

Institution: University of Stirling
Unit of Assessment: 6 Agriculture, Food and Veterinary Sciences
<p>1. Unit context and structure, research and impact strategy</p> <p>Context and structure</p> <p>The Institute of Aquaculture (IoA) has one the world's largest concentrations of expertise dedicated to aquaculture leading research on farmed and natural fish stocks, shellfish and aquatic plants. It brings together cross-disciplinary teams and approaches to tackle the diverse range of challenges faced by the world's fastest growing food production sector. Our mission is to deliver the research and provide innovative solutions to transform the global aquaculture sector to achieve greater sustainability, enhance food security and deliver resilience of aquatic species and ecosystems in a changing world. Our work encompasses fundamental and applied research that ranges from biological discovery, through optimisation of farm production to the development of modern commercial markets and the provision of urgently needed support to communities in developing countries.</p> <p>Our uniqueness and diverse mix of passionate and highly skilled people, coupled with a wide range of state-of-the-art facilities enable us to work with the diversity of species, life stages, systems, and environments reflecting aquaculture practices. We have an extensive network of collaborators established through our research and training programmes and incorporating our own alumni, spanning academia, industry, government and non-government organisations (NGOs) all over the world. This network supports close links with the world's leading companies and International organisations working in the sector. Impact is at the centre of everything we do, working closely with stakeholders in industry, practice and policy, to translate our fundamental science into sustainable solutions, whilst nurturing and training the next generation of talent for the future of global aquaculture.</p> <p>Strategic investments from the University of Stirling have been made at the IoA to tackle the global challenges of the 21st Century by recruiting new staff in priority research areas and upgrading our aquaria to capitalise on technological advances. Researchers have delivered science-based solutions evidenced by changes in industry practices and policies of aquaculture (e.g. new biological sea lice control implemented globally within the salmon sector, carrying capacity of aquaculture ecosystems and practice, and new regulation in the EU Common Fisheries Policy for prawn capture fisheries – see Impact Case Studies).</p> <p>Developments since REF 2014 include:</p> <ul style="list-style-type: none"> • IoA won the coveted Queen's Anniversary Prize for Higher and Further Education in 2019 in recognition of the impact and international reach of our research on aquaculture. This work has improved the sustainability, economy and health and welfare of farmed stocks. This prestigious award highlighted our research commitment to develop innovative solutions for the sustainable development of aquaculture and realise benefits across species, communities, governments and industry; • Ten new strategic appointments were made to strengthen core aspects of our research and teaching activities and expand our expertise in new and emerging priority areas to address global challenges (climate change; fish cognition and behaviour; policy and governance including the appointment of the Head of IoA who is the current Chief Scientific Advisor to UK Government); • The IoA gained an Athena Swan Bronze Award in 2020 acknowledging our commitment to advancing the diverse range of colleagues' careers including women's development in senior levels of science;

- IoA realised a step change in research grant success with income reaching £19.3m of grant award value over the REF period. This represents a 1.7-fold increase over the previous REF coupled to a 35% success rate for project grants;
- The University invested ca. £1.7m across our three experimental facilities supporting freshwater, marine, tropical and temperate research and innovation and including a new state-of-the-art hatchery and a large-scale Recirculating Aquaculture System (£790k) for fundamental and industry relevant research. New marine research capability (£830k) was enhanced by an extended building with state-of-the-art experimental tank systems and a new temperate unit (£100k) in a major development of our facilities. Three new permanent technical staff have increased our capability and resilience;
- The IoA attracted UK and Scottish Government’s funding of £17m through the City Region Deal to invest in capital infrastructure to lead the National Aquaculture Technology and Innovation Hub.

Research Strategy

Our aim is to deliver fundamental and applied science that drives increased **resilience, sustainability and security** (Figure 1) in the global aquaculture sector. Our strategy to achieve this is by developing a structure within the Institute whereby three interconnected research groups (Environment, Health and Production) align their efforts with national and international development priorities. This approach has enabled researchers (29.83 FTE) to prioritise their research agenda, better integrate their skills and gain agility to focus on the most pressing aquatic sustainability challenges such as food security, sustainability including net-zero emissions and ecosystem health, and resilience.

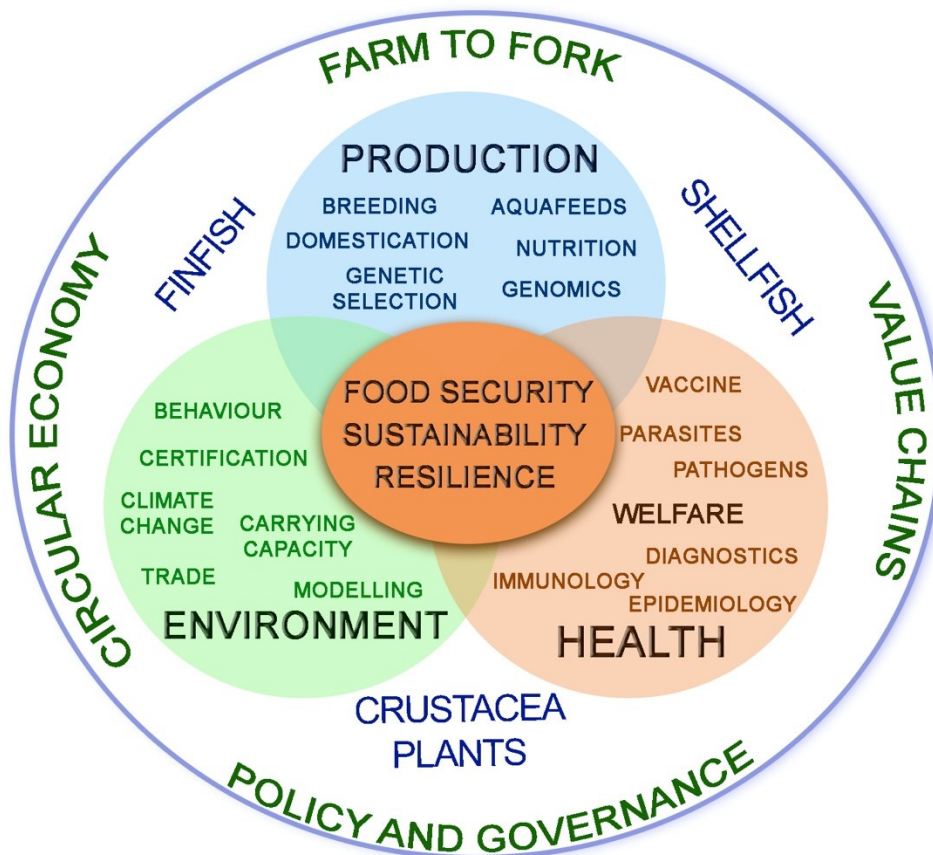


Figure 1. IoA interactions between our research groups (circles), external priorities (green text) and core mission (oval).

The focus and achievements of each research group during the REF period are described below:

i) Production

The Production Research Group addresses the interplay between genetics, environment, feeds and welfare in farmed species throughout the major life-cycle events with direct impact on the global aquaculture industry. The advances in production through manipulating commercial traits such as reproduction; sex determination and differentiation; early development, growth and smoltification (sea water adaptation of juvenile salmon) is achieved using the latest genetic, genomic and bioinformatic technologies in association with phenotyping. The development of sustainably sourced feeds is at the heart of the research with a particular focus on the metabolism of omega-3 long chain polyunsaturated fatty acids (PUFAs) and the development of novel feed ingredients

The group has strong linkages and collaboration with the selective breeding, aquafeeds, aquaculture production, pharmaceutical and retail sectors where basic research findings are directly translated and adopted globally into solutions for enhanced sustainability. The group has active research collaborations across Europe, South America, China, New Zealand, Australia, India and South East Asia demonstrated by joint publications during the REF period.

Impact and Research Highlights of the Production Research Group

This group has consolidated its staff numbers with the recruitment of four new academics at different career stages to expand areas of excellence and put in place succession planning. A new Professor in aquaculture nutrition strengthened the groups expertise in feed formulation using innovative ingredients to support the global expansion of the aquaculture sector. New lecturers have brought additional expertise in invertebrate physiology, salmonid physiology and aquaculture nutrition.

Recent research includes the domestication of cleaner fish species for sea lice control in salmon (**Impact Case Study 1**); new quantitative trait loci for understanding sex determination and manipulate gender in farmed aquatic organisms to improve productivity of the farming sectors; novel oils obtained from microalgae and genetically engineered crops that provide PUFAs into more sustainable salmon feeds; the first demonstration of nutritional programming in salmon for enhanced efficiency of alternative vegetable rich diets with lower environmental impact resulting in enhanced acceptability, digestibility and performance of farmed stocks; the study of gene editing for fish sterility and the impact of recirculation aquaculture systems on fish robustness.

Over the REF period, the group has been successful in securing large grant research income to support the sustainable transformation of the global aquaculture from BBSRC/NERC, Innovate UK, SAIC, and EU. Stirling pioneered research in fish sterility (BBSRC/Innovate UK, Total £2.036m, £751k to Stirling); the development of new genomic tools for commercially important species and traits (BBSRC/NERC, Total £1.5m, £238k); cleaner fish domestication (SAIC, Innovate UK and H2020, Total £15.4m, £2.7m to Stirling); shellfish hatchery (SAIC); fish robustness in Recirculation Aquaculture Systems (BBSRC/NERC, Total £1.8m, £670k to Stirling); nutritional programming (H2020 and BBSRC, Total £7.5m, £1.4m to Stirling); solutions to global PUFAs application in aquaculture, including development of new raw materials, for example, GM-plant (BBSRC); microalgal (BBSRC-IPA); freshwater macrophyte and bacterial (BBSRC Newton Fund) oil sources; refining our understanding of PUFA metabolism in fish (BBSRC-IPA, EU H2020), and assessing impacts of changes in use of PUFA on fish quality attributes (BBSRC, EU H2020, Industry). The group developed and leads the Aquaculture Research Collaborative Hub in the UK (ARCH UK, BBSRC/NERC, Total of £580k, £393k to Stirling) which built the first UK wide aquaculture community and developed a strategic research agenda.

ii) Health

The Health Research Group addresses issues of finfish and shellfish health and welfare with a focus on: i) prevention and control of infectious diseases; ii) monitoring for and ensuring optimal welfare of farmed stocks; and iii) optimising ethical production. The knowledge and tools that we have provided have served to remove or ameliorate major constraints to aquaculture and wild fishery sustainability and resilience globally. Programmes exist in emerging infectious disease, chemo- and immuno-therapy, control of bacterial/parasitic disease and drug resistance, disease diagnostics, welfare, behaviour, fish and shellfish physiology, ecotoxicology, veterinary pathology, epidemiology and fish immunology and vaccinology. We participate and lead many international collaborative partnerships and networks worldwide, involving academic, regulatory, industry, value chain, NGO and consumer stakeholders.

Impact and Research Highlights of the Health Research Group

Ethical aquaculture production is a major priority across the value chain. We have built research capacity to address the emergent challenges of animal welfare in aquaculture. Our fundamental research in understanding of fish adaptability, choice and cognition (EU, Total €4.5M; £290K to Stirling), has led directly to changes in management practices (The Norwegian Seafood Research Fund (FHF), Norway), accreditation and guidance, e.g. RSPCA-assured industry standards, United Nations FAO Technical Guidelines. Research into post-catch survival of discarded Norwegian lobsters (Fisheries Innovation Scotland; £170K to Stirling) has supported a UK landing exemption within EU Common Fisheries Policy (see **Impact Case Study 2**).

Sea lice cost global aquaculture >£700m p.a. With growing awareness of increasing drug resistance in sea lice, the development of novel sea lice vaccines targeting mucosal immunity (SAIC, Total £497K, £262K to Stirling), and understanding the molecular basis of drug resistance in salmon lice (BBSRC, £443K to Stirling) are at the vanguard of parasitic control in salmon aquaculture. Alternative approaches include the novel use of ultrasound to control sea lice (KTP /Innovate UK/BBSRC; £323.5K); and genomic breeding for gill health and lice resistance in salmon (SAIC / Industry, Total £1.07m, £121K to Stirling). Amoebic gill disease in salmon has also been targeted through development of novel vaccines, in research conducted for EU (EU H2020, Total €7.8m, £305K to Stirling).

We are addressing antimicrobial resistance internationally (e.g. India, Vietnam), by eliminating barriers to uptake of alternatives to antibiotics (IDRC-Canada £665K; £443K to Stirling). In the UK, we are improving disease resistance to major pathogens (e.g. *F. psychrophilum*), in salmonids through novel vaccines (SAIC, Total £759K, £344K to Stirling) and improved vaccination strategies for a range of species (SAIC, Total £285K, £119.5K to Stirling).

Improved detection, control and biosecurity have been achieved through establishment of optimal diagnostic windows for viruses, linked with new point-of-care rapid detection methods (e.g. NERC/BBSRC Total £264K, £164K to Stirling). Understanding microbiome dynamics is critical to health and we have programmes including responses to chemotherapy (FHF, total £1.2m, £466K to Stirling), use of functional feeds (Innovate UK, Total £10m and £1.03m to Stirling) and microbiomes of farmed animals (EU, Total €10m, £97K to Stirling).

iii) Environment

The Environment Research Group supports informed decision-making about how aquaculture uses, impacts, and is influenced by the environment. Our systems approach encompasses the life cycle from 'farm to fork'. We work in freshwater, coastal, and marine environments, covering different spatial scales from global to individual organisms. Bringing together biological, ecological, social, and technological aspects, our group transcends disciplines, addressing real-world multifactorial issues that industry, regulators, and other stakeholders face. We also investigate the broader concepts of sustainable aquaculture and its role in food security, as well as its transition to a more circular economy, under an uncertain future of climate change. Environmental models,

remote measurement and monitoring, fieldwork, laboratory experiments, and tank trials underpin our research. Our group brings together experts in ecology, ecotoxicology, animal welfare, socioeconomics and environmental governance.

We lead a wide range of research on ecosystem sustainability, environment interactions, animal welfare, climate change, food security and poverty alleviation, and international trade. We are leading projects in Europe, Latin American ODA countries, Southeast Asia, and China – where most seafood is farmed – and in Africa, where demand is rising rapidly. Strategic partnerships formed with NGOs, regulatory bodies, civic society, national- and worldwide industries have co-created resilient value chains for nutritious food in developing and developed countries.

Impact and Research Highlights of the Environment Research Group

Meeting our mission of “increasing the sustainability, resilience and security of global aquaculture” has been accelerated by four appointments to this research group. Two new Professors provide leadership in understanding how climate change and environmental governance impacts future development of sustainable aquaculture, while complimenting existing research.

Our group has coordinated interdisciplinary projects to develop decision support tools and methods for environmental licensing and regulation (EU H2020 £6.1m, £795k Stirling; Leverhulme Africa Grant, £180K), leading to demonstrable changes in aquaculture governance in Europe and Africa (**Impact Case Study 3**). The “Accessibility and Connectivity” of this research was recognised by winning the EU Atlantic Project Award 2017. Aquaculture for conservation using market-led approaches has, with commercial partners’ in the UK, initiated local research and public awareness through annual Oyster Festivals in Sierra Leone (DEFRA £250k). Climate change research (NERC Research Fellowship, £462k) and adaptation planning (EU H2020 £4.7m, with £240k Stirling) led to changes in marine farm management practices for fish and shellfish in relation to short- and long-term climate variability. Research into movement of aquaculture offshore, away from crowded coasts, provided industry and regulators with insight into the effects these new environments have on fish health and welfare, allowing more informed planning and management (BBSRC £1,1m, £165K Stirling). Research on negative impacts of aquaculture intensification have changed practice in the welfare and treatment of farmed shrimp, winning the prestigious 2020 Global Aquaculture Innovation Award. Eco-intensification research for European aquaculture (EU H2020 £5.4m, £395k Stirling) has allowed improvements in production and competitiveness, while ensuring sustainability and food safety and environmental compliance. More recently, research to support multi-stakeholder approaches to sustainable aquaculture development in Europe and Asia (EU H2020 £1.8m, £202k to Stirling), have strengthened intersectoral cooperation between seafood value chain members.

Future Strategy

Our vision is to create the **National Aquaculture Technology and Innovation Hub (NATIH)** with the **£17m investment secured from the City Region Deal**. The IoA will play a critical role in the development of this unique infrastructure. The NATIH will capitalise on IoA expertise and our network to create a unique platform nationally, co-located with innovators and industry on Stirling campus. Our goal is to expand strategic partnerships to innovate and transform aquatic systems research and realise the full impact of our collaborative research for industry, policy and society. This strategy will include a circular economy and whole systems approach, cross sector engagement, innovation and collaboration for capacity building and integrated solutions to national and international priorities using smart technologies (e.g. UK net-zero strategy, sustainable development goals). We seek to fully integrate aquaculture at the heart of the national UK food strategy. The centre will integrate with Scotland’s new International Environment Centre, a £22m investment from the City Region Deal also hosted by the University of Stirling which, will provide opportunity for interdisciplinary bridging.

Our ambitious aim to lead in developing climate smart and resilient aquaculture and precision farming initiatives is supported by the provision of real-world experimental and commercially

relevant aquaria. Our strategy will capitalise on recent and planned upgrading of our facilities and new strategic appointments in environmental sciences, behaviour, policy and governance, and genetics as well as succession planning for our core research areas (nutrition, health and production). We will grow our collaboration closely with governments, industry and organisations both in the UK and around the world.

Impact Strategy

Impact lies at the heart of the IoA, and we have further intensified impact within our research culture through the Faculty of Natural Science’s Impact Strategy. This has three main objectives: to improve impact literacy through training and the sharing of best practice, enabling identification of a wide range of potential and ambitious impact objectives; to maintain an impact support structure; and, to recognise and track impact as it happens. To achieve these objectives, we appointed Impact Champions at both professorial and ECR level within the IoA who coordinate with the Faculty’s Associate Dean of Impact and the Faculty Impact Committee. Our Impact Case Study leads act as impact ambassadors, sharing knowledge, skills, connections and insights gained during their journeys to successful impact creation. We share our best practice and learn from others across the institution through engagement with Impact Champions in other faculties and divisions and the institutional Impact Working Group. The importance of impactful research for the IoA is recognised and rewarded within the Achieving Success process and as a criterion for research leave.

2. People Staffing strategy

Our staffing strategy has been to strengthen and grow our core research areas by developing our existing academic and research staff and by appointing outstanding scientists who bring added value, address emergent priorities and build capacity. Ten new strategic appointments (Figure 2) have been made during the REF period equally split between core expertise (nutrition (n=2); invertebrate physiology (n=1); salmonid physiology (n=1); parasitology (n=1), pathobiology (n=1)) and new areas required for significant contribution to global challenges (animal behaviour (n=1); climate change (n=2); innovation in policy and governance (n=1)).



Figure 2. Current staff profile, as of 2020 census, with gender data. Total number of people in each category with number of new appointments and promotions in each category.

The appointment of a new Director heralded ambitious plans to widen the IoA’s mission expanding our capacity to influence policy and regulation. As a UK Government Chief Scientific Adviser for the Marine Management Organisation and former Chair of the Scottish Government’s Marine Scotland Science Advisory Board, the new Head enhances the IoA’s reputation as a leader in aquatic food resilience.

Staff development

The University’s annual review and appraisal framework (Achieving Success) enables staff to prioritise research goals according to their career stage. This framework supports the Concordat to Support the Career Development of Researchers and its associated principles of which the University of Stirling became a signatory in 2019. We have consolidated this process to include two of the three research groups heads at each annual review, currently we are running six monthly reviews during COVID-19 lockdown. Annual review identifies development training needs in an inclusive, equitable and transparent manner, supporting high quality research through policy and practise. Our review process supports long-term staff development by providing a bespoke route for academic development. Since 2017, uptake of this process in Aquaculture was 100% for all academic and professional support staff. From an Aquaculture staff survey (2019), 68% of respondents (n=16/24F and n=25/36M) agreed that they were aware of training and support for their career progression. Other practises include supporting flexible working hours around family

commitments, where our data show 68% of staff (n=19/24F and 22/36M) agree that they felt supported when requesting flexible working. Monthly research group meetings provide further support to ensure agreed objectives remain achievable and provide early opportunity to discuss work-related problems. These meetings provide a participatory forum to discuss grant development, manuscript review, journal club debates and research student progression. A final layer of support is embedded into our interdisciplinary research group discussion forums to develop cross-disciplinary initiatives. These are led by early and mid-career researchers, contributing to valuable leadership mentoring, and serve to incubate future transversal research themes and future leaders.

For early career researchers a senior colleague and mentor are assigned for specific personalised support. During probation teaching loads and administrative duties are kept low providing an optimum environment for research consolidation and development. ECRs are actively encouraged to participate in the wide range of personal and career development courses offered by the University. All staff are encouraged to attend courses and develop their skills on academic grant writing; computing and IT courses; teaching skills; training in leadership and management; technical courses; and many more. During the REF period, IoA core staff (n=4) carried out senior leadership and management programmes organised by the Institute of Leadership and Management.

We proactively seek opportunities for early career researchers to apply for research fellowships, especially where they add depth to ongoing research areas. We mentor applications for fellowships, with draft applications reviewed and practice talks and interviews offered to enhance performance. The IoA has hosted 35 research postdoctoral research assistants and one NERC fellow during the REF period. The NERC fellow has been consolidated in a tenure track agreement. Several researchers (n=5) have successfully continued their research as Principal Investigators on external grants.

There are 8 Emeritus Professors currently at the IoA who provide mentorship, sponsorship, dissemination activities and strategic council across the 3 research groups. Selection of honorary staff is based upon strategic relevance to advance our research mission. We have one Honorary Professor who forms a cross-disciplinary Nutrition team that co-developed research in GM-replacement oil for salmon feeds with the honorary Professor providing essential expertise in plant biology. Currently, a further two honorary senior lecturers, health management in aquaculture, based in Thailand and Chile provide a direct link to the dynamic SE Asian and South American aquaculture sectors.

Research students

The IoA admitted a total of 76 doctoral students and awarded 74 doctoral degrees during the REF period. Admissions represent an average of ca 11 per year (2014-20). Our graduate strategy focuses on balancing academic excellence and potential with project impact. We actively recruit international PhD students (overall 43% are from overseas, many benefitting from Commonwealth scholarships n=8) and involve Industrial partners, e.g. BioMar, MOWI, AquaGen with fundamental research directly translated into industry. Many industry-sponsored PhD projects substantially benefit from additional funding from industry partners including access to commercial facilities. Through University of Stirling funding a significant number of match-funded PhD scholarships (n=14; 50% University:50% Industry funding) have allowed us to both capitalise upon our existing industry partnerships and develop new partnerships. These PhD projects facilitated access to large-scale facilities for industrial scale trials (on-farm) with salmon and feed producers such as MOWI, Scottish Seafarms, Cooke Aquaculture and BioMar, and access to the most advanced technologies and purpose-built prototypes for research (e.g. LED lighting systems with Philips). Other projects involved SMEs, such as EuroPharma Ltd. that developed novel diagnostic biomarkers, Pulcea Ltd. that deploys marine physics and medical devices to deliver technical innovations and Otterfery SeaFish Ltd., the only marine hatchery in the UK, all providing knowledge transfer and training to emerging business.

Our international partnerships have proven fruitful with PhD research shared with organisations in Europe (8) and world (25). This is reflected in our PhD student demographics with 27% UK, 30% EU and 43% Overseas. Our capture of British Council-Newton Mosharafa PhD scholarships are very successful with Egypt (n=5) and have increased our significant cohort of African students including Nigeria (n=6), Libya (n=1), Uganda (n=1), Angola (n=1) and South Africa (n=1). Asian PhD students (n=9) mainly funded by Government and Commonwealth account for almost 10% of our PhDs with Bangladesh (n=1), Thailand (n=2), Indonesia (n=1), Philippines (n=1), China (n=2), Taiwan (n=1) and India (n=1). Strategic international collaborations have provided financial and educational support for including the University of Bergen in Norway (n=3), the non-profit research organisation, Worldfish (n=2), the largest Brazilian research organisation, the Brazilian Agriculture Research Corporation (EMBRAPA) (n=1) and EU funding (n=3). Our diverse PhD community is a reflection of our proactive approach to maintaining our research vibrancy through our substantial International network.

The IoA participates in two UKRI funded Doctoral Training Partnerships (DTP). The East of Scotland Bioscience DTP (EASTBIO) established in 2012 with BBSRC funding was joined by IoA in 2019. Our partnership acknowledges our track record and strong links with the commercial sector and support our high-quality bioscience training in aquaculture. The second DTP is the Scottish Universities Partnership for Environmental Research (SUPER). This NERC-funded DTP is led by the Marine Alliance for Science and Technology for Scotland (MASTS) and is built around eight well-established collaborative groups of Scottish universities delivering research in natural environmental science. Each partner institution addresses cutting-edge scientific challenges across the NERC remit in topics as diverse as environmental physics and chemistry, biodiversity, global change and mathematical modelling of populations and ecosystems. Our membership of both DTPs delivers interdisciplinary training with interacting PhD student cohorts through collaborative research accessing expertise and research facilities across Scotland. Since 2019, four IoA based PhD students were awarded these highly competitive DTP studentships. The successful students are jointly supervised by academics from at least two DTP member universities and UK industry, thereby embedding research impact in their training.

Our PGR supervision draws from a wide range of backgrounds and disciplines reflecting our research. All PGR students have a primary and secondary Stirling-based supervisor to ensure resilience and additional supervisors are allocated for multidisciplinary and interdisciplinary projects where extended expertise is required. There is a formal annual review process of both the student's progress and supervision. Reviews are carried out by the PGR panel that is formed by three senior academics from each research group. An integral part of our PGR training is drawn from the University's Institute of Advanced Studies (IAS). The IAS provides the Skills Development Programme that offers training courses and workshops for both students and supervisors. The Programme framework acts as an aid to planning, promoting and enhancing professional and career development and a discussion hub drawing from the experience of successful researchers. Feedback allows us to modify our approach to supervision and is reviewed annually. Recently, we have modified our process, from PRES feedback, aiming at 1st year PhDs where a mini progress review is now undertaken after 6 months of study and followed with a critical assessment at 10-14 months by the PGR panel. Here, data collection, future planning including contingencies and a seminar are requirements. Informally, regular journal clubs are held at the level of research group to develop critical review skills and to push boundaries and promote interdisciplinary thinking.

The IoA organises a biannual PhD conference that is open to external stakeholders and external collaborators – around 50-60 of the 150-200 attendees are external to the University. The event has grown in popularity with an increasing number of stakeholders from a wide range of industries and organisations using this occasion to recruit PGRs. At the same time, PGRs receive valuable feedback from end-users on their research that facilitates impact during the lifetime of their studies. This activity parallels with our Aquaculture Student Association (ASA). ASA, formed and run by PGR students (MSc and PhD), organises social events. ASA leads and organises the 'Aquaculture Careers Day', a one-day annual event that provides networking opportunities with the aquaculture industry and a wide range of sector operators including local business. Since 2018 this event has

been open to all UK students involved in aquaculture research. In 2019, exhibitor stalls from over 15 international companies and 10 invited speakers with approximately 100 people participated in this successful employability forum.

Equality, Diversity and Inclusion

Changes in our organisation and management practises promote an improved culture of care throughout all academic career stages. Examples of positive changes are evidenced by an increase in academic female staff (T&R) from 25% in 2014, to 30%. In 2020, the IoA gained a Bronze Level Athena SWAN award, which recognises our commitment towards a more equitable, diverse and inclusive culture. From 2017/18, committee membership within Aquaculture was refreshed to promote gender equality with an increase in the number of female leads within our committees, e.g. PGR, L&T as well as the first female HOD. In 2017/18, a series of 1-hour training seminars, specific to IoA activities and organised twice yearly, was initiated to promote best practises in research ethics, biological safety, general health and safety, and these are well-attended by all staff and students.

Further evidence of positive change towards a more diverse culture in Aquaculture can be seen through our promotional materials and inclusion of more representative role models within our website. These reflect the international nature of our staff and students as well as provide opportunities for technical support staff to act as role models. The IoA has an active and diverse outreach programme where we promote our research activities via Science Fairs, Widening Participation Schemes as well as UoS open days. Staff of all grades are encouraged to promote equality and diversity within and beyond the IoA. An example is a member of the IoA academic staff who is the co-chair of the Steering Group for Women in Scottish Aquaculture (WISA). This network supports the role of women in the Scottish aquaculture sector, creating a platform for discussion and a network of support.

3. Income, infrastructure and facilities

Our diverse portfolio of funding reflects our broad programmes of research, from fundamental science to applied implementation. Research grant success has seen a step change increase in income and the total grant award value to Stirling over the REF period is £19.3m. This represents a 1.7-fold increase over the previous exercise (£11.5m) coupled to a success rate for project grants of 35%. Major funders, shown as 80% FEC excl. partners costs, include income from UK research council BBSRC (£6.06m to Stirling), Innovate UK (£2.34m to Stirling), NERC (£875K to Stirling), European (EU H2020, £4.8m to Stirling) and the Scottish Aquaculture Innovation Centre (SAIC, £3.2m to Stirling). Most (40%) of our research funding came from UKRI or the EU, with a further 20% from industry and 15% from other International sources including significant contributions from the Norwegian Fisheries Research Fund, the Norwegian Research Council and the International Development Research Centre, Canada (IDRC-Canada).

Extensive industrial partnerships were secured (BBSRC-Industry funding £1.7M) with the world leading salmon companies based in Scotland, Norway, Iceland, Chile, Tasmania and Canada including producers (e.g. MOWI group, Lerøy Seafood Group, Scottish Sea Farms, The Scottish Salmon Company, Grieg Seafood, Cooke Aquaculture, Norway Royal salmon, Huon Aquaculture, Bremnes Seashore), feed manufacturers (e.g. BioMar, Cargill), pharmaceutical companies (e.g. Zoetis, Pharmaq, Merck Animal Health, Ceva), breeding companies (e.g. AquaGen, Benchmark, Landcatch Natural selection, MOWI Genetics) and equipment suppliers (Akva Group). These collaborations have led to a significant number of University of Stirling match-funded PhD scholarships (n=12), access to large-scale facilities for industrial scale trials (on-farm) and extensive knowledge transfer and training (CPD income; £66K 2017-2019; ARCH UK; £370k to Stirling). Upskilling of industry through knowledge transfer partnerships (KTPs) partnering with SME's, currently 3 SME with a total project value of £893K also plays a major role at the IoA in supporting industry through collaboration funded UKRI and Scottish Government Funding.

We have been particularly successful in raising the visibility of aquaculture's role in transforming food systems in the UK that, for example, has led to recent participation in several major Innovate UK initiatives looking at alternative protein sources (Total project value of £12m, £967K to Stirling), fish sterility (Total project value of £2.4m, £751k to Stirling) and cleaner fish research (Total project value of £1.55m, 651k to Stirling).

Close working relationships with governmental departments such as Department for Environment, Food and Rural Affairs (Defra), Marine Scotland Science and the Environment Agency, the Centre for Environment, Fisheries and Aquaculture (Cefas) has significantly enhanced funded research projects and associated PhD recruitment. Importantly, funded International research partnerships including the Research Institute for Aquaculture (RIA3) in Vietnam (Total £665K; £443K to Stirling) and a BBSRC-funded UK-China award (£33K/year) bringing together Chinese Universities from East China sea (Shanghai Ocean, Ningbo and Zhejiang Ocean Universities) fostered new opportunities to develop our International reach in South East Asia with further research, income and postgraduate recruitment.

The IoA capitalised on the successful launch of the Scottish Aquaculture Innovation Centre in 2014, and administered from the University, by deploying its scientific expertise and links with the industry to develop innovative research projects. During the REF period, these projects include:

- Domestication of cleaner fish (two new species, ballan wrasse and lumpsucker) (**Impact Case Study 1**) fast tracking the application of a green alternative to more traditional pest management strategies (total projects value of £6.5m, Stirling income of £1.16m)
- Development of genomic tools for UK aquaculture (including salmon, lumpsucker, mussel, oyster and lobster, total of £1.5m in collaboration with Edinburgh, Aberdeen, Exeter Universities, Stirling income of £198K)
- Impact of recirculation on salmon robustness at sea (total projects value of £1.8m, Stirling income of £671K including £220k from SAIC)
- Many other SAIC co-funded IoA projects over the period studied nutritional, welfare, sea lice and vaccine challenges experienced by the industry.

The IoA is the lead partner for the UK's first national UK wide multi-stakeholder aquaculture network, the Aquaculture Research Collaborative Hub (ARCH UK) which is co-funded by BBSRC and NERC (£550k). The network since its inception in 2017 has grown to 560 members (total of 225 organisations representing all major aquaculture producers, suppliers and research centres across the UK). The main objectives of ARCH UK are to develop a UK aquaculture community by developing a strategic research agenda in relation to UKRI funding priorities (which led to Aquaculture Initiative launched in 2018 with a total of £5.1m granted in an open BBSRC/NERC call including a total of £2.5m in projects with Stirling), and by promoting knowledge exchange and translation of science and technology and strengthen UK capacity building in aquaculture especially through Early Career Researchers.

Sustainability and climate change has been central to our research agenda with successful income streams from Horizon 2020 projects representing 18% of our total funding. The IoA Horizon 2020 portfolio reflects our integration into key European 'Blue Economy' initiatives ranging from environmental policy and management, nutrition and genetics, health, innovation, sustainability in food production and training in aquaculture. The IoA has coordinated a large H2020 project (Total of £6.1m, £795k to Stirling) to develop environmental monitoring tools, technology for real time measurement and methods for regulation and licensing in aquaculture with 16 partners across Europe. Keystone initiatives played a significant role in policy and development across the global aquaculture landscape notably in Africa and Asia including an inter-disciplinary BBSRC-funded project in India, Bangladesh and Kenya (Total of £1.5m; £754K to Stirling) bringing regulators, scientists, public health, human nutrition and health economics expertise together. Innovation in the SE Asian aquaculture sector formed the core of the EU H2020 project entitled, Eurastip- Promoting Multi-Stakeholder Contributions to International Cooperation on Sustainable Solutions for Aquaculture Development in South East Asia (Total €2m, £197K to Stirling) aiming to act as an innovation catalyst to the sector.

Infrastructure and Research facilities

The IoA operates four unique animal research facilities that are essential to our operations: two on campus and two off campus, providing the range of environmental conditions (marine, freshwater, temperate and tropical) and experimental systems (Recirculating Aquaculture Systems (RAS), hatchery and flow-through) required for animal experimentation that are relevant to the aquaculture industry. All facilities are continuously upgraded to ensure we use the most advanced technologies available in line with our experimental ambitions (e.g. computerised and integrated feeding, environmental control and monitoring). A total of £1.7m has been invested by the IoA across our experimental facilities and >£1m in our laboratories during the REF period. Future investments are planned as part of Stirling City Deal with £17m allocated to Aquaculture infrastructure.

The Marine Environmental Research Laboratory (MERL) provides research and commercial contract services with a major focus on improving nutritional value of aquaculture feedstocks and developing novel pest management strategies against sea lice and Amoebic Gill Disease, the two main threats to the global salmon industry. A major asset at MERL has been the further development of our sea lice farm, unique to the UK that provides contract services to the pharmaceutical industry by providing access to a controlled supply of genetically characterised sea lice for resistance to chemotherapeutants and colour phenotypes. MERL is the only marine site in the UK where sea lice research can be performed and as such is highly solicited by external companies in addition to our internal research portfolio. The IoA invested strategically to modernise and increase capacity over the REF period with two new experimental tank systems (£280k) hosted within a new extended building (£213k), the full site equipped with new and improved filtration units, automatic feeding and environmental monitoring systems (total of £335k) and two new permanent technical staff. The IoA secured a total of £2.4m during the REF period in the form of contract research services from many commercial partners including companies specialised in pharmaceuticals and health products (Zoetis, Elanco, Merck Animal Health, Solvay SA, Evolva SA), feeds, additives and alternative ingredients (BioMar, Xanthella Ltd, and Biomin GMBH), LED lighting (Signify) and selective breeding (Landcatch Natural Selection/Hendrix).

The Niall Bromage Freshwater Research Unit (NBFRU) is our salmonid freshwater facility. Capacity at NBFRU has been enhanced with a £790K investment (2019) providing 12 tanks with environmental control through the use of state-of-the-art recirculation technology (RAS) and a new modern purpose-built experimental hatchery to support increased UKRI income. Currently, NBFRU is running at full capacity with the entire facility booked for experimental research extending to 2022. This usage highlights an increased demand from industry for UKRI funded research focussing on freshwater life stages of salmonids.

On campus facilities

Tropical Aquaria

IoA on campus facilities include the only experimental tropical fish holding systems in the UK primarily used to support research on tilapia species (Tilapia Reference Collection breeding stocks of *Oreochromis niloticus*, *O. aureus*, *O. mossambicus*, *O. karongae* and *Tilapia zillii*) and catfish for aquaculture in developing countries but also model species, zebrafish. These facilities allow a wide range of fundamental and applied scientific studies to be performed on genetics (clonal lines, sex determination and manipulation), physiology, reproduction, nutrition, taxonomy, immunology, behaviour. The reputation of the IoA is embedded in the breadth and depth of its engagement with aquaculture worldwide and our facilities play a central role.

Temperate Aquaria

In 2014, IoA built state-of-the-art temperature and light controlled recirculation environmental facilities, temperature and light controlled with automatic feeding and monitoring systems (total of £250k, £100k within REF period). This temperate aquarium is used in a wide range of scientific projects funded mainly by BBSRC/NERC and industry (currently with world leading companies in

salmon genetics, AquaGen; salmon production, MOWI; and lighting, Philips) on chronobiology, environmental manipulations and programming, epigenetics experiments in salmon.

Our aquaria facilities are supported by well-equipped research laboratories where analytical capacity in mass spectrometry (MS) is a particular strength. Institutional funding, with a total of £1m over the REF period, has allowed an enhancement of proteomic capacity (MALDI-TOF; £90K) and a new MS-ICP-MS to update analytical power (£250K). This MS capacity was further increased by SAIC funding (£350K) for an additional LC-MS-MS aimed toward detection of shellfish toxins across the UK. Additional upgrades have been made in cell cytometry and image analysis (£210K), radiography infrastructure (£142k) for skeletal malformation analyses and hydroacoustic technology for individual fish tracking (SAIC, £130k). The Nutrition Analytical Service (NAS), created in 1998 with a current customer list of over 43 organisations including 20 international core customers, is intimately linked to our MS capability and contributes >£0.5m per year to support IoA investments and technical support maintaining state of the art analytical capabilities.

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

Research collaborations

Collaboration and internationalisation are key to IoA mission given the global importance of aquaculture. Our extensive networks and partnerships ensure that our collaborators benefit directly from our work providing significant contributions to the broader research base, economy, and society (Figure 3).



Figure 3. Our active global partnerships across climate zones

Academic collaborative initiatives include:

At national level, the IoA leads and participates in three main initiatives funded by Scottish government and UKRI, the Scottish Aquaculture Innovation Centre (SAIC), the Marine Alliance Science and Technology Scotland (MASTS) and the Aquaculture Collaborative Research Hub (ARCH-UK).

IoA has played a pivotal role in the development of **SAIC**, a Scottish Funding Council (SFC) initiative, by securing over £11m matched by industry. The University of Stirling acts as the administrative hub for SAIC and is a member of the executive board. Highlights from phase 1 of SAIC (2014-2019) include a total of £35.8m leveraged from industry and other sources and 205 FTE jobs created (170 in rural areas). As a result, phase 2 was secured in 2019 with £10m from SFC, Scottish Enterprise, and Highlands and Islands Enterprise for the next five years. IoA is at the heart of SAIC success with £3.2m of SAIC research funding secured, 15-19 studentships/year in our MSc program in sustainable aquaculture (total of 119 during REF period, total value of £595k) and many conferences and seminars co-hosted.

IoA staff have contributed to **MASTS** at all levels from its inception. MASTS is a pooling of over 700 marine scientists and other stakeholders in Scotland. IoA chaired (by Deputy Principal Malcolm MacLeod) the Board of MASTS from 2017 to 2020. From 2012 to 2019 the IoA also led as Research Theme leader for Productive Seas (Professor Turnbull). After a successful first phase when 40 staff were recruited and 80 PhD students were trained in Scotland, attracting over £82m in grant income and a further £30m for infrastructure, a second phase began in 2016. Our continued roles as Forum leader for Sustainable Aquaculture (Dr Davie), members of the Governing Council (Professor Stead) and Executive Committee (Professor Telfer), has led directly to our involvement in the SUPER DTP.

ARCH-UK was launched in 2017 under the leadership of IoA staff (Professor Migaud). Funded by both BBSRC and NERC, ARCH UK helps coordinate national collaboration amongst the UK academic research base contributing to aquaculture research and development. ARCH-UK has produced 10 reports since 2017 to ensure both national and international research funding strategy focusses on addressing key knowledge gaps to safeguard sustainable industry growth and global food security. ARCH-UK has been very active as a knowledge exchange and research translation resource for a national multi-stakeholder audience (550 members, 1780 twitter followers, including 225 academic, industry and government organisations). Staff at the IoA have co-led 6 of the 8 working groups, with more than 30 workshops and training events, including webinars, having reached over 5000 participants across the UK and global aquaculture community. ARCH-UK has led to large BBSRC/NERC collaborative research consortia led by Stirling.

At European level, the IoA has contributed significantly to shape and drive a number of key initiatives including the European Aquaculture Technology and Innovation Platform (EATIP), the Federation of European Aquaculture Producers (FEAP), and the H2020 research infrastructure project AQUAEXCEL. The IoA is one of the ten core member Universities across Europe involved in the EATIP, driving aquaculture innovation, knowledge transfer and European competitiveness. IoA contributed to several of the group leadership including fish health (Professor Adams). The network is directly feeding into the European agenda by prioritising research needs, stimulating cross-regional transfer of knowledge. EATIP was a partner of Eurastip, ASEM Aquaculture platform, Aqua-tnet and is involved in AQUAEXCEL, all involving IoA staff. The IoA plays a key role in FEAP which represents the fish farming sector in Europe and supports and promotes the responsible development of aquaculture through the provision of positions, opinions and advice to the Aquaculture Advisory Council and the Market Advisory Council. IoA is a founding member of AQUAEXCEL programmes since its launch in 2012. AQUAEXCEL²⁰²⁰ is the latest of three consecutive projects bringing 22 partner organisations with access to 39 leading facilities for aquaculture research across Europe. This infrastructure provides partners with opportunities for networking and transnational access (TNA) for research across the consortia. The TNA component of the consortia is led by the IoA which manages the application process (194 TNA projects over the past 5 years).

During the REF period, IoA scientists have been partners and coordinators in a range of research consortia funded through the European Union funded Horizon 2020 program (H2020). Our collaborative activities in this arena focus on nutrition and breeding (<https://www.arraina.eu/> and <https://www.luke.fi/aquaimpact/>), environmental sustainability and climate change (<http://tapas-h2020.eu/the-project/>, Stirling as coordinator; <https://climefish.eu/>) and health management (<https://www.parafishcontrol.eu/>, <https://cordis.europa.eu/project/id/265957/reporting>; <https://circlesproject.eu/>).

At international level, much of the IoA collaborative activity and research partnerships has been guided by the UN Sustainable Development Goals (SDGs). This activity is strategically supported by our influential network of Alumni, now over 1,500 past students from >100 different countries. This network results from providing high quality MSc and PhD research training in conjunction with sustained alumni engagement activity since the late 70s. Recent prestigious appointments of IoA staff in China (e.g. Professor Migaud as Distinguished Professor of the Zhejiang province since 2018; Professor Adams as Honorary Professor at Guangzhou Ocean University) has further extended our access to research in the world's largest aquaculture producing nation.

Aiming at enhancing the sustainability of global aquaculture, IoA is increasingly working with certifiers and advocacy organisations including the Monterey Bay Aquarium Seafood Watch programme; Global Aquaculture Alliance; Aquaculture Stewardship Council and IFFO, the marine ingredients organisation. As founder members of several working groups of the International Council for Exploration of the Sea's (ICES); Socio-Economic Aquaculture working Group and Environmental Interactions of Aquaculture workgroup, the IoA holds an influential position to inform future policy and practice.

Much of our international research activity is reflected by our PhD student demographic with a strong presence in Africa and SE Asia. We contribute to building resilient infrastructure by leading the SARNISSA network (6000 Facebook followers) a go-to source of information for Sub-Saharan Aquaculture. Leverhulme/Royal Society Africa funding supports aquaculture development in Ghana working with both government and NGOs to extend sustainable aquaculture practices and improve employability. Several funded projects (BBSRC and British Council) working with partners in Egypt, Kenya and Tanzania assess the value of a range of nutrition and health initiatives. In partnership with the Consultative Group on International Agricultural Research (CGIAR institute) and Worldfish, we work on human resource development needs for aqua-based food security in sub-Saharan Africa, extended to Bangladesh and SE Asia through Erasmus + funding. We are partners to the Innovative Methods and Metrics for Agriculture and Nutrition Actions programme (IMMANA) and the Leverhulme Aquatic Food for Health and Nutrition initiative all linking public health, nutrition and aquaculture systems. Complementary funded programmes in SE Asia (Thailand, Vietnam and Bangladesh) include the European Asian aquaculture Technology and innovation Platform (EURASTIP) that promotes international cooperation on sustainable solutions for aquaculture development. As an example of success, diagnostic capacity and data sharing for shrimp disease has been developed with producer groups across Thailand.

During the COVID pandemic we have also reached out to international partnerships and audiences through Our Big Fish Seminar series to promote the societal importance of aquatic food.

Interdisciplinary research

IoA has driven interdisciplinary activities across the University of Stirling within the Global Food Security and Resilience and Living Well themes. Our activities aim to pool expertise to address complex questions and include collaborations in the Extremes in Science and Society, Environmental Change and Global Food Security research programmes. IoA collaborates in funded research with multiple Divisions across the University including food security and sustainability modellers (Computing Science and Mathematics), public health (Health Sciences and Sport), environmental assessments of food production (Biological and Environmental Sciences), behavioural change (Psychology) and economics (the Business School). Outside our immediate University, we have collaborations within consortia in the UK (Aberdeen: Human Nutrition; Glasgow: Health Economics) and more broadly in Europe (Bergen, Norway; Copenhagen, Denmark), the USA (Johns Hopkins) and Low-Income countries (Bangladesh and

Philippines). Two examples of funded projects include the development of vaccines against anti-microbial resistance in Aquaculture in Vietnam (IDRC Canada) and the understanding the impacts of microplastics using satellite imagery (NERC; Microbial hitchhikers of marine plastics, with European Space Agency). Research into the global impacts of aquaculture, and more broadly seafood, have been particularly strong in the current REF period. This activity has led to participation in the prestigious interdisciplinary Blue Food Assessment programme, an International coalition of researchers that delivers a high-profile series of peer reviewed papers for decision makers. This forum together with economists (Stanford, USA), sociologists (Michigan State, USA; Cleveland, USA; Manitoba, Canada), climate modellers (Santa Barbara, California, USA), human nutritionists (Harvard, USA) and environmental emission scientists (Stockholm, Sweden) has led to the first in a series of critical opinion high impact publications (<https://doi.org/10.1038/s41467-020-19679-9>).

Contribution to the research base

Although much of the IoA's work is applied in its nature, our fundamental research drives translational opportunities. Some examples of our basic research include the functional biology of omega-3 PUFA metabolism which led to discoveries that their synthesis was far more extensive across the animal kingdom than previously thought. This research had a critical role in the development of ground-breaking genetic modification technologies to allow the production and evaluation of omega-3 PUFA in terrestrial crop plants. Detailed molecular studies demonstrated that sea louse resistance against the parasiticide deltamethrin is determined by mitochondrial mutations, a finding now widely used in susceptibility monitoring in the industry. The behavioural fever paradigm demonstrated the importance of thermal choice in an animal's environment, significantly impacting upon its survival during a pathogen challenge. The study of clock gene pathways in relation to environmental manipulations helps to understand chronobiological processes entraining critical life cycle transition windows of fish (early development and first feeding, smoltification, puberty), and the efficacy and toxicity of chemical treatments.

Leadership in academia and government

The IoA provides leadership roles in Europe's and Asia's largest academic societies contributing the current (Professor Migaud) and past (Professor Stead) Presidents of the European Aquaculture Society and board members the Asia-Pacific Chapter of the World Aquaculture Society. The IoA head is the Chief scientific Adviser to UK Government for the Marine Management Organisation. Several senior IoA academics contributed to UKRI working groups (BBSRC: Veterinary Vaccinology Strategy; Animal Welfare Research Network and panel); Scottish Government Ministerial working groups; British Veterinary Association (Professor Turnbull, President of Fish Veterinary Society)). Within the aquaculture domain, specialist areas such as fish health, nutrition and reproductive physiology are well represented by IoA staff as directors, chairs and board members including the steering Committee of the Gill Health Initiative, and the scientific council of INRA Phase, the largest Animal physiology and farming organisation in Europe. Our staff lead and contribute to the organisation of numerous international scientific conferences across the domain.

Interaction with research users

Much of the IoA's work is undertaken in close partnership with our research users, with most projects containing at least one industrial partner. Examples of long-standing collaborations with world leading industrial research users include those within the Scottish salmon production sector (largest world producer MOWI), feed companies (BioMar), breeding and genetic companies (AquaGen), raw material companies (Calysta), feed additive companies (Lallemand), diagnostics companies (STIM), vaccine producers (Pharmaq/Zoetis), light manufacturers (Signify), equipment and technology suppliers (AkvaGroup) and retailers (Sainsbury's, Tesco) among others. Other research users include various international bodies (Worldfish, FAO), regulatory bodies (CEFAS, SEPA, Marine Scotland, European Food Safety Authority, Global Aquaculture Alliance, Global G.A.P) and government where IoA academics participate to develop policy (ministerial working groups on sustainable aquaculture and the Scottish Parliament Rural Economy and Connectivity committee).

Contribution to economy

Due to the highly applied nature of much of the IoA's research, the rapid adoption and impact has resulted in substantial contributions to the economy of the UK and beyond. Farmed salmon is Scotland and the UK's number one food export, being exported to over 50 countries, with a value exceeding £600m and employing 2300 people in remote and rural UK. Science based solutions provided by IoA contributed to transforming and expanding the global salmon sector through new farm licenses, increased standing biomass and increased productivity, improved welfare and reduction in downgrading. The most recent version of the Scottish Government's economic impact model (based on input-output) shows that for every £100 of turnover within the Scottish aquaculture industry another £93 is sustained elsewhere in Scotland's economy through supply chains and high street spending from the wages paid to employees. The IoA's reach internationally has an even greater contribution due to the scale of aquaculture as an industry in Asia, Africa and South America, where farmed fish is now an equal contributor to food security as wild-capture fish, and greater than that of beef production. IoA research and innovation encompasses all main commercially important species (e.g. tilapia, catfish, carps, shrimps) and impacted global aquaculture while providing knowledge and tools for diversification into new and emerging species.

Contribution to society

Our core mission is to enable greater sustainability, food security and resilience of aquatic species and ecosystems globally through the development of science based practical solutions and the transformation of the UK and world aquaculture food systems. All our activities contribute directly to society by delivering research, training, innovation and knowledge transfer that increase aquatic food availability, nutritious quality, and safety while protecting the environment, safeguarding animal welfare and driving business profitability. Evidence of our contribution can be found all over the world from the implementation of our research, our training programmes and extensive networks and alumni. This success was acknowledged recently by the prestigious Queen's Anniversary Prize and Scottish Government's funding through the City Region Deal in recognition of our impact and reach across communities, governments and industry. The IoA has an active and diverse outreach programme where we promote our core values, knowledge and innovative solutions. Our collective commitment, passion around a shared strategic vision, together with our extensive networks and funding will enable us to tackle current and future global challenges and continue to benefit communities and society at large.