Institution: University of Stirling

Unit of Assessment: A6 Agriculture, Veterinary and Food Science

a. Overview

The Institute of Aquaculture at the University of Stirling is a major international centre of excellence for aquaculture research. Using a range of cross-disciplinary approaches, the Institute focuses on fundamental questions of fish health and welfare, genetics and reproduction, nutrition and feed supplies and environmental and international development issues relating to the long-term sustainability of the global aquaculture industry. These research themes are widely acknowledged as being the cornerstones of future aquaculture developments. This submission presents the work of three research groups in the Institute: Fish Health, Genetics and Reproduction, and Nutrition and Feed Supplies.

The Institute is a division within the School of Natural Sciences along with the other scientific disciplines at Stirling. The benefits of being part of this larger unit, in addition to facilitating research collaborations across a broad scientific community, have been evident through the REF period in strategic developments and investments in new staff and facility upgrades. Alongside the 28 FTE staff included in this submission the Institute has 53 researchers and support/technical staff and trains 80-100 postgraduate research and master students and 30 undergraduates annually. This makes us one of the largest non-governmental aquaculture research and postgraduate training organisations in the world. We work in close partnership with the Sustainable Aquaculture Group which has been submitted to REF Unit of Assessment C17 as part of the University's Environmental Studies programme.

The Institute maintains a wide range of state of the art fish holding and disease challenge facilities for research: the Aquatic Research Facilities, a tropical and new temperate aquarium on campus; the Niall Bromage Freshwater Research Facility and Machrihanish Marine Environmental Laboratory off campus. We also benefit from maintaining commercial facilities: Howietoun hatchery and fisheries, Dunblane and Buckieburn smolt units and Machrihanish Marine Farms, which all contribute to the impact and commercialisation of our research.

The Institute has continued to improve its research profile and research funding has increased with support from Research Councils, EU, the Technology Strategy Board, along with increased support from the aquaculture industry (£7.3m over the REF period). Recent Scottish Funding Council investments in the Marine Alliance for Science and Technology Scotland (MASTS) in Marine Sciences and the Scottish Aquaculture Innovation Centre (SAIC) has further strengthened the role of the Institute and show the importance placed on aquaculture by the Scottish Government. There have been thirteen new or replacement staff appointments across the Institute over the REF period and continued investments in infrastructure (£0.5m over the REF period with £0.65m committed for 2014) and laboratory equipment (through research grants e.g. Illumina Myseq NGS, bioinformatics computing platform, Laser capture dissection microscope) enabling staff to remain at the cutting edge of their research and generate high quality peer-reviewed publications. As one of the world's largest independent aquaculture research institutes, our outputs and impacts demonstrate our leading position in research and training both nationally and internationally.

b. Research strategy

The Institute, since its inception, has had a strong research focus and has strived to maintain a balance between experienced staff and young innovative researchers. Our mission is to increase the sustainability, resilience and security of the global aquaculture industry through the application of high quality research in aquaculture, across four themes:

a) Application of research that reduces or prevents the significant losses caused by disease through a better understanding of host-pathogen interaction and development of effective disease control methods and products. Farm-induced stressors and fish behaviour are also studied to improve farm welfare.
b) The application of the latest genetic and genomic techniques to improve the management,

performance and welfare of existing and potential new farmed aquatic animals.

c) Development of fish feeds that increasingly meet the health needs of consumers in terms of flesh quality, nutritional composition, pollutant contamination, sustainability and traceability while ensuring the health status of the fish and reducing or replacing ingredients from sources that can be directly consumed by humans.

d) Adopting a systems approach to study aquaculture development and its sustainability by researching issues relating to food security and poverty targeting, international trade and competition, environmental management and planning and the development of new species.

These themes address the most significant and developing issues in UK and world aquaculture of direct concern to industry, consumers, regulators and policy makers. All are pertinent to each of our research groups and encourage multi-disciplinary collaboration within the Institute, University and with external institutions. We continually review our research strategy and objectives through our Research and Knowledge Exchange Committee in response to the rapidly changing national, UK and global research funding and food security context. The Institute is also guided by advice from our Independent Advisory Committee, which meets annually. The present Advisory committee (twelve members) has representation from industry (Scottish Salmon Producers Organisation, British Trout Association, Marine Harvest, Lithgows) and academic partners (Norwegian University of Life Sciences, MASTS Directorate, Glasgow and Cranfield Universities, Moredun Institute).

National priorities: The Scottish Government recognises the importance of the Marine sector and particularly the role aquaculture plays in the Scottish economy (>£1,300m in 2012) in recent strategic plans. The SFC has given its support (£17 million) to the MASTS pooling initiative that integrates the research strengths in Scottish marine sciences from ten HEIs and Marine Science Scotland (MSS). The IoA will receive £2.4 million of matched funds over 5 years (up to 2017) to establish three new strategic positions and help grow the aquaculture sector through high quality collaborative research. The Institute has taken a leading role in the formation of the Scottish Aquaculture Innovation Centre (SAIC) that will be headquartered on the Stirling campus. SAIC will co-ordinate a programme of work to address the priority research, training and knowledge exchange needs of the Scottish aquaculture industry with a planned initial budget of over £11m over five years plus additional funds to be agreed for facilities and studentships. The Scottish government is targeting a 50% increase in finfish and 100% increase in shellfish production by 2020. The MASTS and SAIC initiatives will be central to achieving the proposed expansion and the Institute will make a substantial contribution to the research, training and knowledge exchange required to achieve these ambitious targets. Staff are also members of the Scottish Government Ministerial Working Groups on sustainable aquaculture (Richards, Turnbull, McAndrew, Bell) that will inform policy for the period up to 2020.

European: The Institute has a seat on the European Aquaculture Technology and Innovation Platform which is influential in setting the agenda for the Horizon 2020 programme. We participate in international collaborations and networks that encourage an exchange of personnel and ideas, thus widening experience and access to new methodologies. Recent successful examples include the EU AquaExcel infrastructure project, which coordinates research in the fourteen main aquaculture facilities across Europe and funds access to scientists to collaborate and undertake research in their varied facilities. Similarly, we were actively involved in the management committees of three European Cooperation in Science and Technology platforms: WELLFISH on welfare of fish in European Aquaculture (>100 scientists from 20 EU countries), LARVANET, a multidisciplinary network on the critical factors for fish larval production in European Aquaculture (35 partners from 17 EU countries) and AQUAGAMETE on the assessment and improvement of the quality of aquatic animal gametes to enhance aquatic resources (34 partners from 18 EU countries). We were also involved in several EU concerted actions including Reprofish on Improving accessibility to finfish reproduction knowledge (39 partners from 13 EU countries) and Aquagenome (21 partners from nine EU countries). Institute staff have been key partners in fifteen major FP6 and FP7 EU research projects and networks since 2008 and coordinated the EU feasibility study of triploid Atlantic salmon production project (SALMOTRIP, 2008-2011), EU Sustainable Ethical Aquaculture Trade project (SEAT, 2009-2012) and the Sustainable Aquaculture Research Networks in Sub Saharan Africa (SARNISSA, 2008-2011) with more than

1600 registered members sharing information and contacts across borders and languages. We also manage the AQUA.TNET, a European Thematic Network in aquaculture, fisheries and aquatic resources management.

International: Internationally we have many links through our large and influential network of Alumni, now over 1,250 students from 102 different countries (since the foundation of the IoA) that continues to provide new students and research opportunities. These include projects in aquaculture development in sub-Saharan Africa, namely Ghana, Malawi and Uganda. In Brazil, collaboration has been initiated with EMBRAPA in 2010, the largest agriculture research organisation in Brazil, to work on reproductive bottlenecks of new species (arapaima, colossoma and catfish species) for the diversification of aquaculture in South America. Within the University sector in Brazil, we also work with Para state University and the Federal University of Rio de Janeiro, the latter involving studying marine microbiology relevant to aquaculture. We have long standing collaborations with the government and University sector in Mexico through the Mexican Research council (CONACYT) on the development of Aquaculture (seven PhD students funded during the REF period). This includes a project with CONAPESCA and University of Morelia to develop a tilapia selective improvement programme. In the USA, we have developed new research collaborations with MOTE (Florida) and the Institute of Marine and Environmental Technology (Maryland) on Gulf of Mexico emblematic species. We also have an extensive portfolio of active collaborations in Asia, for example we have a long established agreement for co-operation in research with Zhejiang University (China), CanTho University (Vietnam), Tokyo University of Marine Science and Technology (Japan), Mymensingh (Bangladesh), College of Fisheries, Mangalore (India), Asian Institute of Technology and the Aquatic Animal Health Research Institute (Thailand), Worldfish (CGIAR), World Organisation for Animal Health (OIE) and NGOs including Fairtrade, Global Aquaculture Alliance and the North Atlantic Salmon Conservation Organisation (NASCO). Our international collaborations are best demonstrated by the fact that 40% of all our research outputs over the REF period have published with non EU International co-authors from organisations across North (mainly USA) and South America (Brazil, Mexico, Chile, Argentina), Asia (Vietnam, Bangladesh, Japan) and Australia, Norway and Iceland.

Research groups

Fish Health: The main focus of this group is to carry out fundamental research to understand the biology of pathogens and parasites, and especially to develop methods for the diagnosis and control of disease. This involves scientists and veterinarians with expertise in virology, bacteriology, parasitology, immunology, pathology, epidemiology and welfare (Adams, Bron, Green, O'Hare, Richards, Thompson, Turnbull). Recent appointments in microbiology (Desbois), molecular immunology (MacKenzie, Boltana) and virology (Weidmann), have strengthened the group and ensured succession planning. The group has grown to 11 research-active academics and seven postdoctoral researchers. Fundamental research has elucidated host-pathogen interactions, mechanisms of disease resistance and susceptibility, and enabled epidemiological network modelling. Current research involves the characterisation of immune response to pathogens using transcriptomic and gene expression studies for viral, parasitic and bacterial pathogens. Molecular based studies have helped elucidate the complete life cycle of several species of myxozoans, including the causative agent of proliferative kidney disease. Our research has contributed to national and international aquatic animal health and welfare strategies, and much of this is conducted in collaboration with competent authorities in the UK (Marine Science Scotland, Cefas), Europe (European Food Safety Authority) and further afield (OIE). Research in pathology and virology has provided important data on the complex aetiology and pathogenesis of a related group of diseases in salmon, including cardiomyopathy syndrome, salmon pancreas disease and heart and skeletal muscle inflammation. With the ongoing issues surrounding infestation of salmon with the sea louse much of the group's effort has been devoted to developing existing and new control strategies. Welfare research has informed industry-based codes of practice on the causes and avoidance of fin damage in trout. Close links with industry have ensured effective technology transfer. Many new diseases were first diagnosed and described at the Institute through our referral services and international links. The first commercial fish vaccines were developed at the IoA, and this work continues with novel methods being used to identify potential vaccine antigens. For example, application of immunoproteomics has led to the

successful development and patenting of an effective recombinant vaccine for *A. hydrophila* in tilapia and carp. The group are also the first to explore the potential of DIVA vaccination for fish to enable discrimination between vaccinated and infected animals; this is very important for the pathogens that are 'notifiable' such as Infectious Salmon Anaemia virus and Koi herpes virus. Significant progress has also been made in the development of immunodiagnostic methods and monoclonal antibodies have been developed to a large number of fish pathogens. Multidisciplinary international collaboration over many years was responsible for the original diagnosis and characterisation of a significant bacterial disease (*Edwardsiella ictaluri)* in *Pangasius* catfish and this led to the production and marketing of the first fish vaccine in Vietnam. We also play a central role in fish welfare through UK and EU projects. This includes behavioural, functional and ethical studies in the laboratory context, on farms and with the entire value chain from producer to consumer. New appointments have increased our capacity in this area with scientists working on the evolutionary biology of the innate immune response integrating behaviour, immunity and nanotechnology towards improved aquatic animal health. We are fully aligned with the 3Rs and have a number of projects developing alternative *in vitro* models, such as the use of cell culture and wax moth larvae for studying pathogenicity, but live fish work is still a key and distinctive element of our research. Current research projects utilise a range of infection and behavioural models to better understand host-pathogen interaction and are developing new veterinary medicines, immuno-modulators and other disease control methodologies.

Genetics and reproduction: This group combines reproductive physiology, endocrinology, chronobiology (Migaud, Taylor, Davie, Vera), the latest molecular genetic, genomic technologies and bioinformatics (McAndrew, Penman, Taggart, Bron and Bekaert) and molecular biology related to ecotoxicology (Leaver and Sturm) to better understand the biological mechanisms underlying major life-cycle and commercial traits in farmed fish. The group has grown to 11 research-active academics and four postdoctoral researchers. By controlling reproduction and applying genetics and genomics we decide when any individual farmed fish is bred and why. The knowledge gained is improving the reproductive and commercial performance of farmed aquatic organisms. The group is actively involved in the development and domestication of established, emerging and "new" aquaculture species by pioneering broodstock management strategies to close culture cycles to help diversify the industry. This work is funded by various national and international agencies and industry in the UK and Europe (halibut, seabass, sea bream, wrasse, sole, cod, turbot), America (snook, pompano, arapaima) and Asia (carp and tilapia). Wrasse, as cleaner species for sea lice, have attracted a lot of attention over recent years as an alternative to chemical treatments. The group is leading a large project, co-funded by Technology Strategy Board (TSB), Marine Harvest and Scottish Seafarms (£2.2m), aimed at the production of farmed wrasse for the Scottish salmon industry with a focus on broodstock management, population genetics, gender control and larviculture. In species that have already been domesticated, the research is focusing on selective breeding strategies and the development of tools to prevent inbreeding and to enhance phenotypes. In 2011, the first full genome sequence of a farmed fish, the Nile tilapia, was released based on an isogenic tilapia line developed and supplied by our group (publically available, publication pending). Previous EU projects, BBSRC and SFC investments in developing genomic technologies for farmed species have resulted in the identification of a major disease resistance Quantitative Trait Locus (QTL) in Atlantic salmon that has been implemented in the Landcatch Natural Selection breeding program in 2009 and sold to other salmon breeding companies during the REF period. The group has helped to produce a High Density (HD) Single Nucleotide Polymorphism (SNP) chip (Affimetrics) for salmon to identify other important QTL (2012-2013). We have also developed HD SNP genetic maps for a range of commercially important species including tilapia, halibut and sea bass using Next Generation Sequencing (NGS) RAD tagging technology (2011-2013). These maps have enabled us to identify SNP close to sex-determination loci and will help the development of consistent single sex lines of tilapia and halibut through the use of sex-linked markers to fast track progeny testing, and further understand the complex sex determination in sea bass. Another key research topic of the group is stock management strategies for the control of puberty, which represents a major commercial issue in fish farming as it limits productivity, impacts on fish welfare and can lead to introgression if reproductively competent fish escape and breed with wild stock. This field of research integrates all of the skills of the group. Three main strategies are investigated by the group in a species-specific manner: photoperiod regimes to suppress or delay reproduction;

induction of sterility using chromosome set manipulations and single sex production when one of the sexes performs better (grows better and/or matures later). Group publications have expanded our understanding of the photoneuroendocrine system in fish including light perception, clock entrainment and puberty. The group was amongst the first to publish on some of the genes involved in these pathways in commercially important fish (kisspeptin in tilapia published in 2008, clocks and diodinase in salmon published in 2009 and 2013). Research over the REF period has also focused on the development of sterile triploid salmon, monosex halibut stocks and improving the consistency of YY male tilapia in all-male production systems, work funded by large EU and industry projects coordinated by the group. The group is now investigating the underlying physiological mechanisms of triploidy at the cellular, molecular and genome wide levels. Chromosome set manipulation has also been used to generate novel genotypes and isogenic clonal lines that are being used with our EU partners in the AquaExcel infrastructure project to analyse complex traits such as sex-determination and immune responses.

Nutrition and feed supplies: Feed comprises 40%-60% of the production costs of farmed fish. Increasing prices and reduced availability of marine fish meals (FM) and oils (FO) have focussed development on more sustainable cost-effective alternative feeds that meet the macro and micronutrient requirements of farmed fish, whilst maximising the benefits of fish for human health. Research is focused on the major European aquaculture species e.g. Atlantic salmon, rainbow trout, carp, sea bream and bass. The group (Bell, Tocher) has made three new appointments during the REF period (Monroig, Albalat and Almaida) and also support four postdoctoral researchers. In 2006 salmon feeds contained 20%-33% fish oil (FO) and 35%-45% fish meal (FM) but our work in the EU FP6 project “Aquamax” reduced both FO and FM to ~15% each with replacement by vegetable oils (VO), principally rapeseed, while FM was replaced by plant proteins (PP) including Soya Protein Concentrate, wheat, corn glutens, and legumes. However, trials with the fish species above showed reduced growth and altered lipid deposition when substitution was high, particularly with PP, probably reflecting reduced micronutrient levels following replacement of FM with PP. The current focus is now on re-evaluation of these requirements in “alternative” feeds while reducing levels of anti-nutritional factors (ANF) present in PP. Precise definition of the essential nutrient requirements for all major aquaculture species is being investigated in two large studies, EU FP7 ARRAINA and TSB-SAP. A major achievement has been the full growth cycle culture of salmon, trout, and sea bream on feeds with maximum replacement of FO & FM using VO blends and PP. These fish are net producers of marine protein as diets containing 80% PP and reduced FO can produce 1kg of marine protein from 0.5kg of FM/PP blend. The industry now use these formulations thereby reducing ‘fish in:fish out’ ratios, while ensuring good growth and product nutritional quality. Recent findings indicate that flesh omega-3 LC-PUFA content is a heritable trait in salmon, and families with enhanced ability to retain omega-3 LC-PUFA when fed diets low in n-3 LC-PUFA have been identified. The genetic basis for the different family phenotypes is under investigation, and many key genes involved in lipid and fatty acid metabolism have been studied, particularly in salmon, to elucidate nutrient-genome interactions. For example, the molecular mechanisms that control fatty acyl desaturase and elongase gene expression, and thus regulate LC-PUFA synthesis, have been elucidated. Molecular tools were developed that have been used in studies investigating metabolically engineered oilseed crops to produce omega-3 LC-PUFA. Application of these novel GM-oil ingredients are ongoing as part of a BBSRC IPA award. Food safety remains a concern and methods for measuring contaminants including dioxins, PCBs and PBDEs in fish and feeds are available. New methods to analyse polyaromatic hydrocarbons are also being developed. Research on new aquaculture species has led to production of goldsinny and ballan wrasse for biological control of sea lice on salmon at MERL, and the Nutrition Group has worked with industrial partners to develop feeds for wrasse broodstock and larval culture. Our expertise in omega-3 PUFA has allowed the Group to develop a rapid process, in conjunction with Glasgow Health Solutions Ltd, to measure fatty acid concentrations in human blood samples using an automated fatty acid analyser capable of 400 analyses/week for a range of companies including Vifor Pharma, Efamol, Barlean’s and Professor John Stein at Oxford University.

Current Major Projects: The TSB Sustainable animal protein initiative has funded three major projects: vaccine for sealice control, domestication of cleaner fish to reduce sealice numbers in salmon cages and the feasibility of developing a UK Faba bean protein concentrate as a

replacement for imported fishmeal and soya protein. TSB Genomes is also funding the construction of a salmon SNP chip that will speed up the adoption of genome wide selection in Atlantic salmon. These TSB projects represent an investment of over £8m in the Scottish salmon farming sector. We will also develop clonal fish lines as experimental models and for International sequencing projects on salmon, tilapia, carp and sea bass (EU AquaExcel project). The BBSRC IPA project on sustainable sources of omega-3 polyunsaturated fatty acids for aquafeeds from genetically engineered oilseed crops will also address the global lack of omega-3. The EU ARRAINA "Aquaculture feeds and fish nutrition project" is paving the way to the development of efficient and tailored sustainable feeds for European farmed fish. These programmes will produce outputs with direct impact on the industry and policy makers. New collaboration has also recently started with a world leading lighting company (Philips) to perform research on the biological efficiency of light in fish and the development of new lighting technology systems for aquaculture. The SFC funding for the MASTS and SAIC initiatives will also run into 2017 and 2019 respectively.

c. People:

i. Staffing strategy and staff development

This submission includes eleven new academic appointments made during the REF period. The MASTS initiative in Scottish marine science has funded a senior lecturer in Virology (Weidmann) and a lecturer in Bioinformatics (Bekaert) with the Universitymatch funding the appointment of two lecturers in Epidemiology (Green) and Ecotoxicology (Sturm) to support this initiative. These posts attracted major starts-up funding for modernising laboratory space, new equipment, support staff and studentships (>£3.34 m up to 2017). The appointment of MacKenzie as a senior lecturer and Boltana as a University Impact Fellow strengthens our work on fish immunology and marine biotechnology. Another key strategic recruitment was made during the period with Taggart now fully employed at the end of his RCUK Fellowship in the area of fish genomics. The Genetics and Reproduction group was also awarded a University Impact Fellowship in the novel area of fish chronotoxicity (Vera). The new staff greatly enhance the Institute's strengths in the application of the latest molecular, genomic and bioinformatics techniques to the management and improvement of fish. The Institute has also received strategic funds from the University for three lectureships in nutrition (Monroig), Reproduction (Davie) and proteomics (Albalat). These appointments significantly strengthen the research groups and provide a balanced staffing profile which will aid succession planning.

The Institute takes great care to support new staff and to integrate them rapidly into our research culture so that they quickly become established and productive researchers. All new staff are allocated to an appropriate research group, and are allocated a more senior colleague mentor who is able to provide day-to-day advice in a supkportive environment. The University was one of the first to adopt the The Concordat to Support the Career Development of Researchers in 2008 and was awarded the EU HR Excellence in Research Badge in 2011 for compliance with the principles of the Concordat. The University has recently had the badge renewed and was awarded the Athena Swan Bronze award for its support of women in science in 2013.

All academic staff are supported in their personal and professional development through the University *Achieving Success* appraisal programme. Objectives are set and training and development actions to support their achievement agreed. Progress and outcomes are monitored at regular follow up meetings. Staff are also encouraged and funded to attend workshops and meetings relevant to research funding and external collaboration. New staff are given start up costs (£5-£10k in the first year) and if eligible, allocated research students. They will also be given funds to attend relevant scientific conferences and are also expected to participate in University and external training courses and workshops on research-related topics, including, for example, grant applications, financial management and team leading skills.

ii. Research students

We have always regarded research students as a major element of our research strategy and have sought funding from a wide variety of sources. The number of overseas students we attract is an excellent demonstration of our research and teaching strengths (69 MSc and 85 PhD from non-EU

countries present during the REF period). Many of these students are directed towards the Institute as a result of our large (>1250) and ever more influential Alumni who are encouraging their own staff, students and progeny to study at the Institute. We have also seen an increase in numbers of CASE and Industrial CASE studentships awarded. During the period, we have had thirty 50% funded Institute, University, Knowledge Transfer Network and MASTS studentships that have enabled us to attract matched funding from a wide range of industrial, regulatory and Non Governmental Organisations. This has the advantage that we can increase the overall numbers of research postgraduates and also improve the student experience through seeing how their research matches with their sponsors needs. The MASTS initiative will provided 50% match funded studentships in the future and it is an important part of the remit of the new innovation centre (SAIC) that it will also invest in postgraduate training linked to the Scottish aquaculture industry from 2014. We will also seek to build on past successes by obtaining funding from governmental and intergovernmental organisations such as the Association of Commonwealth Universities and with the new training agreements with three Chinese Universities (Qingdao Ocean, Guangdong Ocean and Zhejiang Ocean Universities).

The Institute now has a centralised web-based reporting system, which requires that all students are assessed annually during their period of study. Both students and their principal and additional supervisors contribute to the process before assessment by the Post Graduate Research Committee who will interview students at least twice during their period of study. Final assessment is by the University Admissions, Progress and Awards Committee. Critically, student progress at the end of the first year is assessed to confirm their registration at PhD level. This ensures that we maintain our high submission and award rate. The Institute adheres to UK Research Council Codes of Practice on research and compliance is audited both internally and externally.

All postgraduate students take part in Induction Courses run by the Stirling Graduate School on the facilities and support services provided by the University for postgraduates. The Graduate School also organises a series of seminars and workshops throughout the year on a range of generic and research skills. The Institute runs its own seminars and workshops on a range of specific skills required (use of laboratory equipment, safety and regulations, statistics, experimental design and presentation skills). In addition, where appropriate, postgraduates must attend courses on the uses of radioisotopes and instrumentation, Home Office and Animal Licence Regulations, and other transferable skills. MASTS funded students also attend the MASTS Graduate School Annual Science meeting, retreats and special courses. The Institute Seminar programme offers research seminars including lectures by invited speakers, Institute staff and postgraduate students. We organise a conference where all postgraduate students produce posters and give an oral presentation of their research and its impact in their third year. The meeting is open and attracted 250 registered participants from within the University and a wide range of industrial and government scientists in 2012. This gives our students experience to present their work under a time restraint in front of a large well informed audience. All our students join the very cosmopolitan Aquaculture Students Association (38 nationalities in 2012) which is particularly active in organising social events, supporting students and providing a forum for scientific discussion and dissemination of information mostly through our facebook pages. Our PG students are also represented on a number of School and Institute committees.

Many of our PG students undertake their research on live fish based in the most appropriate fish holding or disease challenge facilities and species. The IoA hold a range of commercially important warm and temperate water species in both fresh and saltwater environments in scientifically controlled and/or commercially relevant conditions. We also maintain a number of model fish species as well as unique clonal and single sex lines and native marine and freshwater species. Our fish rearing facilities provide a fantastic research and teaching tool for our students.
The large cadre of younger scientists, research students and research fellows brings an enthusiastic and positive research driver to the Institute through seminars, open discussion and workshops organised within the Institute. The Institute has employed over 44 different research assistants and post doctoral research fellows from ten different countries across the various research groups over the period, making a significant international contribution to the training of young scientists in the field of aquatic science.

d. Income, infrastructure and facilities

Income

The total research contract spend over the period (>£7.3m) has continued to increase from many different funding sources. Research income has steadily increased by >150% from the start (£1.3m in 08-09) to the end of the REF period (£2.14m in 12-13). This shows the strength and sustainability of the Institute in its ability to obtain funds for strategic research related to increasing the efficiency and sustainability of aquaculture. This was achieved in part through increased funding from the Research Councils and UK government funding (from 40 to 47%), UK industry (from 5 to 16%) and non EU industry, commerce and public corporations (from 0.2 to 9%) over the REF period. The EU remains a major funder (28-44% over the period) and for a majority of these projects the Institute grant holder acts as the overall Co-ordinator. During the period we were awarded £150K under the EU Infrastructure Programme Aquaexcel (2011-2015) to allow European Scientists to undertake their research in our laboratories and extensive fish holding facilities at no cost to them. The TSB projects awarded in 2012 (£3.435m out of total project costs of £7.68m) show the confidence the industry have in our ability to deliver excellent applied science. The Scottish Government now recognises the importance of aquaculture to the national economy and has provided new funds in 2011 (£0.9m) through a variety of initiatives (e.g. Scottish Partnership for Animal Science Excellence). The SFC MASTS pooling initiative made a significant investment in aquaculture (£2.6m) and has enabled much greater collaboration between Scottish universities through the Sustainable Aquaculture forum. Staff have also been awarded new grants during the period from BBSRC (£350k), Scottish Aquaculture Research Forum (£170k), DEFRA (£692k), Food Standards Agency, CEFAS and Royal Society (£180k), and the farming industry (£650k).

The Institute received substantial income, in excess of £400k over the period from an annual turnover of £1.3m, from the supply of industrial services and contract research. Services include disease diagnosis, water quality analysis and environmental impact studies, Nutritional Analytical Service and recently the rapid analysis of Ω3 and Ω6 lipid levels in human whole blood. Our consultancy service (Stirling Aquaculture) utilises the varied research expertise of Institute staff on a range of international development projects throughout the world in particular fish farm developments in Ghana and Uganda during the period. We supply genetically improved red YY male tilapia and broodstock worldwide. The off-campus research facilities are Good Laboratory Practice accredited enabling us to undertake contract work for many leading pharmaceutical (Pfizer, Novartis) and feed (EWOS, BioMar, Skretting) companies. We have a five year contract with Marine Harvest, the largest fish farming company in the world, to develop and run a wrasse hatchery and fingerling production unit to supply cleaner fish to the salmon industry in Scotland (£1.5m). These facilities are essential to demonstrate, to the industry and other contractors, credibility as far as commercial-scale aquaculture studies are concerned. Howietoun, our brown trout hatchery and ongrowing farm provides fish for restocking throughout the UK, and our salmon hatchery together with three smolt production sites that supply grow-out farms have a turnover of £600-900k p.a. The Industrial Services provide valuable income to the Institute, however their principal function is to promote continuing contact and opportunities for collaborative research with industry. The additional income generated by these activities enables us to maintain and upgrade our fish facilities (on campus and external), fund higher technical staffing levels and helps to subsidise the maintenance and replacement of analytical equipment.

Infrastructure and facilities

Our research and commercial facilities, unique in the UK, are an asset that we continually seek to improve to match changing research and commercial requirements. Fish holding and research facilities include dedicated tropical experimental fish holding and laboratory facilities and separate temperate and tropical disease challenge facilities on campus. All have seen significant upgrades during the period to enhance our research capacity, the latest is a dedicated aquatic chronobiology aquarium to understand the effect of light and temperature on fish behaviour and physiology (£140K) (partly sponsored by Philips Lighting). We also maintain off-campus commercial scale research facilities for temperate freshwater fish research at the Niall Bromage Freshwater Research Facility (trout and salmon). We operate a commercial fish farm producing brown trout for restocking and salmon smolts to the Scottish salmon farming industry at Howietoun and a freshwater cage smolt

ongrowing site at Dunblane reservoir. These facilities offer realistic training and research opportunities for our students. At Machrihanish, Kintyre, we have our Marine Environment Laboratory with a recently rehoused experimental tank setup (£373K) for nutrition trials and disease challenges. We also maintain a sea lice production unit to supply both drug susceptible and drug resistant sea lice, critical to our research work on reducing the impact of this parasite. Adjacent to this site we maintain a large-scale temperate marine production system and hatchery, presently dedicated to the development of wrasse as cleaner fish for the salmon industry. All of our facilities have associated office, laboratory and accommodation for visiting staff and postgraduate students. The Institute also has close contacts with most aquaculture companies in the UK and overseas whose facilities are also made available for large scale field trials (Ardtoe Marine Laboratories, Marine Harvest Field trial unit). We have well-equipped laboratories dedicated to fish health (vaccine development, virology, microbiology, parasitology, pathology, immunology) and environmental monitoring (ecotoxicology, water chemistry). SRIF investment has enabled us to develop new genetics, genomic, proteomic and nutritional research laboratories. Since 2008 MASTS has funded major equipment upgrades including re-equipping the virology laboratory (£80k), new large memory computing capacity for bioinformatics (£50K), Illumina Myseq NGS technology (£100K) and technical support. It has also funded additional computing for a Geographical Information Systems (GIS) laboratory. The Nutrition laboratories have upgraded their GC/MS systems and purchased automated equipment for rapid contaminant analysis, there have also been upgrades to our electron microscopes (TEM & SEM) and the purchase of a laser capture dissection microscope. Investments in facilities made during the REF period ensure that we remain a global leader in aquaculture research.

e. Collaboration and contribution to the discipline or research base

The Institute has research collaborations with a number of HEIs and other institutions both in the UK and overseas. Within the UK a major and productive collaboration exists with the University of Aberdeen in the SFC-funded Scottish Fish Immunology Centre and strong links exist with the Universities of Glasgow and Bristol in the field of fish welfare, with University of Liverpool in epidemiology, University of St Andrews in fish genomics and with Imperial College, London in aquaculture development. Collaborations also exist with the Roslin Institute in quantitative genetics, QTL analysis and functional genomics. These links are evidenced by many joint publications. The Institute has formal agreements with strategically important partners including the Royal Dick Veterinary School, to develop joint research in microbial pathogenesis and the Moredun Research Institute in relation to vaccine and diagnostic developments. We have also signed a Strategic Alliance Agreement with The Centre for Environment, Fisheries and Aquaculture Science (Cefas) to develop collaborative research in areas of common interest. We have very strong research associations with a number of European HEIs, often fostered through collaborative EU projects and networks. Our extensive involvement beyond Europe has also led to many research links with HEIs and research organisations in, *inter alia*, Mexico, Pakistan, India, Bangladesh, Thailand, Vietnam, China, Japan, USA and Brazil. In addition there are strong links with Worldfish (CGAIR) and FAO Rome which have led to our research in this area having a significant effect on the aquaculture policy of these organisations. Senior staff also participate in or advise many important national and international committees or groups e.g. Richards (EATiP, SSPO veterinary advisor, Scottish Ministerial Group on Sustainable Aquaculture, EU DG Mare and DG Research, BBSRC Animal Health Research Club) and McAndrew (MASTS executive committee and Forum leader for Sustainable aquaculture, Knowledge Transfer Network Animal Sciences Group) and act as editors for peer reviewed journals; Tocher (Aquaculture and Fish Physiology and Biochemistry) Bell (Aquaculture Nutrition and British Journal of Nutrition), Bron (Journal of Aquatic Animal Health), Ross (Aquaculture Research) and Richards (Editorial Board of Veterinary Record and World Agriculture). Institute staff have been elected to lead on MASTS research themes (Turnbull) and research fora (McAndrew) to enhance collaboration and identify research priorities and funding opportunities.