilus edulis*; and hydroids, such as *Amphisbetia operculata*. Dominant fouling species may vary considerably based on timing of deployment, i.e. seasonality of settlement is often highly species-specific [24]. The effects of light and wave exposure will decrease with depth; in deeper waters, the fouling assemblage rapidly transitions to an animal-dominated community.

In moderate current speeds, approaching 0.5 m/s (i.e. the full-scale wave test site at Billia Croo), aphotic fouling communities comprise a mixture of soft-bodied animals such as *Alcyonium digitatum*, *Metridium dianthus* and several species of hydroids, and hard-bodied encrusting animals including barnacles, bryozoans, and saddle oysters (*Anomia ephippium*). As current speeds increase, soft-bodied organisms are less likely to be found (except in limited spaces of relative shelter) presumably because of direct hydrodynamic stress or indirectly through current-driven scour [29]. With less competition for space resource, the aforementioned hard-bodied foulants flourish in higher flow conditions, such as those targeted by tidal energy technologies, i.e. the full scale tidal test site at the Fall of Warness. Many of these encrusting species (i.e. bryozoan colonies and saddle oysters) are of small size and low profile, with relatively minor hydrodynamic and loading impacts expected (although component corrosion may be an ongoing issue with unmanaged biofouling). From a hydrodynamic standpoint, when compared with other fouling organisms in this environment, high profile, non-compliant barnacle shells create greater impacts on drag [30; 31] The dominant fouling role of sublittoral barnacle *Chirona hameri* fouling in high-current velocities and its massive size makes it an obvious concern to technologies working in tidal environments in the North Atlantic [11].

In the current studies, deployment of the BioFREE system and data collection has occurred out of season for recruitment of larger barnacles but has revealed the importance of other encrusting organisms such as calcareous tube-worms, bryozoans and saddle oysters, as well as abundant early recruitment of hydroids.

These hydroids typically form a turf, often associated with colonies of burrow-forming amphipods. This turf forms the major part of autumnal fouling assemblages recorded at EMEC test sites, although notably less abundant at the Scapa Flow test site featuring relatively little tidal flow. While fouling from higher-profile, less compliant, encrusting organisms may produce a greater hydrodynamic performance penalty than softer, turf-forming species such as hydroids, the latter group of foulants is still expected to substantially increase drag and mass, and promote corrosion of unprotected components.

Based on abundance observations in Orkney and current available knowledge of life cycles of key fouling organisms, Want *et al.* [11] developed a 'traffic-light' system identifying periods of high, medium and low fouling risk from several key species in local waters. This table has been updated with findings from the BioFREE project (TABLE 3). For many species, the timing of prime settlement is in late spring – early summer. However, there are some important exceptions with certain species most reproductively active during the winter. In other geographic regions both key fouling species and primary settlement times would be expected to vary considerably [32].

Outputs: Success of the emerging MRE industry depends on maximising energy capture and minimising

TABLE 3
PERIODS OF SETTLEMENT ASSOCIATED WITH MAJOR FOULING ORGANISMS 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.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Amphisbetia operculata	Green	Green	Green	Green	Orange	Red	Red	Red	Red	Orange	Green	Green
Anomia ephippium	Green	Green	Green	Green	Green	Green	Orange	Red	Red	Red	Orange	Green
Chirona hameri	Green	Green	Orange	Red	Red	Orange	Green	Green	Green	Green	Green	Green
Ciona intestinalis	Green	Green	Green	Orange	Red	Red	Orange	Green	Green	Green	Green	Green
Ectopleura larynx	Green	Green	Green	Orange	Red	Red	Red	Red	Red	Red	Orange	Green
Fucus spiralis	Green	Green	Green	Green	Green	Orange	Red	Red	Red	Orange	Green	Green
Metridium dianthus	Green	Green	Green	Green	Green	Green	Orange	Red	Red	Orange	Green	Green
Mytilus edulis	Green	Green	Orange	Red	Red	Red	Red	Red	Red	Orange	Green	Green
Saccharina latissima	Red	Red	Red	Red	Orange	Orange	Orange	Orange	Orange	Red	Red	Red
Schizoporella japonica	Red	Red	Red	Orange	Green	Green	Green	Green	Orange	Red	Red	Red
Semibalanus balanoides	Green	Green	Orange	Red	Red	Orange	Green	Green	Green	Green	Green	Green

asset downtime. Growth of fouling organisms leads to reduced efficiency of energy capture, accelerated corrosion of subsea structures, increased loadings on cables, as well as affecting accuracy of sensors used to assess performance and the hydrodynamic resource; existing anti-fouling and corrosion strategies are costly and time consuming.

Knowing when and where major fouling occurs can inform scheduling decisions on deployment and maintenance of devices and sensors. Avoiding periods of major settlement and scheduling cleaning operations to maximise removal of the most problematic foulants, may form part of an effective strategy to minimise the consequences from fouling. With better understanding of seasonality and settlement dynamics, it may even be advantageous to encourage selective fouling of less problematic organisms, with lower drag and loading impacts, whose presence may subsequently reduce settlement of more nuisance fouling species.

Limitations in effectiveness of anti-fouling coatings are expected when applied to components featuring greater structural and hydrodynamic complexity, e.g. couplings, manifolds, and potentially rotating features [33]. There is a lack of rigorous study of coating performance in tidal areas where high current speeds may increase the rate of antifoulant dissolution [34] and coatings may be further compromised by sediment scour/abrasion [8]. Advice gleaned from testing anti-fouling and corrosion coatings, material choices, and coating application methods will contribute further to reducing costly impacts of marine growth and inform the latest technological advances. Enhanced multifunctional coatings for use by MRE developers on their devices will assist them in protecting strategic components and helping to increase output efficiency levels.

The BioFREE system has been proven successful in capturing critical data from hard-to-access marine habitats and provides a platform for testing coatings and materials used in the sector. Continuing study will be necessary to address knowledge gaps in seasonality and succession of fouling. While this research has focused on less well-studied areas used by the MRE sector, there are broader implications of biofouling impacts and mitigations, e.g. the loading and drag consequences of fouling on mooring functioning and survivability is a critical issue for floating wind devices and aquaculture installations.

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