

Institution:

Heriot-Watt University (HWU)

Unit of Assessment:

Sub-panel 7: Earth Systems and Environmental Sciences

1. Unit context and structure, research and impact strategy

We are proud of our track record of achievement in Earth Systems and Environment at Heriot-Watt University (HWU) and our ambition to become a world leading institution to bring solutions to critical global challenges across the terrestrial, aquatic, and environmental sciences has led to extensive targeted investment in this Unit since 2014. We attracted The British Geological Survey (BGS) as a strategic partner that co-located to HWU campus in 2016 with the completion of the **Lyll Centre for Earth and Marine Science and Technology** including new infrastructure, supporting cutting-edge biogeochemical, microbiological and geoenergy analytical capabilities and staff (£23M investment NERC, Government and HWU see section 3). Since 2014, research has intensified, and our unit has nearly doubled in size to 35 FTE (up from 18 FTE) largely due to investment in the Lyell Centre and recruitment of outstanding mid-career scientists. Further the **Wolfson Aquarium for Climate Change Research** opened in 2017 and doubled our aquarium facilities to >50,000L of seawater and continuous supplies of de-chlorinated freshwater delivered to purpose-built temperature/pH/gas-controlled rooms for aquatic research. On the terrestrial-side we have developed major research programmes on carbon and water cycling in tropical areas through significant GCRF investment. We have expanded (investment of £7.5M) our **International Centre for Island Technology** (ICIT-Orkney HWU's Stromness campus) to become a leading research centre for marine technology research embedded within a framework of environmental and socioeconomic sciences. Our Unit lies within the School of Energy, Geoscience, Infrastructure and Society (EGIS) with the integration of the HWU-BGS vision championed by a Director of the Lyell Centre (40% appointment HWU, 60% BGS). The School of EGIS, comprising institutes and groups spanning engineering, earth, biological, and social sciences facilitates interdisciplinary collaborations poised to deliver research solutions focused on the UN-SDG.

Research and Impact strategy

Our unit is formed of three integrated themes drawn together by expertise in policy and governance of natural resources (Figure 1). Staff are aligned within and across the themes Fundamental processes, human Impacts, and human Solutions that align directly to address critical global challenges with impact-driven research across scales from molecules to global ecosystem processes within the atmosphere-land-ocean continuum.

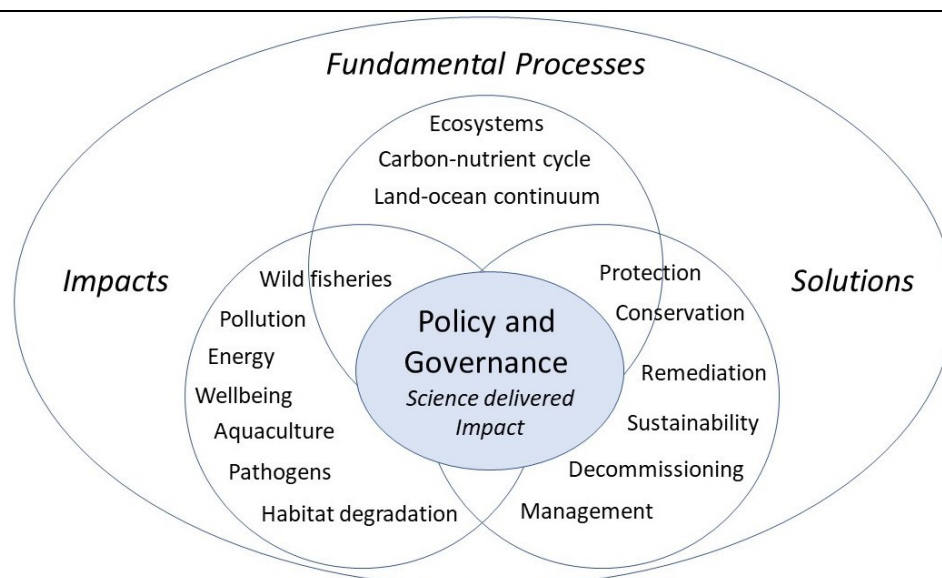


Figure 1. Academic staff (35 FTE) in our unit work on research topics across three integrated research Themes- Fundamental Processes, human Impacts and human Solutions, which are overlaid by expertise in Policy and Governance to deliver impact from our scientific investigations.

Achievement of vision and progression of strategic plans set out in REF2014

Investment in new infrastructure and staff based on our strategic research since REF2014 has delivered our new approach for addressing critical global challenges through multidisciplinary research across three integrated Themes ***Fundamental Processes*** which supports our understanding of ***Impacts*** and innovations for ***Solutions*** across which our expertise in ***Policy & Governance*** drives implementation. Establishment of the Lyell Centre has delivered an international centre of excellence for innovation in terrestrial, aquatic and environmental sciences that captures the strengths of both HWU and BGS to focus on research that provides practical evidence-based solutions to critical global ecosystem challenges of the Earth's surface, sub-surface, oceans and atmosphere. Since 2014, we have doubled our academic staff, generated >£15M in research funding awards (with £12M spent in the period), increased our ongoing roster to >10 postdoctoral researchers and >50 PhD students, and for REF 2021 we have selected 86 of our top peer-reviewed scientific journal articles that have already accumulated >2000 citations.

Synergy of HWU and BGS within the Lyell Centre

The co-location of BGS at HWU within The Lyell Centre has created an exciting and vibrant collaborative research environment across both institutions that is a major addition to the UK research base and innovation strategy. This has allowed increased synergy in key alliances such as the Marine Alliance for Science and Technology Scotland (MASTS), Scottish Alliance for Geoscience, Environment and Society (SAGES) and the Scottish Universities Life Sciences Alliance (SULSA). Some of these synergies include:

Marine geology & habitats: Shared BGS/HWU interests in geological and habitat mapping (e.g., collaborative work on offshore renewables, deep-sea mineral resources and associated environmental impacts), will be strategically important as deep-water resources are exploited in UK continental shelf and other settings (e.g., British Overseas Territories). Current joint projects in research related to environmental assessment for sea floor development for resource extraction include the GCRF One Ocean Hub (UKRI) and SMARTX (NERC).

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Marine technology & engineering: Shared use of marine equipment (e.g., BGS seabed coring, drilling, vessels, and scientific divers) and development of innovative robotic approaches for sub-sea survey and sampling (e.g., Edinburgh Robotics Centre and UKRI ORCA, Institute of Sensors, Signals and Systems; and bespoke deep-sea landers).

Integrated Ocean Drilling Programme (IODP): BGS role as host of IODP's UK operations encourages development of joint mutual interests (e.g., joint bids on Expedition 339 material).

The Lyell Centre has doubled our critical mass of Terrestrial, Aquatic and Environmental researchers and enables HWU and BGS to share expensive infrastructure. For example, the relocation of BGS Marine Operations, including marine drilling engineering technology to Lyell has created exciting opportunities for co-design of sea-going scientific equipment and research cruise mobilisation facilities (e.g. sea-bed lander systems and sub-seabed sampling sea-floor drills), and joint lead of deep-sea expeditions on environmental assessment and exploration of mineral deposits. Similarly, BGS staff within the Centre regularly uses existing University workshops and other experimental facilities including the University's marine renewable campus on ICIT-Orkney. Most importantly, the Centre fosters unified Atmosphere & Terrestrial & Ocean research and technology developing and expanding the University's expertise alongside the BGS's world-renowned reputation in Earth science with defined societal relevance and wider impact.

Research Themes and Composition

Research across our unit is highly integrated and links understanding of **fundamental processes** of earth systems with characterization of human **impacts** and implementation of human **solutions** that are delivered through our expertise in **policy and governance**.

Theme 1: Fundamental processes (Earth sciences across interfaces)

Our contribution to fundamental understanding of aquatic and earth sciences evolves from investigations that crosses levels of biological organization (molecular to global processes) and time (paleo-environmental changes, modern systems of carbon cycling, future predictions/simulations). Of critical importance is our focus on interfaces including those of land-river water, freshwater-marine, coastal-open ocean, sea surface-deep sea, and atmosphere-water (both freshwater and marine).

Aquatic Processes

Our research on fundamental ecosystem processes from rivers to estuaries, coastlines to open ocean, and the sea surface down to the deep seabed, underpins much of the applied research expertise in the aquatic science theme. Pioneering work (**Pereira**) using globally unique analytical facilities in the Lyell Centre have enabled characterization and resolution of the composition of dissolved organic matter (DOM) from head water streams through to rivers and marine waters and investigation of the role of low molecular DOM as a largely unknown but reactive carbon and nitrogen pool that rapidly interacts in the environment. Work on microbial methane oxidation (**Pratscher**) has unravelled the microbial biological sink for atmospheric methane (NERC Fellowship) and a methane biofilter system for widespread application and carbon capture is now in development. Industrial collaborations strengthen the sustainability aspect, by investigating microbial lignin degradation in the environment to optimize and increasing resource recovery and recycling (NERC National Productivity studentship). Work on sulphur cycling and processes influencing formation of harmful algal blooms (**Pratscher**) is being integrated with Brazilian fish farming applications (**Henry**). Closely embedded within research on fundamental processes are integrated challenges around rainforest management, social innovation of indigenous

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communities, community-based work, and land use change (e.g., mining and agricultural expansion near the forest-savannah boundary) that directly address UN SDGs. Aligned and parallel to this work are projects on Amazonian agricultural expansion, environmental sciences and development of sustainable future for tropical South America (Brazil, Colombia, Peru) and more recently in Southeast Asia (**Wagner**).

Our research to understand fundamental processes of aquatic ecosystems progresses across the freshwater continuum through interfaces with coastal to open ocean and deep-sea environments by combination and integration of multiple activity strands. Plankton ecology and ocean biogeochemistry alterations in relation to changing climate and acidification are key strengths (**Poulton**, with NERC-Defra funding). Our expertise in understanding global carbon cycles is extended through research on air-sea exchange of gases integrated with marine Earth Observation (EO) (**Woolf**) that advance the fundamental understanding of air-sea exchange processes, and application of EO data have led to an estimation (with uncertainty) of the global air-sea CO₂ flux. Climate-related oceanographic expertise is highlighted by new approaches to understanding the occurrence of oxygen minimum zones in pelagic ecosystems (**Hoogakker**).

Oceanographic expertise is complimented by our work in benthic ecology of shelf and deep seas. Research on coastal biogeochemistry and photophysiology of carbonate systems (coralline algae and coral reefs) along with ocean acidification research (**Poulton**) has led to a better understanding of the importance of mesophotic primary production and the importance of carbonate systems (**Burdett**, Leverhulme Trust, NERC). The response of biogeochemical cycling in soft-sediment communities subject to trawl disturbance (**Sciberras**) reveals a highly context dependent nature of the response in the microbial community (NERC). Our deep-sea research (**Sweetman**) is pioneering a better understanding of the ecological effects of deep-sea mining and is extensively supported by research councils (NERC, Horizon 2020) and industry (SmartEX 2021-2025; Deep-Green 2020-2022; DeepCCZ 2017-2021). State-of-the-art deep-sea landers and infrastructure investments of the Lyell Centre have positioned our unit at the forefront of deep-sea research with baseline investigations in areas protected from mining and in mining-license areas in the Clarion-Clipperton Zone (UK1, Ocean Minerals of Singapore, NORI-D, BGR). Our investment in deep-sea research capability has enabled expertise of academics in microbiology (**Pratscher**), ecotoxicology (**Hartl, Henry**), and pathophysiology of aquatic organisms (**Henry**) to be applied directly within these research projects (NERC, Deep-Green). Collectively, we have emerged as a unit that can investigate across the key fundamental processes of deep-sea ecosystems. Further we (**Sweetman**) along with an international consortium have developed modelling approaches to predict and map effects of multiple stressors from climate change within the deep sea. Research informing how best to restore deep-sea ecosystems post-anthropogenic disturbance has arisen from the EC MERCES project (2016-2020).

Earth science processes

Our overarching aim is understanding of earth surface processes and feedbacks, with complex drivers and environmental impacts, element flows (biogeochemical cycles), climate, energy, ecosystems and society. We focus on critical interfaces, both spatially and through geological time, and place modern challenges into the geological context to inform on possible future trajectories of climate. Research within earth science processes is closely linked with those focused on the energy transition in EGIS's Institute for Geoenergy Engineering (UoA12, joint with University of Edinburgh). Our leading innovation covers new technologies, including advancing analytical and method capabilities for novel field and laboratory applications. Examples of working closely with industry and other leading innovation partners, include:

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- the design, development and application of low-cost field based greenhouse gas sensors (Pereira, Partner BGS);
- extended Automatic Solvent Extractor (ASE) facilities (Magill, Partner ThermoFischer), and;
- the next-generation Rock Eval Pyrolyses 7S system (Wagner, Partners: developed by IFPEN and commercialized by Vinci, France; this work led to two patents in 2017 and 2018, led by IFPEN (Wagner as co-author).

Earth Science research is organized into two main research topics:

1. Modern systems and carbon cycling (described above)
2. Paleo-environmental change with intense cross-fertilization across groups and schools, as well as pioneering individual research work.

Our expertise in paleo-environmental research complements and enriches our modern perspective by high resolution research into major evolutionary steps and perturbations of past climate using sediments from international scientific drilling and field-based sampling. Pioneering contributions to the broad field of (paleo)climatology and archaeology have been made (**Magill**) by bringing past African landscapes alive, with all their dynamic and multi-directional processes and trends that impact the environment and its ecosystem services (e.g., water, carbon/nutrients and vegetation/food). This novel approach links archaeology with environmental biogeochemistry to understand the multi-dimensional interactive relationship of humans and Earth's resources. Research on the deoxygenation of the Pacific Ocean (**Hoogakker**), from modern to past, has advanced our understanding of processes causing changes in ocean chemistry and links to atmospheric CO₂. Excellence of this work is further demonstrated by research awards including the prominent UKRI Future Leaders Fellow (**Hoogakker**) for the project '*Fate of ocean oxygenation in a warming world*'.

The aspect of anoxic oceans has been taken further back in time (**Wagner**) by investigation of brief periods of global climate and environmental change in the Paleogene-Cretaceous greenhouse world, linking long term geological processes (e.g. ocean gateway evolution) with multi-scale climate and biogeochemical response (e.g. continental watershed evolution/continental runoff, aquatic carbon production and burial biotic response) and global modelling (e.g. orbital forcing, atmospheric and ocean, circulation, carbon-climate feedbacks, emerging ocean basins as carbon sinks). Our deep-time research also directly crosses-over to fundamental questions about fossil energy (gas and petroleum) and the role of deeply buried black shale as potential catalysts for fluid rock interactions, microbial interaction (deep biosphere) and leaching of organic and metal components of environmental concern (pollutants). The latter aspect is closely tied to central challenges of the UKGEOS program within which we (**Pereira, Wagner**) secured exclusive access to initial water and rock samples from the UKGEOS Glasgow study site to support an ongoing PhD project.

Theme 2: Impacts (Understanding human impacts)

Our understanding of fundamental processes of ecosystems integrates directly into investigations of impacts on these ecosystems. This theme cuts across the wide variety of human-induced stressors on environments at local and global scales and is directly aligned to understand impacts on resources and services provided by ecosystems. As such, research contributes directly to addressing key aspects of the UN-SDG.

Human impacts in fisheries, seabirds, and marine mammals

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Research spans local and regional systems to global initiatives informing sustainable fisheries policy. This expertise links directly to our projects on fundamental processes including GCRF-funded research programme '*Sustainable Oceans, Livelihoods and food Security Through Increased Capacity in Ecosystem research in the Western Indian Ocean (SOLSTICE-WIO)*'. One example is our leadership (**Kaiser**) on the international initiative '*Trawling: finding common ground on scientific knowledge for best practices*' funded by international fishing companies and Walton and Packard foundations. This project developed methodologies to compute trawling footprints from 0-1000m depth using remote electronic monitoring data and underpinned by a global meta-analysis of the impact of fishing on the seabed which enables prediction of the system recovery (**Sciberras, Kaiser**). Methodologies we developed have been implemented by two international and one national organisation: International Council for the Exploration of the Sea to estimate Good Ecological Status, Seafish (in the *Risk Assessment for Sustainable Seafood* tool) and the Marine Stewardship Council (used by Conformity Assessment Bodies to undertake independent evaluation of fishing impacts). Our group has a close working relationship with the seafood industry on data-poor fisheries (Sainsbury's, The Cooperative, M&S, Young's Seafood, Lyons Seafood, MacDuff Shellfish, Scottish White Fish Producers Organisation, EDPR and Seafish) who funded four PhDs focused on scallop fisheries and static gear metiers. Advice and scientific support for demonstrating and implementing sustainable practice is provided to Orkney Sustainable Fisheries (**Bell**) (stakeholder and Government engagement on regional inshore fisheries) leading to changes in inshore fisheries management, e.g. minimum landing sizes. International research and knowledge translation is exemplified by the *DataMares* project (**Johnson**) engaging with small-scale data-poor Mexican fisheries and seafood supply chains enabling instantaneous insights into temporal and spatial patterns in catch composition and overlap with species of conservation significance e.g. vaquita.

The expertise has been expanded by new appointments (**McWhinnie, Votier**) with excellence in research with seabirds and marine mammals and their interactions with other users of their environment (shipping, fisheries, renewable energy). Research focused on marine spatial management has provided insights into solutions to mitigate the effects of vessels; noise, entanglements and disturbance. Current projects include: ePICentre (EU Horizon 2020) aimed at reducing impacts of arctic shipping on marine mammals (2019-2023) and projects aimed at reducing tourism impacts on cetaceans in the Hauraki Gulf, NZ (2019-2022), and Canadian Department of Fisheries and Oceans project monitoring vessel activity in killer whale foraging areas (2017-2022). Seabird research has developed methods for managing seabird populations in the face of anthropogenic change, e.g., forage fisheries and African penguins in southern Africa, albatrosses and bycatch in the Falklands (Falkland Islands Government - funding), as well as developing a gulls research roadmap in urban environments (NERC iCASE studentship). More applied research focuses on quantifying the potential positives and negatives of offshore renewables. Together, this research supports a holistic approach to managing marine ecosystems, for instance, via implementation of Marine Protected Areas and by engaging stakeholders in new ways. Linked with this, are projects to understand how tropical seabird assemblages are responding to global change and the development of new solutions to management (funded - Bertarelli Programme for Marine Science and DARWIN Plus).

Ecotoxicology

We have an extensive track-record of organismal research in ecotoxicology with state-of-the-art facilities and internationally recognized research leaders. Since REF 2014, >£3M in external funding (NERC, FP7, Horizon 2020, Marie-Curie) has been secured to support ecotoxicology

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research that investigates effects of toxicants in organisms ranging from unicellular algae to invertebrates and fishes. Our research (**Fernandes, Henry**) has been supported (Horizon 2020, NC3Rs) to develop new methods for toxicity assessment and translation of effects across organisms. We maintain cultures of model organisms (algae, daphnia, amphipods and zebrafish), and use a variety of other model organisms in our studies (e.g. crabs, amphipods, mussels, sea anemones, clams, sponges, tropical corals), we have established methods and published results of molecular and toxicological responses to develop new model organisms representative of specific ecosystems of interest including temperate freshwaters (pond snail *Lymnea stagnalis*), tropical estuarine and marine ecosystems (tropical marine amphipod *Parhyale hawaiiensis*), and tropical freshwaters (fish Lambari *Astyanax* sp.) (funding from Brazil CNPq and FAPESP). Recently funded projects apply our expertise in ecotoxicology (**Henry and Hartl**) to address f deep-sea mining effects (UK NERC, Deep Green).

Our research on ecotoxicology of engineered nanomaterials is internationally excellent and is a component of the NanoSafety group at HWU (Co-director **Fernandes** and toxicologist in UoA8). Within *this* unit we have particle analysis capabilities including electron microscopy and dynamic light scattering and zeta sizer equipment for investigating aqueous phase particle behaviour. Our research (NERC, EU FP7, Horizon 2020) has reported on particle toxicology and the influence of particle agglomeration, sorption of toxic substances to these agglomerates, and effects of sorption on the bioavailability and toxicology of substances and particles. We (**Henry**) have effectively demonstrated that nanoparticle absorption across epithelial membranes is minimal in numerous aquatic organisms and toxic effects are more consistently linked to disruption of tissue surfaces. We have developed and published innovative methods for maintaining nanoparticles in the aqueous phase for testing homogeneous dispersions to reduce variability inherent among toxicity tests.

The breadth of research on presence and environmental impacts of plastics is extensive on local and global scales. The *RealRiskNano* project (**Henry**, NERC Highlights topic) has provided fundamental new information on the environmental fate, bioavailability, toxicant sorption/desorption, and toxicology of nano-micron sized plastic particles. Prominent published results are on the importance of microorganisms and exopolymeric substances in seawater that lead to the formation of microorg-agglomerates of plastic particles that alter physicochemistry, association with dissolved substances, and environmental fate (**Gutierrez**). Research (**Henry**) has demonstrated that absorption of nano- and micro-sized plastic particles is minimal in aquatic organisms through experiments with fluorescently labelled and ¹⁴C-labelled particles that served to realign the scientific community regarding the realistic risk of toxic effects from plastic particles. Among the most highly cited and impactful articles was documentation that the amounts of microplastics accumulated in wild mussels and therefore risk for human consumption is minimal compared to the microplastic particles that humans are exposed to from indoor dust. Henry was central to establishing a consortium (*Consortium for Plastics and Sustainability*, COMPASS) which encompasses *all* HWU Schools for mapping the future direction of the interdisciplinary challenges of plastics in the environment and global economy. This consortium also includes external partners in academia, industry, and regulatory agencies. Within this context we are addressing the critical global challenges of management of plastics with engagement at numerous international locations, with recent UKRI-GCRF grant awards (3SIP2C, £3.47M, NE/V006088/1, **Kaiser** +7 Vietnamese partners) to work on Sustainable Solutions.

Theme 3: Solutions (Implementation of solutions for human impacts)

Our understanding of fundamental processes of ecosystems and how humans interact with these ecosystems are the foundations for this Theme. Research to improve efficacy of ecosystem management is applied on local, regional and global scales, and conservation strategies of fisheries and implementation of vaccines at organismal level are central.

Conservation & Restoration

This group specialises in marine biodiversity research needed to underpin management and sustainable development, with a focus on restoration and enhancement, Marine Protected Areas (MPAs) and Marine Spatial Planning (MSP). The expertise in biogenic reefs research (**Sanderson, Harries, Porter**) has led to the multi-award-winning *Dornoch Environmental Enhancement Project* with industry (Glenmorangie) and NGO partners (2014-2021), which aims to restore 4M flat oysters to the Dornoch Firth. Archaeological approaches have demonstrated the historic extent of flat oysters in the UK and northern Europe, pinpointing areas where restoration may be feasible. This work also triggered a KTP (with **Bell**) with Orkney Shellfish Hatcheries (2020-2023) designed to stimulate businesses to produce a local source of flat oysters which are notoriously difficult to rear. Hosting the Native Oyster Restoration Alliance in Edinburgh 2019, has placed HWU at the leading edge of an international movement to restore the European native oyster which was once a key species in the provision of ecosystem services in UK waters. In addition to oysters, the group specialises in more broadly in the ecology of biogenic habitats that are important carbon stores. Important advances have been made in understanding the extent of the distribution of biogenic reef fauna, such as horse mussels and flame shell reefs (**Harries, Sanderson**) and their overlap and interaction with potentially damaging fishing activities such as pot fisheries (**Kaiser**). The group have been strengthened by the appointment of **Sciberras** with expertise in systematic review of environmental evidence e.g. in relation to the utility of fully protected versus partially protected marine areas, which was recently featured as a key piece of evidence in the Cabinet Office review committee for Highly Protected Marine Areas (HPMAs). Expertise in fouling communities and interactions with hard man-made structures has important implications for alleviating maintenance costs of offshore installations (**Want**). This research is at the forefront of biodiversity/industry interactions with funding through EU- FoDTEC (forensic analysis of decommissioning tidal energy converter infrastructure) and WEP+ (wave energy project with biofouling) and the NERC-funded 'BioFREE' Innovation Placement in partnership with the European Marine Energy Centre. Collaborations on biodiversity of marine invertebrate communities of coral reefs has taken place with Heron Island Research Station (Great Barrier Reef), Qatar (Ministry of Environment and Municipality), Malaysia (University of Malaysia Terengganu) and Brazil (University of Pernambuco).

Pathobiology and Food Security

Understanding relationships between pathogenicity and virulence factors, management of infectious pathogens, and investigating molecular biology of drought tolerance in plants are key activities of our group aimed at preserving food security. Substantial progress has been made (**Smith**) in understanding environmental determinants of adaptation of pathogenic bacteria to specific niches associated with virulence capabilities of the exemplar bacterium *E. coli* (which has a miscellany of pathotypes ranging from commensal to highly invasive). Results have demonstrated the significant influence of host-generated metabolites on bacterial colonisation and survival within distinct host tissues and the consequent effects on pathogenicity. Conversely, bacterial metabolite profiles/composition have been identified that distinguish adaptation to different environmental conditions and distinct pathotypes. Further, recent investigations (**Smith**)

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are characterising the profound influence of semi-synthetic cephalosporin antibiotics on bacterial phenotype and host interaction capabilities. Together, these findings are highly pertinent to developing our investigations of differential pathobiology (e.g., invertebrate immunology, **Dyrynda**) in aquatic environments and species, notably those of immediate relevance to aquaculture. Such studies have led to **Smith** and colleagues to identify a range of factors with applicability to detection and differentiation of pathogenic and non-pathogenic bacterial strains. Importantly, outputs have included components with potential for development as agents for disease control (**Smith, Henry**) and several of these leads have been piloted as vaccine candidates in model and target species. is conducted. **Lyndon** leads the Fish vaccine research program (in our John Muir Aquarium) that underpins testing for market release of over 0.5 billion vaccine doses per annum to fish-farms across Europe. These vaccines prevent established and emerging fish disease that would otherwise compromise security and future expansion of important human food supplies. This work forms the basis of one of or submitted impact case studies. Research with barley and model plant species (**Morris, Alexander**) have moved forward understanding of key molecular pathways linked to dormancy/germination of seeds and drought tolerance. Control of barley germination is critical to malt preparation and subsequently whiskey and other spirits. Intricate experiments by our group with *Arabidopsis thaliana* and strains incorporating fluorescent transgene signals have revealed transmembrane proteins involved in water/osmotic regulation, and are poised to contribute to addressing reduced crop yields of increasingly saline soils of agricultural lands.

Integration of our themes to deliver impact: - Policy and Governance

Our research relating to 'Policy and Governance' is focused on the challenges of delivering a sustainable maritime economy (the Blue Economy) and mitigation and adaptation to climate change. Our research spans three broad themes:

1. Jurisdiction, governance and planning.
2. Rights, values, social welfare, and community benefits.
3. Sustainable development and space allocation.

ICIT-Orkney has been the focal point for our Policy and Governance research. From its inception in 1989, ICIT-Orkney has been at the heart of interactions between industry, government, academia and community. ICIT-Orkney research interests have grown from offshore oil and gas environmental assessment to other uses of the seas, and more recently on the development of marine renewable energies (wind, wave and tide).

ICIT-Orkney has participated in several large EU funded programmes FP7 and FP8 (Horizon 2020). The €9m FP7 *MESMA* programme (*Monitoring and Evaluation of Spatially Managed Areas*, **Johnson, Kerr**, Side 2010-2014, HWU €200K) designed a generic MSP framework for Europe and contributed directly to the drafting of the EU MSP Directive. Our lead on a case study of the Pentland Firth and Orkney Waters (PFOW) Marine Plan involved close working with Marine Scotland. This relationship continues with our participation in the implementation of regional MSP for PFOW (see below). New PhD research (supervised by **Johnson, Kerr**) is considering the integration on international national and regional MSP policy.

MESMA was followed by the €2.5m H2020 *MARIBE* programme (*Marine Investment in the Blue Economy*: **Johnson, Kerr** 2014-2016, HWU €200k). *MARIBE* considered EU ambitions to develop multi-use platforms (MUPs) in pursuit Blue Economy. MUPs offer potential efficiencies in use of sea space as well as beneficial economic synergies between uses. Working with industry and regulators *MESMA* developed business cases for a series of MUP designs. *MESMA*s results

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directly influenced subsequent H2020 funding calls. The €9m H2020 *MUSICA* programme (*Multi-Use of Space for Clean Island Autonomy*: **Johnson, Kerr**, Getchell 2020-2025, HWU €200k) is implementing *MESMA* findings in a MUP demonstrator project to supplement energy and water provision on the Greek island of Chios. This MUP integrates energy (wind, wave, solar), desalination and aquaculture.

Staff within ICIT-Orkney have led significant projects establishing the hydrodynamic and ecosystem impacts of wave and tidal energy (MRE). Working with Marine Science Scotland (MSS), and 6 academic partners, the £975k Terawatt programme (EPSRC, £351k: Side, **Bell**) created detailed hydrodynamic profiles of the Pentland Firth and modelled ecological effects of changed energy profiles. The follow-up £948k Ecowatt 2050 programme (EPSRC, £319k: Side, **Woolf, Bell, Harries**) extended this work to study cumulative ecological impacts of MRE. A NERC Innovation Placement award (**Woolf**, HWU £48k), and MSS/SNH funding (£40k, **Porter**) embedded two ICIT-Orkney postdocs (Waldman & Miller) within MSS to help incorporate Terawatt/Ecowatt results into national modelling for aquaculture and MRE. **Woolf** is supervising an Energy Technology Partnership PhD in modelling the optimization of MRE arrays.

Further work targets national and regional MSP policy including climate change, and carbon management. ICIT-Orkney led the audit of 'blue carbon' in PFOW, a first of its kind, study developing a methodology for the regional assessment on carbon stored in benthic habitats (Scottish Government, £45k: **Porter, Sanderson, Want, Bell**). ICIT-Orkney continues to support the implementation of the PFOW pilot regional plan, e.g. a meta-analysis of environmental data for PFOW (European Maritime and Fisheries Fund/OIC £15k: **Kerr, Porter, Johnson, Bell, Fernandes**) is improving the quality of environmental data used in regional planning. Other work seeks to improve community consultation processes and the communication of science within the PFOW MSP (Scottish Wildlife Trust, £15k: **Johnson**). ICIT-Orkney has provided research-based advice on MSP to: the Scottish Parliament Cross Party Working Group on Fisheries; the Scottish Offshore Renewables Research Framework (SpORRAn); the Scottish Parliament's Environment, Climate Change and Land Reform Committee; and the Convention of Scottish Local Authorities.

Biogenic habitats as Essential Fish Habitats and as carbon stores has been the focus of several studies as well as restorative intervention projects for these habitat types (Scottish & UK Government, £250k **Harries, Porter Sanderson**). The Dornoch Environmental Enhancement Project (Glenmorangie, Total £655k **Sanderson, Mair, Harries, Porter**) has shown that native oysters (*Ostrea edulis*) can be restored throughout the European MPA network as well as unpacking the essential knowledge required to do this. Combined with hosting the Native Oyster Restoration Alliance in Edinburgh 2019 (150 scientists and growers), this has placed HWU at the leading edge of an international movement to restore the European native oyster.

Environmental management of oil and gas decommissioning is the focus of the *INSITE 2 CHASANS* project (NERC, £550k, **Porter, Want, Bell, Woolf**). In this program, the team will develop oceanographic models to understand connectivity between oil and gas infrastructure in the North Sea and validate with population genetic analysis for specific species. This will enable impact forecasting on species distributions when oil and gas infrastructure is removed, or introducing new offshore wind farm infrastructure. This work involves significant stakeholder interaction across the North Sea offshore industry and will help transition from oil and gas to renewables in the UK's blue economy.

Our Policy & Governance expertise has been strengthened by the recent (2020) addition of **Diz** and **Kelling**. Research cuts across shallow and deep-sea systems and focuses on the law- and policy-making and operationalisation of the ecosystem approach to management and the

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ecosystem approach to fisheries, including through area-based management tools, at local, national (Canada, UK, South Africa, Ghana, Namibia, Fiji, Solomon Islands, Cook Islands, Mauritius, Seychelles, Brazil, etc.), regional and global levels (through UN processes). Significant achievements include deputy Directorship of *One Ocean Hub* (GCRF £20M, 2019-2024), co-leadership of an Ecosystem Services for Poverty Alleviation (ESPA) project on small scale fisheries (2015-2017), and representing ESPA at various UN meetings on results of marine-related projects (2018). Impact is achieved at an international level through multiple consultancies on fisheries law and marine biodiversity undertaken for UN agencies by **Diz** (e.g., FAO and UNEP) and for European Parliament, OECD, International Pole and Line Foundation (**Kelling**) on policy interventions maximising livelihoods in small-scale fisheries through interventions in seafood supply chains.

Forward look across themes

We believe that our research strategy is robust and will be resilient through the challenging future landscape of the post-COVID and post-BREXIT world. Our research collaborations are already broad (North/South America, Africa, and Asia) in addition to work in the oceans of the world, and these will continue to expand. In addition to the many new developments arising directly from the existing synergies as listed our three themes above, there is scope for planning exciting new ventures. Among these new ventures include *Breathing Oceans* (€2M ERC Starting Grant 21-26, **Pereira**) or Marine Mapping & Ecosystems that integrates the considerable acoustic mapping expertise of BGS with marine ecologists and robot engineering specialists of HWU to create interdisciplinary teams able to explore new approaches to marine habitat and facies mapping. This initiative complements well our expertise in maritime spatial planning primarily based at ICIT-Orkney and also Edinburgh (**Fernandes** and **Sanderson**) with a new appointment (**McWhinnie**) a specialist in MSP. Future ambitions include the development of a centre of excellence in the impacts of deep-sea mining working with academia, governments and industry. We will create a virtual deep seabed environment, in conjunction with HWU Global Research Innovation and Development (GRID), which will allow researchers and innovators test hypothesis and equipment in a virtual environment that they can control and change. We are presently increasing staff compliment and expertise in this area to include environmental law. We are fully engaging with the European Green Deal especially with proposals developing from the ICIT-Orkney-led policy focused research.

Research Governance

Staff within research groups led by individual academics are arranged within the Institute of Life and Earth Sciences (Director: **Fernandes**) and overseen by the Head of EGIS (Chrisp) and School Management Team including Deputy Head of School (**Henry**) and Director of Research (Geiger also on the University Committee for Research and Innovation). School Management takes responsibility for strategy delivery and compliance with University research policies. This includes ethics and integrity where the School is represented on the University Research Ethics Committee. In addition, staff in this unit have a leading responsibility in the University for maintaining and reviewing use of animals in the John Muir Aquarium that is fully licensed by the UK Home Office for investigations including exposure to toxicants and live pathogens. Research in this unit are also active in reducing the need for animal testing with work funded by NC3Rs to develop new for toxicity assessment methods and translation across organisms (**Henry**). Staff also ensure work involving GMOs is fully compliant with regulations.

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We encourage staff to engage with the Open Science agenda and are pleased to have reached our REF OA target (0 non-compliant outputs).

2. People

Staffing Strategy and Development

The research intensification strategy of HWU has been the focus of our staff recruitment initiatives within Earth Systems and Environment. We have attracted new, proven, high performing academic staff or those with potential in the case of early career researchers through Lyell Centre appointments, and Bicentennial Research Leader initiatives for a total of 18 additional staff since 2014 (nearly doubled in size since 2014 and total for HWU UoA7 is 35 FTE). This recruitment strategy has enabled us to populate our three research themes with:

- established researchers with internationally profiles **Kaiser** (HWU Chief Scientist), **Ludden** (President of International Union of Geological Sciences), **Wagner, Votier**;
- prominent emerging scientists at Associate Professor level (**Sweetman, Poulton**); and
- high-profile early career researchers (7 with ECR status on the REF census date) poised to carry forward our ambition to be a world leading institution to bring solutions to critical global challenges for years into the future.

Staff have a primary focus aligned within one of the research themes but work across themes to provide a dynamic research environment that links research on fundamental processes of earth systems with environmental impacts and implementation of solutions. Our recognition of the importance of governance and policy is unique and evidenced by recruitment of new staff (**Diz, Kelling**) to compliment seven existing staff engaged in various aspects of policy and governance of natural resources. In addition, associated funding successes have meant that our research community continues to expand with >10 postdoctoral research associates (PDRAs).

The development of research leaders is supported by programs within EGIS to deliver training (e.g., unconscious bias training, anti-bullying/harassment training) and guidance through processes (Professional Development Review- reviewer training and support), and mentoring by senior academics.

Staff development

The integration of senior academics with ECRs has accelerated research activity and provided considerable opportunity for career progression and development for junior members of staff. New academics are assigned a mentor (other than their line manager) and guidance is given for annual professional development, probation and promotion. ECRs can serve as second supervisor of PhD students with experienced staff acting as first supervisor. Considerable research time (70%) is allocated to new staff and PhD studentship allocations provided to foster a research-intensive culture that is demonstrated by weekly seminars with numerous invited international experts as invited speakers and expectations for all research students to deliver presentations of their research. Teaching is research-led with courses developed and integrated at all levels (UG, MSc, and PhD) into research programs. Allocation of teaching is reduced (<30%) for first several years of appointment to enable development of research programs. Since appointment, all new staff have continued to publish top-quality research outputs and secured new funding to establish and support their research groups. Evidence of staff development is indicated by the promotion of staff appointed since 2014 (**Sweetman** to Professor, 2019 and **Hoogakker** to Associate Professor,

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2020), and by staff securing prominent funding targeted at staff early in their career (e.g., **Hoogakker's** UKRI Future Leaders Fellowship and **Pereira's** ERC Starting Grant).

PGR Students

The PGR student community has grown considerably since REF2014 as a consequence of investment in PhD studentships (e.g., James Watt Studentships) and Doctoral Training Programs (DTPs). Training of research students is integral to our work and this has particularly increased in strength over time in partnership with the Marine Alliance for Science and Technology Scotland (MASTS) Graduate School and more recently the 2 NERC DTPs (*SUPER* and *IAPETUS*). These DTPs offer PhD students cross-institution insight and external visibility that contribute the overall quality of PGR education. Research students are engaged in focused MSc programs in marine sciences (~40 students per year) and >50 PhD students working on research project across the three Themes of scientific investigation represented by our academics in this unit. Our program attracts numerous international students to the MSc program and PhD students funded by scholarships from their own countries are attracted to conduct their research under the direction of academics within our program. The PGR community is very dynamic and inclusive with many virtual student groups also emerging during the covid-19 pandemic.

PhD students complete a rigorous program that is guided by HWU policies and infrastructure. The offers personal mentoring and guidance from supervisors, participation in discipline-specific scientific communities, and contribution to outreach events. The £7M Heriot-Watt Postgraduate Centre combines facilities for training, outreach and interaction with other postgraduate students across the university and workshops under the Researcher Development Framework. In addition, this Centre provides a hub for PGR student training, forum for prominent international lectures and inaugural lectures of our professors, and a location for conferences. An annual PGR Conference is organized and led by PGR students and encompasses the overarching cross-disciplinary characteristics of our unit and HWU. Across our unit PhD students are required to give annual presentations that detail their research plans, progress of research, and research results.

Equality and Diversity

Promotion of equality, diversity and inclusion (EDI) is a prominent objective within our unit and is implemented by policies, actions, and training aimed to deliver a dynamic and fair workplace for all of us. HWU has a robust framework to support EDI and has been awarded the Athena SWAN Institutional Bronze Status, and our School of EGIS also has a Bronze Athena SWAN award. An HWU-wide Equal Opportunities Committee ensures effective linkages and fairness across the HWU governance structures. The HWU Equality and Diversity Policy details the tenets and training is provided in diversity in the workplace, cultural sensitivity, unconscious bias training, and equality impact assessment. The positive actions HWU has taken to support researchers' career development and the measures in place to implement its declared principles have been recognized externally. Within our UoA7 13 of the 37 are women; and the Director of EGIS's Institute of Life and Earth Sciences (**Fernandes**) and Director of the Lyell Centre (Shimmield, in this academic management role) are both females. During new staff recruitment, we have implemented a policy to require gender balance on the shortlisting and interview panels. Interview panel members are required to take a course in unconscious bias training, and there is an emphasis on fairness in everything we do throughout the appointment process. We are pleased

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that in our submitted outputs the proportion of those attributed and associated with men and women shows no significant difference.

3. Income, infrastructure and facilities

Income

Our ambition to become world-leading is built on investment of >£25M in new infrastructure and staff since 2014 and has positioned us to make unique contributions to solve critical global challenges. Our research income is almost £12M compared with <£5M in REF2014 (doubling the per annum figure from £850k to £1,700k), and our successes reflect strategies put in place to support researchers. Staff have secured awards from diverse sources indicative of the multidisciplinary nature of our unit and include UK Research Councils (>£4.6M BBSRC, EPSRC, NERC); the European Commission (>£4.7M); UK Government Departments, Scottish Funding Council, local authorities, and other UK sources (>£2.3M); UK Charities (>£0.4M); and UK Industry and Commerce (>£3.0M).

New Infrastructure

New infrastructure since 2014 serves to enable delivery across our three integrated research Themes. A centrepiece is the **Lyell Centre for Earth and Marine Science and Technology**, which opened in 2016. The Lyell Centre, a strategic partnership between HWU and BGS is a £23M investment (NERC, the Scottish Government and HWU). Within the Lyell Centre is the **Wolfson Aquarium for Climate Change Research** opened in 2017, (£250k Wolfson Foundation). This doubled our aquarium facilities (600m²) to >50,000L of seawater and continuous supplies of de-chlorinated freshwater delivered to purpose-built temperature/pH/gas-controlled rooms for aquatic research. This facility is designed for UK Home Office standards for research with vertebrates and for adherence to biosecurity regulations to avoid transmission of pathogens. We have expanded ICIT-Orkney (investment of £7.5M) to become a leading centre for marine technology research bringing together environmental and socioeconomic sciences.

The Lyell co-location provided us with **unique access to BGS facilities** through shared use of marine equipment (e.g., BGS seabed coring, drilling, vessels, and scientific divers) and development of innovative robotic approaches for sub-sea survey and sampling (e.g., Edinburgh Robotics Centre and UKRI *ORCA*, Institute of Sensors, Signals and Systems; and bespoke deep-sea landers). BGS role as host of IODP's UK operations enables access to joint bids on topics of mutual interest (e.g., joint bids on Expedition 339 material), and facilitated access to BGS reference cores and archives.

Facilities

Facilities for aquatic research are exceptional within our unit and extend from highly controlled laboratories to extensive capabilities for research conducted within the numerous environments addressed across our three research themes. In addition to the new Wolfson Aquarium, facilities within the John Muir Building (>200m²) provide a freshwater and marine (>20,000L of seawater held on site) research space that includes fish vaccine and pathogenicity testing facility, four isolated climate-controlled environmental chambers (20m² each) and the zebrafish research facility (25m²) housing wildtype and transgenic zebrafish. Vaccine efficacy is supported by

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extensive collection of microbial fish pathogens for notifiable fish diseases and complete microbiological facilities for propagation, characterization, and identification. Capabilities for fish pathology include fish necropsy laboratory, complete microbiology/molecular biology laboratories, purpose-built histopathology laboratory and biological imaging facility that serves across all research themes.

Ecotoxicology laboratory

These facilities enable investigation of toxicants in model organisms (algae, daphnia, amphipods and zebrafish) and use a variety of other model organisms (e.g., crabs, amphipods, mussels, sea anemones, clams, sponges, tropical corals). We have established methods and published results of molecular and toxicological responses to develop new models representing specific ecosystems of interest including temperate freshwaters (pond snail *Lymnea stagnalis*), tropical estuarine and marine ecosystems (tropical marine amphipod *Parhyale hawaiiensis*).

Scientific Dive Team

Currently **Harries, Porter, Sanderson**; this capability is rare within the UK with wide-ranging equipment for sampling and surveying. Our own research vessel, RV Serpula (26.5 ft Kingfisher, 8-ton displacement hull, 130 HP Perkins Sabre diesel engine), has all appropriate navigational and safety equipment, dive ladder, winch, derrick and A-frame for trawling and deployment of benthic sampling gear. A drop-down video system with 150m umbilical cable enables monitoring of the seabed and collection of samples from the deck. We also have three zodiac inflatable boats and associated outboard engines. Sampling equipment includes long arm Van-Veen Grab, Carib Corer, Multi-Corer, Beam Trawl, Naturalists Dredge and Pipe Dredge.

Deep-Sea Ecology

Sweetman's research group runs the Lyell Centre's state of the art deep-sea lander facility and includes two seafloor respirometer landers, two baited-camera landers (with digital still and video capabilities), a seafloor micro-profiling lander equipped with O₂, sulphide, pH micro-sensors and two baited-trap lander vehicles. All landers are capable of being deployed to 6000m depth. The landers therefore allow researchers to study respiration, nutrient fluxes, quantify C- and N-turnover at the seafloor, biogeochemical profiles, document the diversity of seafloor scavengers and predators in 98% of the available ocean habitat.

Research support

The university has a centralised research and business development professional support team, the Research Engagement Directorate (RED) works directly with individual researchers as follows:

- *Research Development* - provides specialist support for academic staff seeking to win research funding. Facilitating all funding activity including support for Fellowship applications (e.g., Hoogakker's UKRI Future Leaders Fellowship) and GCRF opportunities.
- *Business Development* – works with academics to increase research income from industry and business (e.g., facilitating engagement with Glenmorangie, Aquapak among others)
- *Policy, Strategy & Impact* – ensuring and supporting research policies. The unit supports approaches to impact including the award-winning Public Engagement Team (e.g., facilitating activities at science festivals such Science, Jellyfish, Science & Art EISF 2016) and delivered a refresh of training for ethics for staff in this unit.

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- *Legal Services* – this group provides essential advice on contract and IP arrangement (for example provided effective support for establishing contractual relationships across Europe for Pereira’s EC Starting Grant)

4. Collaboration and contribution to the research base, economy and society

Members of our UoA7 submission make contributions to the research base, economy and society across each of our integrated research themes.

International contributions

Across our Research Themes, staff translate our research and expertise into the wider international agendas of sustainability, environment and conservation policy. These include leadership of international research programmes, science meetings and engagement with international bodies such as the UN (and related Conventions), the IUCN and the Areas Beyond National Jurisdiction (ABNJ) processes. In 2020, **Ludden** was elected as President of the International Union of Geological Sciences. Our staff contribute significantly to processes aimed at managing human pressures. **Sweetman** provided evidence to the UN International Seabed Authority (I.S.A.) on deep-seabed mining and its impacts on pelagic and seafloor ecosystems in ABNJ. He also sits as an expert on the International Maritime Organisation GESAMP working group focused on deep-sea mining (working group 42). In 2019, he co-led a UN ISA meeting in the USA to assess the effectiveness of the MPA network set up in the Clarion-Clipperton Zone (CCZ) to protect seafloor biodiversity and ecosystem function from the impacts caused by deep-sea mining, leading to the establishment of new MPAs in the polymetallic nodule-rich areas in the E and NW of the central CCZ. **Fernandes** was appointed as scientific expert to the European Commission from 2008-2016. She has also been a scientific adviser to the OECD over the last 10 years. **Henry** presented the keynote address and chaired the plastic session at UNESCO Workshop on Emerging Pollutants in Water Resources in Latin America and the Caribbean conference (Campinas, SP State, Brazil), together with numerous invited seminars and presentations on plastics in the environment. Popular press articles achieved extensive international reach and led to radio interviews and other outreach avenues for public consumption. **Gutierrez** was nominated as the UK’s expert on the microbial response to the Deepwater Horizon oil spill. **Wagner** is a senior member of the global International Ocean Drilling Programme (IODP) community, with leading roles as shipboard chief scientist (IODP 339), Co-I on two scheduled expeditions (IODP 388 and 392, Wagner). **Pratscher** was an invited discussion leader for **Gordon Research Seminar** on “Solving Important Microbiological Questions in the “Omics” Era” (2015, Mount Holyoke College, USA). **Woolf** is a keynote speaker invited to the 5 yearly Gas Transfer at Water Surfaces conference (delayed to 2022). He has organised and chaired several conferences in air-sea gas exchange (Oceanflux GHG – IFREMER 2014 and 2016).

Our contribution to international conservation of biodiversity and has both legislative and practical application and conservation impact. **Diz** has contributed to international policy and law-making, including the Convention on Biological Diversity Thematic Workshop on Marine and Coastal Biodiversity for the Post-2020 Global Biodiversity Framework, was an invited panellist at UN events including on the negotiation of a new marine biodiversity treaty, the Convention on Biological Diversity’s process to describe ecologically or biologically significant marine areas and on mainstreaming of biodiversity into fisheries. She is an advisor for the EU’s International Ocean Governance Forum and has joined the Expert Advisory Working Group (co-sponsored by the

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Government of Germany, Ministry of Research) on the Ocean Governance and Science-Policy Interface Session of the kick off Conference for the U.N. Decade of Ocean Science for Sustainable Development (June 2021, Berlin). **Wagner** was appointed Chair of the International Research Committee (ISC) for the Iwokrama International Centre for Rainforest Conservation and Development, Guyana. **Votier's** research on African penguins has under-pinned policy on fisheries closures and MPA implementation in South Africa leading to recovery of threatened species. **McWhinnie** has been invited to contributed to expert working groups and taken part in advisory panels for informing government policy and management measures internationally (Canada Department Fisheries & Oceans Southern Resident Killer Whale Technical Working Group and Cumulative Effects Assessment for Southern Resident Killer Whale and Northern Resident Killer Whale Canada and Sothern Resident Orca task force U.S. Department of Fisheries and Wildlife and NOAA, America). She also contributed to a review of vessel management measures by the American and Canadian Coastguards for the Bering Strait and provided recommendations related to marine vessels for Arctic MPA Management Plans that have now been integrated and adopted for the Tarium Niryutait MPA.

Our staff make wide-ranging and impactful contributions to the international sustainable seafood agenda. **Johnson** is part of the writing team (representing fisheries in Palau) for the World Ocean Assessment II which was adopted by the U.N. General Assembly in 2020. He was commissioned by the China Dialogue think-tank to write 'Sustainable Seafood: China's role in the global ocean' resulting in a letter in Science. He sits on the advisory board of Eachmile technologies and Fishcoin which are blockchain innovation NGOs. **Kaiser** and **Diz** are elected members of the I.U.C.N.'s Fisheries Expert Group and **Kaiser** co-authored a policy document on Other Effective Conservation Measures (OECMs) in relation to fisheries that was adopted by the Convention for Biological Diversity and gave the context to discussions at COP25 (Madrid). He also chaired the International Science Advisory Committee for the Dutch Government's 'Pulse trawl' project from 2015-2020. **Kelling** was an invited Panel speaker at major fisheries fora, including Designing the Future for Fisheries Certification Schemes, Japan, the 10th International Forum on Illegal, Unreported and Unregulated Fishing in Chatham House, London. Kelling is also seconded as Project Director to the FCDO-funded Nepal Renewable Energy Programme (NREP), a 4.5-year, £18M programme that commenced in February 2019. Several of our team contribute to International Council for the Exploration of the Sea advisory working groups (WGs) (**Bell** – *Nephrops* WG, Impacts of Wave & Tidal Energy Study Group, Chair of Workshop for reference point for *Nephrops* stocks, **Sciberras** – WG Fishing Benthic Impact & Trade-offs 2021-2023 and member of Comparative Ecosystem Based Analyses of Atlantic & Mediterranean marine systems (COMEDA) **Votier** ICES WG Discard Survival).

UK Science Base Contributions with Global Significance

Our staff have made substantial contributions to the UK science evidence base through their contribution to public committees, bodies or evidence for Government bodies and Ministers. For example, **Kaiser** is a trustee of 'Fishing into the Future' started by the Prince's Charity's International Sustainability Unit, was a member of the UK Cabinet Office review of Highly Protected Marine Areas which published the 'Benyon report' in 2020 and currently chairs the UK Government/Industry initiative 'Future of our inshore fisheries'. Both **Kaiser** and **Henry** provide advice on UK seafood sustainability issues through membership of the Seafish Expert Panel. **Bell** was appointed to the Technical Advisory Committee for Fisheries Innovation Scotland, is Scientific Advisor on the Board of Orkney Sustainable Fisheries and was Northern Islands leader on the recent Marine Scotland Pressures Activities Assessment. **Henry** has presented results to Lord

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Randall at 10 Downing Street and met with UK Ministers in Parliament discussing priority solutions for managing plastics in the environment. **Fernandes** has advised on aquaculture management (e.g. UK, Scottish Parliament) and nanosafety (UK Parliament and EU scientific committees). **Kerr** gave evidence to Scottish Government cross-party working group on fisheries, and to the Environment, Climate Change and Land Reform Committee on spatial planning. **Sanderson** served on the OSPAR Benthic Specialist Group, Interagency Marine Monitoring Group and UK Technical Advisory Group, on methods and strategy development under Marine Strategy Framework Directive, the Habitats Directive and the Water Framework Directive. **Votier** contributes widely to seabird research and conservation serving as Chair of the Seabird Group (300+ members), Trustee for the Scottish Seabird Centre (2021 onwards), establishing a long-term monitoring gannet monitoring project in Pembrokeshire (since 2006) and managing the long-term Skomer guillemot project established in the 1970s. Porter has contributed to development and revision of Scotland's Marine Atlas and the State of Orkney Environment report (linked to the development of Statutory Marine Planning for the Orkney region – to which **McWhinnie** has contributed marine mammal expertise). Poulton provided in-person evidence to the House of Commons Science & Technology Committee inquiry on Ocean Acidification (2017). **Hoogakker** was an author of the Geological Society 'climate statement', and acted as Deputy-Chair for a NERC Standard grant panel. **Poulton** is a panel member for NERC fellowship proposals. **Fernandes** is a member of the NERC Facilities Committee.

Public engagement

Through a series of high-profile public events (e.g., Edinburgh Geological Society Public Lecture in October 2019, **Wagner**; Edinburgh Science Festival panel discussions, bi-annually since 2014, Fernandes) and – increasingly important - media coverage. To this end, communicating sciences is a core element of our strategy going forward. Our high impact contributions at conferences, public events, and top-class journals have secured regular and high impact outreach and media coverage. Examples include broadcasting **Magill's** work on the 'world's oldest cheese' or 'ancient human consumption of termites', reaching >500 million and ~50 million worldwide, respectively. **Pereira** worked with a variety of global media outlets in his Ocean greenhouse gas work including the Guardian, Sun, Scotsman, Die Welt and Bild reaching over 7.1 million people (McDaid PR). This has also led to interviews for TV (BBC Worldwide) reaching an estimated 500 million people, and radio (Ecoshock, US; NDR, Germany). **Pereira** has also presented the scope his work direction directly to the First Lady of Guyana (2019) and the UK's Chief Scientist, Sir Mark Walport (2017). **Henry** has delivered numerous keynote addresses at plastic industry events, and to public audiences on the topic of plastics in the environment including the Royal Society of Biology event "Marine plastics: is it too late to save our oceans" at the Royal Institution of Great Britain. **Kerr** gave a keynote at the HWU 'Year of the Sea' event at Westminster, House of Commons in 2018. **Kaiser** appeared on Sky News doing a 6-minute interview on the implications of Brexit for UK fishing, and published the 3rd Edition of 'Marine Ecology: Processes, Systems and Impacts' which is one of the most widely adopted Marine Ecology textbooks in the UK and globally, of which Chapter 18 was the top downloaded chapter in 2020 on the Oxford University Press 'Global Citizen' webpage.

External recognition of excellence

The emerging global profile of Earth Systems & Environment at HWU has also been recognised through prestigious awards and other esteem indicators. **Hoogakker** won the Philip Leverhulme

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prize for Earth Sciences 2018 and was awarded a UKRI Future Leaders Fellowship. **Pratscher** was awarded a 5-year Independent NERC Fellowship (IRF) on "Single cell genomics and characterisation of the atmospheric methane oxidizing clade USC alpha and their response to climate change" (2014-2019, NE/L010771/1 / NE/L010771/2). **Gutierrez** was awarded (2015) the Energy News Researcher of the Year Award in the category Energy and the Marine Environment for outstanding work on microbial responses to the Deepwater Horizon oil spill. **Burdett** was awarded 2018 Charles Lyell Award for Environmental Science (British Science Association), and had a speaker invitation to 2019 New Scientist Live. **Fernandes** was a highly cited researcher in 2018 (Web of Science). **Poulton** was named/awarded "2021 Foundation Future Leader" as part of the Foundation for Science & Technology 2021 Future Leaders Programme. **Kaiser** was elected as a member of Academia Europaea in 2018. Election of **Magill** as Research Fellow of the National Museums Scotland and Fellow of the Royal Botanic Gardens Edinburgh, **Wagner** was appointed as Distinguished Visiting Professor (China University of Geoscience, Wuhan). Research on oyster reef-restoration (**Sanderson**) was recognised in the VIBES Awards 2017 (winner of Hydro Nation Award) that recognizes business collaboration that have developed innovative water treatment, won Walpole British Luxury Awards 2017 ("Luxury With a Heart") celebrating high-end products from British businesses, won RSPB Nature of Scotland Awards 2017 (winner of Corporate Award), recognising the best of conservation in Scotland, and won the Guardian University Business Collaboration Award 2019. In 2016, **Ludden** was awarded a CBE for Service to Geoscience.

Editorial roles and panel service

Editorial roles undertaken by staff through the last REF period include for example: Editor-in-Chief Journal of Fish Biology (**Kaiser**), Editor Scientific Reports (**Hoogakker**), Associate Editors: Atmospheric Science Letters (**Woolf**), Journal of Plankton Research (**Poulton**), Frontiers in Marine Science (**Johnson** and **Hoogakker** guest editor), ICES Journal of Marine Science and Journal of Applied Ecology (**Votier**) and board memberships of Marine Policy (**Kerr**), Fish & Fisheries, Conservation Letters (**Kaiser**), Oceans (**Woolf**), Environmental Evidence (**Sciberras**).