



UNIVERSITY OF
STIRLING

Annual Report
2000 - 2001

The Institute of Aquaculture

University of Stirling



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Highlights

- SHEFC Science Research Infrastructure funding to the value of £299K has been awarded for new analytical equipment and laboratory refurbishment.
- The Institute is a partner with the University of Aberdeen in a SHEFC Research Development Grant award to establish a Scottish Marine Immunology Centre.
- A Joint Equipment Research Initiative grant was awarded for the purchase of a “real-time” PCR machine.
- Aquatic Vaccine Unit staff have won a SMART award to establish a new company to develop and market diagnostic reagents.
- The Institute has been awarded the management contract for the next phase of the DFID Aquaculture and Fish Genetics Research Programme with funding until 2005.
- MSc taught course numbers were lower than anticipated, although research postgraduate and undergraduate numbers were maintained.
- Research on vaccine and chemotherapeutant development remains a major activity of the Disease Group, with substantial industrial funding.
- Virology research continues to expand with major new EU and UK funding for work on nodavirus and infectious salmon anaemia.
- A number of research programmes are now in place concerned with the selective breeding of important aquaculture species including, salmon, rainbow trout, bass, halibut and Asian carps.
- New programmes are being developed on candidate aquaculture species, particularly with maturation and nutrition of cod and halibut.
- Important advances have been made in the factors characterising PUFA metabolism in fish, particularly by the application of molecular techniques.
- A major EU-funded programme on the substitution of fish oils in aquaculture diets is now in operation building on previous work in this field.
- This has been the most successful year so far in terms of turnover and contracts completed for the Environmental Services consultancy.
- New EU-funding has been obtained to support ecotoxicological research including detoxification systems in fish and the development of assessment systems for aquatic environments.
- A whole range of projects is now in progress on aquaculture production systems in developing countries involving numerous collaborations with UK and overseas institutions.
- Howietoun has had a successful year with the production of salmon smolts but brown trout sales have been affected by the foot and mouth outbreak.
- Agreement has been reached on the development of a commercial marine fish hatchery at Machrihanish between the University and industry partners.
- Stirling Aquaculture has continued with management support for a number of commercial marine farms.
- The Institute hosted a major Scottish-Norwegian conference on “Sustainable Futures for Marine Aquaculture”.

Introduction

The Institute has continued to make excellent academic progress in 2000-2001, with a number of significant new initiatives coming to fruition.

We have always been proud of our international role in aquaculture development and it is thus particularly satisfying to report that the Institute was successful in its bid to manage the next phase of the DFID Aquaculture Research Programme, together with the former Fish Genetics Programme, in a new Aquaculture and Fish Genetics Programme managed by Professor James Muir. This will help ensure that we stay at the forefront of international aquaculture development. The Institute has many links with the European aquaculture industry and it was a great pleasure to host the Scottish-Norwegian conference on “Sustainable Futures for Marine Aquaculture”. This was especially appropriate since this year has seen the final approval for a marine fish hatchery at Machrihanish which will be a fully commercial joint venture between the University and Lakeland Smolts Ltd, a subsidiary of Marine Farms of Bergen. We anticipate significant financial and research benefits from this activity.

Commercial research is an increasingly important part of the Institute's activity and it is very pleasing to report that Dr Sandra Adams and colleagues received a SMART award to establish a new company, Aquaculture Diagnostics Ltd to market diagnostic reagents developed in the Institute.

The financial position in the Institute remains difficult and much will depend on the results of the current RAE exercise. However, we continue to find new ways to improve the scientific infrastructure and this year we are pleased to have received substantial funding through the SHEFC Science and Research Infrastructure Fund which will allow upgrading of much of our analytical equipment together with limited laboratory refurbishment. This award will be of particular value to the Environment and Nutrition Groups. A “real-time” PCR machine was purchased with support from the Joint Equipment Research Initiative and this has already proved extremely valuable as detailed elsewhere in this report.

Collaborations are an increasing feature of scientific research and we were delighted to partner the University of Aberdeen in a successful Research Development Grant bid to SHEFC to establish a centre for marine fish immunology. This will provide access to excellent new facilities in Aberdeen and also provide significant new equipment at Stirling.

Research grant income is a vital part of our finances and depends very much on the motivation and enthusiasm of staff to continue to make increasingly detailed applications to funding bodies in the full knowledge that the majority will not be successful. Inevitably income will fluctuate to some degree as the priorities of funding bodies change but staff manage to maintain a steady flow of new grants and this year we have obtained significant new Research Council and EU funding.

The Institute is also increasingly being utilised as a key source of scientific advice reflecting its international status and informing policy decisions in aquaculture which will significantly affect the future direction of our research. This underlines our national and international significance as a major centre in aquaculture research and development.

I am pleased to report further promotions for Institute staff. Stephen George was awarded a Chair in Aquatic Toxicology and Donald Baird was awarded a Senior Lectureship. During the year we were sorry to lose the services of Malcolm Beveridge who has moved to a prestigious post as officer-in-charge of the Scottish Executive Freshwater Fisheries Laboratory at Pitlochry. I should like to thank Malcolm for his enormous contribution to the Institute over the years and we look forward to close relationships with the Pitlochry laboratory.

R H Richards

Teaching

Postgraduate

Both the MSc Aquaculture and MSc Aquatic Veterinary Studies/Aquatic Pathobiology courses were run in 2000-2001. Student numbers were relatively low with 16 participants in the MSc Aquaculture course and 9 in the MSc Aquatic Veterinary Studies/Aquatic Pathobiology course. Only 6 students were from non-EU countries.

The students on the disease courses were generally of a very high calibre and three distinctions were awarded, to Leo Foyle, Lauke Labrie and Charles McGurk. The Sir William Wiepers Memorial Prize was awarded to Lauke Labrie and the Royal Highland and Agricultural Society of Scotland silver medal to Charles McGurk, who also held the exhibition awarded by the Fishmongers Company.

From the MSc Aquaculture course the Royal Highland and Agricultural Society of Scotland silver medal was awarded to Helene Roussel and the External Examiner's prize to Stephanie Chew.

Following enormous efforts by course staff there will be 25 students on the MSc Aquaculture course next year, although non-EU students will still be relatively few in number. It seems doubtful that this group of students will increase to any significant extent in the foreseeable future. Following the departure of Dr Malcolm Beveridge the role of course director for the MSc Aquaculture course has been taken up by Dr Trevor Telfer.

Twenty one new research postgraduates joined the Institute last year. This is a gratifyingly high number, although the number of non-EU students remains low. Eleven PhD students graduated in 2000-2001.

The Institute was awarded 2 NERC CASE studentships in 2000-2001. Charles McGurk will study with Dr Sandra Adams and Dave Morris funded by a CASE award with Aquatic Vaccines Ltd and Philip Williams will be supervised by Dr Donald Baird with CASE funding from the National Water Research Institute and the National Hydrology Research Centre, Canada.

Undergraduate

In the 2000-2001 Aquaculture honours year there was a total of 11 students. Four of these students obtained upper second class honours degrees and the remainder 2(ii)s. The semester 8 projects undertaken by these students covered a very wide range in terms of both geographical location and project content. Projects included; tilapia fry transport (Thailand); anti-fouling coatings for oysters (Australia); diets for green-lipped mussels (New Zealand); diets for rock lobster larvae (New Zealand); sand scallop clearance rates (Bermuda); farmer managed aquaculture (India); digestion in *Chirostoma* sp. (pez blanco) (Mexico); aquaculture curriculum design for a public aquarium (USA) and tilapia genetics, scallop farming and aquaculture enhanced fisheries (all completed at the Institute of Aquaculture). Feedback from the project supervisors, the external examiner and the students themselves was exceptionally positive. During this year the semester 3, 5 and 7 undergraduate units offered by the Institute were also in operation. Numbers were fairly well maintained and the courses well received by students. This was particularly true of the new half unit semester courses which were offered for the first time.

Other

The annual fish disease course was held again in January with an increased number of participants. Given that this course has run for over 25 years this is an indication of its relevance and value to the UK and Irish aquaculture industry. SCOTPIL courses for Home office personal licensees were run and a number of visiting groups of students from UK and European higher education establishments visited the Institute and Howietoun.

Disease Group

Parasitology

Sea lice research continues to be a major activity within the Parasitology Group.

During 2000-2001 the LINK funded sea lice vaccine project continued and two large cohorts of fish were vaccinated and their responses tested. Dr James Bron has continued his BBSRC funded project concerning the triggers for moulting and metamorphosis in copepodid larvae of the salmon louse in collaboration with Professor Christina Sommerville and Professor Alan Teale of the IOA and Professor Huw Rees of the School of Life Sciences, University of Liverpool. Work on this project is currently focusing on the use of subtracted cDNA libraries, which are being used to examine differential gene expression during settlement and metamorphosis of the parasite. Work is also proceeding to isolate native genes using degenerate primers to critical genes recognised to be important in the moulting and metamorphosis of other arthropod species.

The LINK project, carried out by Ricky Butler, to develop an *in vitro* culture method for sea lice is now complete and has succeeded in producing an artificial salmon skin equivalent which has attracted further, industrial funding. A post-doctoral research fellow, Dr Helen Hayes, and a new PhD Research student, Lynne Mallon, are currently furthering this work.

Lice research is also being continued by Dr Denni Schnapp, who joined the Parasitology Group in June, employed by BioMarine to look at potential biocontrol methods for sea lice. Dr Shinn was awarded £2K from the Faculty of Natural Sciences to continue his work on the use of inductively coupled plasma mass spectrometry to profile the elemental composition of sea lice populations. A significant new finding in our sea lice research programme was the discovery of a hyperparasitic microsporidian parasite in Scottish *Lepeophtheirus salmonis* by Mark Freeman. Mark presented his work at the Annual Meeting of the Society for Invertebrate Pathology in Amsterdam in August and won the first prize for the best student presentation. Phoebe Carter was another prize winner with her poster on "The Impact of Cadmium on *Dactylogyrus extensus*" at the Fourth International Symposium on Monogenea, at the University of Queensland.

Industrial funding from five salmonid fisheries organisations as well as the Environment Agency is behind a new research project to investigate the *Argulus* problem currently causing considerable economic loss amongst this rapidly growing and important leisure industry. Nick Taylor has so far investigated nearly a hundred sites to collect data which will be subjected to a risk assessment analysis during the 2nd year of the project.

Professor Sommerville was awarded funding from DEFRA to work with Dr Andy Shinn and Dr Jim Kay of the Department of Mathematics, Glasgow University on the development of a semi-automated system of recognition for *Gyrodactylus salaris* based on statistical classifiers. Earlier work by the team had demonstrated the greater efficiency of statistical classification over current molecular methods in discriminating this species from other salmonid gyrodactylids. This project, which is in collaboration with Drs Steve Feist and Matt Longshaw at CEFAS, Weymouth has reached an exciting phase where a rapid method of preparation of specimens has been developed which allows for semi-automatic whole shape analysis, which will yield data for the statistical classifiers.

Dr Brons' interest in image processing and analysis continues, in collaboration with Dr Shinn, with the development of improved

techniques for the 3D visualisation of sensilla distribution and techniques for the semi-automated capture of data reflecting sclerite morphology in *Gyrodactylus* species. A separate image analysis project has been carried out as part of a LINK / SQS-funded project on fish welfare in collaboration with PhD student Aly Bell and Dr Jimmy Turnbull of IOA and Professor Felicity Huntingford and Dr Colin Adams of the University of Glasgow. This has resulted in the development of novel methods for analysing the distribution of farmed Atlantic salmon within cages using sonar imaging.

The LINK project on alternative chemotherapeutants against 'white spot', *Ichthyophthirius multifiliis*, came to an end in 2001. This project in association with the British Trout Association, Vericore, Scottish Quality Salmon and DEFRA, identified three promising compounds for future use against this serious problem in freshwater salmonid production. Professor Sommerville's interest in exploring the further usefulness of emamectin benzoate took her and Janet Stone to Greece and Turkey funded by Schering Plough and Stirling Aquaculture to trial the drug against serious parasite pathogens of sea bass. Janet has completed a series of trials to develop the drug for Schering Plough, now marketed as Slice, an extremely efficacious and safe treatment for sea lice. Technical monographs are currently in preparation.

A long term programme of research studying the myxosporean, *Sphaerospora truttae* was continued in 2000 by Astrid Holzer. Astrid is supported by the Austrian Academy of Sciences and has taken a molecular approach to the study of the transmission and early infection stages of this parasite. This has yielded exciting new information already and holds considerable promise for the next year of research.

Over the last year, Parasitology has hosted five international scientists under the EU Large Scale Facility Programme. In December, Professor Tor Bakke and Miss Benedicte Nilsen from the Zoological Museum, University of Oslo undertook a comparative study of the surface sensilla system of a number of *Gyrodactylus* species infecting salmonids, including the notifiable pathogen in the UK and Norway, *G. salaris*. Previous work by Dr Shinn, using the method of chaetotaxy, determined species specific sensilla patterns for a range of species. Professor Bakke and researchers in the Parasitology Group collaborated to investigate the inter- and intra-specific stability of these patterns between populations of *Gyrodactylus* in Scotland and Norway as a reliable taxonomic tool for the discrimination of species.

Later in March 2001, Dr Tomas Scholz and Mr Roman Kuchta from the Institute of Parasitology, Ceske Budejovice, Czech Republic made a visit to Parasitology to investigate the diversity and biology of tapeworms of the genus *Eubothrium* resident in freshwater and marine salmonids in Scotland. Then in May, Dr Iva Kralova from the Institute of Parasitology, Slovak Academy of Sciences, Kosice, Slovak Republic joined the Parasitology Group to build on Dr Scholz's research using methods of DNA analysis to investigate the taxonomy and intraspecific variability of *Eubothrium* species. This collaborative venture with Drs Scholz and Kralova continues to build on the ongoing cestode work within the Parasitology Group.

Parasitology has produced four successful PhD students this year with Bryony Banks, Stuart Bell, Ricky Butler and Polly Douglas all submitting high quality theses.

Vaccines and Immunology

The Aquatic Vaccine Unit focuses on two main areas of disease control- the development of rapid methods for the detection of fish pathogens, and the development of fish vaccines. Currently research grants are held for studies on proliferative kidney disease (PKD), pasteurellosis, bacterial kidney disease (BKD), rainbow trout fry syndrome (RTFS) and infectious salmon anaemia (ISA). PhD students in the laboratory also perform research on these and other diseases. The new aquarium

space provided by the Aquatic Research Facility is now making a major contribution to research in this area.

Proliferative kidney disease (PKD) remains an important field of research within the Vaccine Unit. This disease, caused by an unusual myxozoan parasite, continues to pose a severe restriction on rainbow trout farming in the UK. Immunological studies and the identification of chemotherapeutants for this disease are being addressed by a number of projects within the unit. Having just completed a one-year DEFRA funded project on the immune response of rainbow trout during the disease Dr David Morris and Dr Sandra Adams are continuing in this area of research. A new 3-year project funded by DEFRA, involving collaboration with Professor Secombes at Aberdeen University and the Moredun Research Institute, will provide important data by examining the antigens of the parasite as it develops in the fish host. Ultimately it is hoped that by elucidating the nature of immunologically important antigens it will be possible to develop a vaccine for PKD. Charlie McGurk has now started a NERC CASE funded PhD studentship, further examining aspects of vaccine development for this disease.

A further extension to a LINK Aquaculture project in conjunction with Aquaculture Vaccines Limited and Alpharma Animal Health is also being co-ordinated by Dr Adams. The project is examining in detail a promising chemotherapeutant for the control of the disease following on from work conducted by Dr David Morris on a previous LINK Aquaculture project. The scientist working on this project is Charlie Morris who has previous experience of PKD after completing his doctoral studies on this disease at Stirling.

Most of the other research in the Aquatic Vaccine Unit involves bacterial pathogens (*Renibacterium salmoninarum*, *Photobacterium damsela* subs. *piscicida*, *Flavobacterium psychrophilum*, *Mycobacterium* spp. and *Aeromonas hydrophila*). The project on pasteurellosis vaccine development, funded by the EU AIR programme, awarded to Dr Adams and Professor Richards, is now in its fourth year. Partners in Greece (Dr Vassilis Bakopolous, a former PhD student now at the University of Patras) and Italy (Drs Marco Galeotti and Donatella Volpatti, University of Udine) and industrial partners (AVL and Selonda Aquaculture, Greece) form the consortium. Dr Marianne Pearson, the post-doctoral scientist on the project has purified and characterised capsular carbohydrate antigens from the bacterium, and prepared polyclonal antibodies to investigate the role of the capsule in infection. Dr Pearson manages clinical trials testing new antimicrobial agents for use in aquaculture. Trials are conducted to GCP and GLP standard where requested by clients and data from these trials are used for the regulatory approval of new on-farm therapeutants. Mr Niall Auchinachie provides technical support for this work. Clinical trials also include the examination of alternatives to antibiotic therapy such as the use of lytic bacteriophage to control bacterial septicaemias. Mrs Liz Haughey provides technical support for this project.

The project on bacterial kidney disease (BKD), funded by LINK Aquaculture and co-ordinated by Dr Adams and Professor Richards has now been completed. However, AVL have given funds for a three month extension to complete crucial field trials. This research is in collaboration with the University of Plymouth and industry (BTA, SQS, AVL). Dr Kim Thompson, post-doctoral scientist on the project at Stirling, is testing the efficacy of recombinant antigens provided by Dr Keirnan at Plymouth. It is intended that sequences encoding protective antigens then be used to develop a vaccine. One of the recombinant proteins has yielded promising results and is presently being field tested. Ms Emine Turgut, a PhD student from Turkey, is working in close collaboration with Dr Thompson to investigate the expression of novel antigens from *R. salmoninarum* cultured in cell lines and *in vivo*. A standardised challenge method has been set up and both antibody-based techniques and DNA detection methods have been developed to detect *R. salmoninarum*.

Dr Thompson and Dr Margaret Crumlish are currently co-ordinating a DFID funded project to develop strategies to improve diagnosis and control of bacterial disease in small-scale freshwater aquaculture in South East Asia. Partners involved in the work include Dr Chinabut and Dr Somsiri from the Aquatic Animal Health Research Institute in Bangkok, Thailand and Ms Dung from CanTho University, Vietnam. David Miles has now completed his PhD examining the immune response of a variety of fish species to *Aphanomyces invadans*, the causative agent of epizootic ulcerative syndrome. Dr David Morris in collaboration with Dr James Turnbull and Dr Flavio Corsin (Liverpool) are presently completing a project, also funded by DFID, validating molecular detection methods for WSSV in shrimp.

A project is also under way in the Aquatic Vaccine Unit on rainbow trout fry syndrome (RTFS) vaccine development, awarded to Professor Richards and funded by LINK Aquaculture, with post-doctoral scientist Dr Ruth Campbell. The BTA and Alpharma Animal Health are industrial partners, and Dr Adams and Dr Thompson are assisting in co-ordinating the project as both have students working on related topics. Mr Ioannis Vatsos (who is now with Selonda) developed PCR methods to detect *F. psychrophilum* in the environment and Mr Manuel Fuentes is developing monoclonal antibodies. The LINK project was recently given a six-month extension so that vaccine trials could be completed for a series of promising vaccine candidates.

A one-year project, co-ordinated by Professor Richards with collaboration from Dr Sandra Adams, Dr Bill Starkey (Virology), Dr David Morris and Mrs Karen Snedden funded by DEFRA on the standardisation of methods to detect ISAV has now been completed. This work will continue with a new three year EC funded ISAV project, on validation of diagnostic methods, with collaborators in Norway, Denmark and the Marine Laboratory at Aberdeen. Dr Thompson and Dr Starkey will both work on the project at Stirling.

A new SHEFC research and development grant was also recently awarded to set up the Scottish Fish Immunology Centre at Aberdeen University with Stirling and the Scottish Executive Marine Laboratory as partners. Dr Sandra Adams and Professor Alan Teale at Stirling and Professor Chris Secombes, Dr Bill Melville from Aberdeen University and Tony Ellis from the Marine Laboratory are all involved. This will provide new equipment, technical support and training for a variety of immunology projects.

DNA-based diagnostic tests have now been developed in the Aquatic Vaccine Unit for a number of fish pathogens, including *F. psychrophilum*, *Mycobacterium* sp., *Piscirickettsia salmonis*, *R. salmoninarum*, *Tetracapsula bryosalmonae*, ISAV and IPNV. These PCR tests are being used in parallel with the established antibody-based tests to detect pathogens in fish and the environment. *In situ* hybridisation methods have also been established for the detection of pathogen DNA in fixed tissue sections. Monoclonal antibodies have been developed for the detection of a variety of fish pathogens and fish immunoglobulins and recently Dr Adams was awarded a SMART grant to commercialise these reagents through a new spin-out company (Aquatic Diagnostics Ltd) to be based in the Institute. Dr Thompson has been seconded out on a part-time basis as Technical Director, while Mrs Snedden will be fully seconded to the company as the project scientist.

Visiting scientists to the Aquatic Vaccine Unit this year include two scientists funded through the EU Large Scale Facility Programme. Ms Valentina Zapulli from Padova, Italy had a short stay working on *Photobacterium* spp., while Mr Allesio Bonaldo from Bologna, Italy spent 3 months working on the effects of chromium on the fish immune system.

Crustacean Disease

Two of Dr Turnbull's projects have been successfully completed in the last year. The first, funded by DFID, was an epidemiological study of white spot disease of farmed shrimp and was conducted in collaboration with the University of Liverpool and research centres in India and Vietnam. It has produced a wealth of data and a range of tools for the study of aquatic diseases. The second, funded through the LINK Aquaculture scheme by NERC and SQS, examined the effects of stocking density and feed deprivation on the welfare of farmed Atlantic salmon. This project was conducted in collaboration with the University of Glasgow and colleagues from Stirling. It has produced novel techniques and methods of analyses for the behaviour and welfare of farmed fish. The results have been presented to the sponsors and are being prepared for publication. Dr Turnbull has also been collaborating with other members of staff in the University of Stirling and elsewhere to use population based sampling and analytical techniques to develop aquatic animal health strategies and to improve the sustainability of livelihoods of poor families reliant on aquatic resources. He has already secured further funding to continue these areas of research.

Diagnostics

An interesting consultancy was made by Professor Ferguson on behalf of OKIOC (Offshore Kazakhstan International Oil Company) which required a trip to Almati (Kazakhstan's capital) in December 2000 to investigate reports emanating from workers in the University there, that oil-related pollution was responsible for the depletion in the Caspian Sea's beluga population, and hence of caviar production. Other interesting cases included nodavirus disease and isolation from a range of marine flatfish species important to the broadening aquacultural base in Scotland, and a still unclassified *Bacillus* sp. associated with a new disease in farmed *Pangasius* catfish in Vietnam. Several GLP pathology studies were conducted, and along with vaccine companies and local veterinary practices, there was an extensive and still ongoing co-operative programme of research into the effectiveness of IPN vaccines.

Virology

Nodavirus research has continued to represent the main research activity of the Virology Group. This work is funded by the European Union, and is performed in collaboration with researchers at IFREMER, Montpellier, and AFSSA, Brest. Research at Stirling is aimed at the development of molecular diagnostic procedures, and analysis of the genetic variation of circulating strains of fish nodaviruses.

Dr Bill Starkey has recently developed a nucleic acid sequence based amplification (NASBA) procedure for the detection of nodaviruses in clinical samples. NASBA is an isothermal nucleic acid amplification procedure that amplifies RNA directly, and thus is particularly suited to the detection of RNA virus targets such as nodavirus and infectious salmon anaemia virus. Detection of amplification products is achieved through the use of an electro-chemiluminescent detection system and a target specific nucleic acid probe. The system exhibits a wide dynamic range and a high degree of specificity. In preliminary experiments, the NASBA procedure has been successfully used to detect nodaviruses in clinical samples from several fish species including sea bass, grouper, Atlantic cod, Dover sole and striped jack. This system has been adapted to run in "real time" using fluorescently labelled molecular-beacons for detection, has proved to be highly sensitive, and is capable of producing results in four hours, as compared with virus isolation in cell culture, which may require up to two weeks.

The design of nucleic acid probes and primers for nodavirus molecular diagnostics, and the development of nodavirus vaccines, is dependent on knowledge of the nucleotide sequence and antigenic variation exhibited by fish nodaviruses. The nucleotide sequence of

the coat protein gene of more than fifty nodaviruses isolated in the period 1996-2000 from Europe, Asia and Japan have been determined and we have also identified nodavirus infection in the United Kingdom for the first time. Nucleotide sequence and phylogenetic analysis of nodaviruses isolated from UK farmed halibut, cod, and Dover sole indicate that these viruses are closely related and form a single serotype. These findings are of considerable importance for the development of aquaculture systems for novel fish species in the UK. In 2001, work aimed at the characterization of nodavirus antigenic diversity has commenced. Janina Garcia e Costa has joined the group as a PhD student with the objective of identifying regions of the nodavirus capsid which are recognised during protective immune responses. This work will involve the production of a panel of monoclonal antibodies against fish nodaviruses, and is a collaborative venture with the Aquatic Vaccine Unit. The results of this study will facilitate the rational design of nodavirus vaccines.

Studies aimed at the development of nodavirus vaccines have continued during the past year. This work is funded by Aquahealth Vaccines, and forms part of a collaborative project with Dr Nuno dos Santos of the University of Porto and scientists from the University of New Brunswick, Canada. Whole virus and recombinant protein-based vaccine preparations are currently in production. An assessment of the protective efficacy of these vaccines, and analysis of immune responses in immunised fish is ongoing.

Research aimed at the development of real time diagnostic procedures for infectious salmon anaemia virus (ISAV) has continued. These molecular diagnostic procedures enable the detection of specific targets during the process of nucleic acid amplification, without the need for time consuming analyses of reaction products inherent in conventional PCR methods. Establishment of real time diagnostic methods in the virology laboratory will play an important role in the diagnosis of aquatic pathogens. Initial work is aimed at optimising real time RT-PCR detection procedures using molecular beacons for fluorescent detection of ISAV in clinical samples, and will facilitate rapid identification of ISAV isolates prevalent in UK aquaculture. This work is funded by DEFRA and the BBSRC.

The Virology Group has recently received funding to study herpesvirus infection of koi carp. In recent years, enormous losses of koi have occurred in Europe, Israel and the USA. Koi herpesvirus (KHV) has been associated with several of these outbreaks of disease. Work on the KHV at Stirling will initially focus on characterization of the disease pathology and the development of serological and molecular diagnostic procedures for KHV.

Reproduction and Genetics

This year has been a most successful one for staff in Reproduction and Genetics (R&G). There has been much interest from potential students and sponsors, particularly with regards to the sustainable management of broodstock fish, breeding programmes and welfare and the control of gender and maturation; these included potential projects for established farmed fish species like salmon, trout and tilapia as well as newly developing ones like cod, halibut, bass and bream. Not all these opportunities have been taken up principally because of the finite capacity and time constraints of existing R&G staff for grant and post-graduate supervision.

DFID Fish Genetics

A notable achievement this year was the management role awarded to the Institute for the DFID's Fish Genetics Research Programme. This award was no doubt partly in recognition of the international

reputation of R&G staff, in particular Brendan McAndrew and David Penman.

Genetic Improvements for Carp

David Penman and Brendan McAndrew visited partner institutes in Asia (the University of Agricultural Sciences, Bangalore, India, the Bangladesh Fisheries Research Institute, Mymensingh and the Northwest Fisheries Extension Project, Parbatipur) several times this year in connection with the project on "Genetic Improvement Strategies for Production in Exotic Carps for Low Input Aquaculture in Asia". This project is funded by the DFID Aquaculture and Fish Genetics Research Programme. The project aims to contribute to poverty alleviation through improved management of stocks of non-native species of carps, which are of major importance in aquaculture in some Asian countries. The challenges faced in management of non-native species are in some ways greater than those faced for indigenous species, and some non-native species (e.g. silver carp, common carp) are of importance in the diets of poorer sectors of society in certain countries. John Taggart has been developing microsatellite DNA loci for Chinese carps and Dr Younus Mia, from the Bangladesh Fisheries Research Institute, spent nearly four months working in the IOA to develop molecular genetic markers for the silver and bighead carps, to be applied to assess the level of introgression between these two species in Bangladesh hatcheries.

Sex Determination

Simon Harvey has made good progress on a BBSRC project, led by David Penman, Niall Bromage and a colleague from Brunel University, Darren Griffin, which is using molecular and cytogenetic techniques to analyse sex determination in tilapia, and to develop techniques which can be applied to analyse sex determination in other species of fish. The development of chromosome microdissection and fluorescent *in situ* hybridisation (FISH) techniques has enabled us to distinguish X and Y chromosomes in tilapia. This is a major advance because previously it has not proved possible to differentiate sex chromosomes for most species of fish. These gender specific probes offer the possibility of development of simple "dip-stick" type methods of distinguishing male and female fish before they undergo sexual maturation.

Rafael Campos-Ramos is now coming towards the end of his PhD on the synaptonemal complex and sex chromosomes in the Nile tilapia. The synaptonemal complex (SC) is formed through the pairing of chromosomes during meiosis (in gametogenesis). Studies on mammals and birds show delayed or incomplete pairing of the sex chromosomes, and analysis of SC's in fish enables the identification of sex chromosomes through pairing anomalies where conventional karyotyping fails to do this for most fish species. This technique is also being used to study the origin of differences between the karyotype of *Oreochromis karongae* and the typical *Oreochromis* karyotype.

Md Tariq Ezaz is also nearing the end of his PhD. He has used bulk segregant analysis (BSA) to compare DNA from XX and YY Nile tilapia and thus isolate DNA markers which are X- or Y- linked. After DNA bands were isolated which only appear in the XX or YY pools in the initial screening, they were sequenced to allow unique PCR primers to be designed and tested in other fish to verify their usefulness in rapid identification of genetic sex. Several sex-linked markers have been found, and these are currently being further analysed.

Marine Fish

Over the past few years there has been a considerable growth in interest in the culture of marine fish like the cod, halibut and halibut in northern waters and bass and bream in southern Europe and specifically in questions relating to their reproduction and genetics.

Presentations on the control of maturation made to the British Marine Finfish Association (BMFA) Board of Directors and the BMFA Workshop in Inverary by Niall Bromage, Mark Porter and Andrew Davie have resulted in the award of two new projects on the photoperiod control of maturation in cod and halibut. The former project also involves collaboration with Marine Farms, the Institute's partner in the cod hatchery development in Argyll, and staff at Machrihanish. Work by Andrew Davie has shown that maturation in cod can be inhibited by continuous light and spawning time can also be adjusted to produce out-of-season eggs.

Mark Porter and Danitzia Guerro-Tortolero also successfully used light to modify maturation and growth in cage-farmed sea bass. This was an important development because early maturation amongst male fish is one of the most significant problems in sea bass culture.

Work on the nutritional requirements of broodstock halibut was also initiated in January this year with the support of the BMFA, Nutreco and Trouw and Otterferry Seafish Ltd. Emma Alorend, working under the supervision of Gordon Bell and Niall Bromage, has now completed the first year's spawning of the stock. The effects of additional amounts of the polyunsaturated fatty acid, arachidonic acid, in the diets of broodstock halibut will be carefully monitored over the next reproductive cycle, the aim being to improve the quality of the gametes, which is a major constraint for the further growth of halibut farming.

Photoperiod-Growth and Reproduction

Work by John Taylor and Ben North with the support of a NERC ROPA award to Niall Bromage and Mark Porter has shown that photoperiod manipulation can be used to enhance fish growth and improve food conversion efficiency in rainbow trout. Detailed studies by Wendy Futter supported by the BBSRC and the BTA have also identified the exact time in development that melatonin, the hormone which is controlled by light, begins to exert its action on controlling rhythmic functions in fish.

Iain Berrill, supported by a NERC Industrial CASE award to Niall Bromage and Mark Porter, is currently producing promising commercially applicable results in his project with Marine Harvest on the effects of photoperiod and diet on the timing and incidence of precocious maturation in Atlantic salmon.

During this year Dr Rana continued to develop his research interest in tropical fish reproduction with two PhD students. Research on reproductive biology of the silver bream, *Rhabdosargus sarba* is currently underway in Oman in collaboration with Sultan Qaboos University and the Ministry of Agriculture and Fisheries Resources. In addition, a PhD programme has been initiated to study reproduction and mass seed production and quality in Caspian Sea *Barbus* spp. in collaboration with the SHILAT, the Ministry responsible for fisheries in Iran.

Dr Rana is also currently developing a project on the role of aquaculture in urban and periurban zones and fringes in Sub-Saharan Africa. This project will conduct a natural resource audit and investigate resource and access constraints with an emphasis on hatcheries, seed production and supply, and on farm feed production systems.

Welfare and Stocking Density

With the support of a DEFRA (Department of the Environment, Food and Rural Affairs) and a BTA award to Niall Bromage and Mark Porter, Ben North has been working on a project on stocking density in trout in collaboration with CEFAS (Centre for Environment, Fisheries and Aquaculture Science) in Weymouth. Results this year have shown that the stocking density of fish is a complex question because fish occupy a 3-dimensional space and the carrying capacity of the water

supply is dependent on a series of water quality and biotic factors. Preliminary results would suggest that providing satisfactory water quality conditions are maintained then the welfare requirements for the trout will be safeguarded.

In conjunction with this project Niall Bromage has been serving as an EU invited representative on the Council of Europe Committee which is establishing a code of conduct for fish farming which will properly consider the welfare requirements of fish. It is intended that this document will form the basis of an EU Directive on the Welfare of Farmed Fish.

Selective Breeding

A major theme over the last year has been the development of breeding programmes for a number of commercially important farmed fish species. These projects reflect the growing recognition that genetic management and selective improvement will form the basis for the further development of a sustainable fish farming industry. Every other farmed animal or plant species used as foods for man has been genetically improved for yield and consumer acceptability. The pre-requisite for the genetic management of any farmed stock is the ability to identify the genetic relationship between individuals in any given mating. This has been very difficult in fish because it is impossible to physically tag the many small offspring. Previously, the young fish had to be ongrown in separate family tanks until they were large enough to be handled and survive the tagging operation. Most farms cannot afford this level of capital investment and have utilised a "greenfingered" approach to genetic improvement or broodstock replacement; they have merely chosen the largest or fastest growing animals for the next generation, which in the absence of any pedigree information has often resulted in the genetic degradation of farmed stocks through inbreeding and genetic drift.

Recent development in the identification of highly variable genetic fingerprinting techniques that are easily analysed using the polymerase chain reaction (PCR) and fluorescent visualisation techniques means it is possible to identify the fingerprinting of broodstock fish and identify their offspring in large commercial populations. This technology alone has dramatically improved our ability to design new cost effective broodstock management and improvement programmes for a wide variety of species with very different biological characteristics.

Projects include work in Cyprus with the Alkioni fish farming company to design a programme for the gilthead seabream (*Sparus auratus*). Cameron Brown has been developing genetic fingerprint techniques based on the use of a number of microsatellite marker loci required to discriminate the offspring from the hundreds of potential families that arise from this mass spawning species. The markers will enable the number of families represented in the output from the broodstock to be assessed as well as individual male and female contributions to the spawning success.

By contrast the Atlantic halibut offers a completely different set of biological characteristics that need to be taken into account in the design of a broodstock replacement and improvement programme. This is a large, long lived and potentially highly fecund species, which means that the industry will rely on relatively few broodstock compared to other farmed fish species. In these circumstances the correct choice of broodstock is of utmost importance in order to ensure that the industry receives the highest quality seed and that the genetic resource is not compromised by poor management.

The largest supplier of halibut in the UK is Otterferry Sea Farms on Loch Fyne who are funding a Teaching Company Scheme (TCS) whose aim is to transfer the genetic skills, developed by the R&G Group at the Institute and the breeding skills of the Roslin Institute, to

Otterferry and to develop the protocols and management skills needed to ensure the longer-term sustainable management and improvement of halibut culture. Once again molecular markers are being used with new tagging systems to identify the fish with the highest genetic value to the company.

Work is also in progress on a breeding programme for rainbow trout. Although this is an established industry there has been no concerted action to improve the genetic resource base of this species. The UK industry is composed of a relatively large number of small producers that have not had the financial resources to develop their own breeding programmes. The industry also relies heavily on out-of-season imported eggs to obtain a year round supply of young fish. In collaboration with the BTA and funded by the LINK programme, R&G staff at the Institute and Neil Cameron of the Roslin Institute, are identifying the breeding goals for the UK industry. Based on this information they will assess the levels of genetic variation for important traits that contribute towards these goals in the strains supplied by the major UK hatcheries.

Genetic Maps and Gene Banking

Margaret Cairney and John Taggart are concluding an EC FAIR funded project (SALGENE) to generate a genetic body map for Atlantic salmon. This is a collaborative project with partners from the Norwegian College of Veterinary Medicine, Oslo; the National University of Ireland, Galway and the Danish Institute of Animal Science, Tjele. The work, which has been funded for three years (1999-2001) aims to isolate and identify new genes from Atlantic salmon using a strategy based on cloning and characterising expressed sequence tags (ESTs). Stirling's role in the project is to generate and characterise ESTs from spleen and kidney cDNA libraries. Currently the work is on schedule. Nearly 2000 ESTs have been partially sequenced, of which 60% show significant homology to identified genes within the GENBANK database. This project, in conjunction with the recently completed SALMAP, which identified and mapped c 300 microsatellite markers in the salmonid genome, should improve, in a quantifiable manner, our current knowledge of salmon genetics and biology.

Recent funding from the EU to study the molecular genetics of the European seabass includes John Taggart as part of the multinational BASSMAP team that will identify new molecular markers and important genes and place these in the first genetic map of a marine fish species. John's expertise in the important SALMAP and SALGENE projects will ensure that the lessons learnt in these projects will be applied in the new programme.

This year also saw the completion by Krishen Rana of a manual for the genebanking of aquatic species with an emphasis on tilapia genebanking and the development of a functional prototype of a complete field kit for the genebanking of tilapia and other aquatic species.

The combination of molecular and quantitative genetics has opened up the possibility of cost effective genetic management and improvement even for relatively small operations. Future developments will not only need breeding programmes but also a greater understanding of the genes that control many commercial traits so that we can identify individuals with the correct genotype without the need for many generations of selection.

R&G staff, especially Mark Porter, have been much involved in collaborative studies with two Norwegian groups who have visited the Institute to work on two salmon photoperiod and melatonin projects with the support of the EU Large Scale Facility Programme.

Aquagene

The Aquagene Group led by Professor Alan Teale was joined in February by Mrs Cathryn Dickson. Mrs Dickson, who formerly worked in Biological Sciences in the University of Stirling, brings molecular biology technical support to the group.

The major research areas during the past year have continued to be the molecular biology of polyunsaturated fatty acid (PUFA) synthesis in fish, bacteriophage applications in aquaculture and local adaptation in brown trout in Norway.

Dr Morris Agaba has led the group's efforts in fatty acid molecular biology research, and, working closely with Dr Douglas Tocher and colleagues of the Nutrition Group, has made some remarkable advances in 2001. An important contributor to this success has been Ms Nicola Hastings, whose post-graduate studies are focused on PUFA desaturase genes and their products. Ms Hastings cloned, and following expression in yeast, functionally characterised an entirely novel desaturase from zebrafish (*Danio rerio*). This gene is the first characterised desaturase in fish and the first to be described in any organism that has both D6 and D5 desaturase functions. An indication of the importance of this finding is that in her second year as a post-graduate student, Ms Hasting's paper has been accepted by a prestigious scientific journal, and she has been asked to describe her work at two major international scientific meetings. The group is now moving on to clone further desaturases from a range of fish species with a view to determining the molecular basis for inter-species variation in PUFA synthesis ability.

A second gene family that may contribute to such variation is the fatty acid elongases. Dr Agaba and Mrs Dickson have cloned elongases from a range of fish species and functionally characterised the zebrafish gene product. In the coming year, together with Dr Tocher and colleagues, they will compare the functions of the various genes and determine their substrate preferences.

The bacteriophage research has been taken forward by Dr Marianne Pearson with the technical support of Mrs Liz Haughey. Their work is supported by the BBSRC. A number of new bacteriophages with activity against *Aeromonas salmonicida* have been isolated during the past year. Their host range, stability and lytic capacities have been quantified, and their activity in protecting fish from *A. salmonicida* challenge will be the focus of research in this area in the coming year.

Research into local adaptation in brown trout is conducted by Mr Kevin Glover and his supervisor Dr Øystein Skaala in the Institute of Marine Research in Bergen, Norway. Mr Glover is registered for his Ph D studies in the University of Stirling where most of the molecular genetics components of the studies have been based. Professor Teale and Dr John Taggart have been closely involved in this collaboration with the IMR, and serve as Mr Glover's University supervisors. Good progress has been made over the past year. An in-depth study revealed no evidence for a genotype-environment interaction in juvenile brown trout in terms of responses to different feeding levels. On the other hand, evidence was obtained of a genetically determined difference in susceptibility to sea lice between sea run and freshwater- resident brown trout populations.

Professor Teale and colleagues were awarded a Joint Equipment Research Initiative grant by the BBSRC during 2001. This has been used to establish a real-time PCR capability within the Institute that will be of benefit to all research groups engaged in molecular biology studies. Professor Teale and colleagues are also in the process of finalising a research contract with the EU to support a three-year research project on antibiotic resistance in aquaculture environments in South East Asia. This project, which will begin in early 2002, will be co-ordinated by the Stirling group and will be conducted with Belgian and Italian partners, and partners in three South East Asian countries.

Nutrition

The main research effort of the Lipid Nutrition Group continues to be to identify and characterise the factors controlling polyunsaturated fatty acid (PUFA) metabolism and deposition in fish. A variety of molecular biological and molecular genetic methods, together with *in vivo* assays of PUFA biosynthesis are being deployed to that end.

The fatty acid desaturation programme is being pursued by Dr Douglas Tocher in collaboration with Professor Alan Teale and Dr Morris Agaba of the Molecular Genetics Group of the Institute along with a joint Ph.D student, Ms Nicola Hastings. The programme's aims are to clone fish D6 and D5 fatty acyl desaturases and fatty acid elongases, enzymes of paramount importance in the conversion of 18:3n-3 to 20:5n-3 and 22:6n-3. A cDNA was isolated from zebrafish (*Danio rerio*) with high similarity to mammalian D6 desaturase genes. When the zebrafish cDNA was expressed in *Saccharomyces cerevisiae* it indicated that the zebrafish gene encodes an enzyme having both D5 and D6 desaturase activity. As described in the "Aquagene" section it is the first report of a functionally characterized desaturase enzyme of fish, and the first report of a fatty acid desaturase in any species with both D6 and D5 activity. Work is continuing on the search for other desaturase genes from zebrafish, carp and marine fish (plaice and turbot), as well as further characterisation of the existing zebrafish and carp cDNAs. The search for further fish desaturase genes will be increased by the addition in October 2001 of an experienced post-doctoral researcher, Dr Xioazhong Zheng who will be specifically focussed on cloning the desaturase and elongase genes from Atlantic salmon.

In addition to the above project, two other projects are targeted at this initiative. The first was run in parallel to the work described above and consisted of dietary trials with both tilapia and zebrafish designed to characterise the hepatic fatty acid desaturation - elongation pathways in these species. This experiment used zebrafish obtained from Edinburgh University and F1 progeny of tilapia isogenic lines produced in-house, fed optimised diets (vegetable oil vs fish oil). It showed, for the first time, that hepatocyte desaturation activities were increased in fish species, other than salmonids, fed vegetable oil diets rich in C₁₈ PUFA. This experiment provided two resources. First, the cDNA prepared from tilapia F1s on the vegetable oil diet, which is desaturase-induced, will be used for the identification and subsequent isolation and characterisation of tilapia desaturase cDNAs. Second, both cDNA pools together will be used for investigating differential expression through differential display approaches (performed by Dr Morris Agaba). The second project is also investigating differential gene expression, but in this case *in vitro* using the EPC-EFAD cell line and technology well established in the Nutrition Group. A cell culture experiment, similar to the dietary trials with tilapia, was performed to characterise the effects of 18:3n-3 and 22:6n-3 supplementation on desaturase activities, and to provide material for the production of cDNA pools representing gene expression under different treatments. More rapid progress in this area can be expected with the availability of a Real Time PCR instrument in the Institute.

The fatty acid desaturase enzymes are inducible and are repressed by dietary 20:5n-3 and/or 22:6n-3. A method developed by Dr Michael Bell using dietary administration of deuterium-labelled 18:3n-3 has allowed us to measure the rate of formation of 22:6n-3 *in vivo* in fish for the first time and confirm this directly. These studies found also that the formation of 22:6n-3 was slow, it taking 3-4 weeks for a pulse of 18:3n-3 to be fully metabolised to 22:6n-3 in rainbow trout. The rate of biosynthesis of 22:6n-3 was lower than expected. The original work on essential fatty acid requirements in trout found that rainbow trout fed from first feeding on a diet containing no 20:5n-3 or 22:6n-3 and just sufficient 18:2n-6 and 18:3n-3 to meet the essential fatty acid

requirement, were able to grow and accumulate 22:6n-3. In our study the fish were not able to maintain their tissue concentration of 22:6n-3. We are currently investigating two possibilities to account for these differing results. First, that farmed rainbow trout fed commercial diets containing fish oils and fish meal over many generations may have lost the capability to synthesise 22:6n-3. Second, that diets containing high levels of lipid may up-regulate β -oxidation, thus catabolising most of the substrate, 18:3n-3.

Peroxisomal proliferator activated receptors (PPARs) are a family of nuclear hormone receptors known to have various important roles in regulating lipid metabolism in animals, specifically in the regulation of genes involved in fatty acid oxidation and adipogenesis. Drs Michael Leaver and Douglas Tocher obtained major funding from BBSRC to investigate the role of PPARs in regulating lipid metabolism in fish. Plaice PPARa, PPARb/d and PPARg genes have now all been cloned and are in the process of being fully characterised. Further funding in this area was obtained through the award of an EU RTD project grant to Drs Leaver and Tocher to study the role of PPARs in Atlantic salmon in a multi-partner project also studying sea bream. The work on salmon PPARs will be accelerated by the appointment of M. Tariq Ezaz as an EU post-doctoral fellow after valuable initial work with Dr Stephanie Fontagne, a visiting post-doctoral researcher.

The high levels of PUFA in fish diets makes them prone to oxidation and oxidised fatty acids can then damage the fish. A project on antioxidant protection in juvenile marine fish feeds was pursued by Drs Douglas Tocher and Gordon Bell in an EU-funded project, "The Study of Antioxidant Systems in Cultured Marine Fish in Relation to Growth, Quality and Disease Resistance During the Early Developmental Stages". Our partners were the University of Cadiz, the Norwegian University of Science and Technology (NTNU), Trondheim, and the Laboratory of Aquaculture and Artemia Reference Centre (ARC), University of Ghent. The study showed that vitamin E was very important in antioxidant defence systems whereas vitamin C and astaxanthin were not effective on their own, although there were indications that they could act synergistically with vitamin E. Furthermore, there were important species differences with the rank order in their ability to tolerate peroxidative stress being sea bream > turbot > halibut.

A number of projects have continued with the aim of substituting fish oils with vegetable oils in salmon diets. A major new multi-partner EU - funded study coordinated at Stirling "Researching Alternatives to Fish Oils in Aquaculture (RAFOA)" was started in January 2001 by Professor John Sargent, Dr Gordon Bell and Dr Douglas Tocher. Dr James Henderson has been appointed to a 3.5-year post as RAFOA Research Technician and Dr Xioazhong Zheng has been appointed to a 3-year post as RAFOA Research Fellow. The NERC LINK Aquaculture programme "Fish Oil Substitution in Salmonids" has continued along with studies funded by the Home Grown Cereals Authority, Malaysian Palm Oil Board and J L King with Hull University on substituting rapeseed oil and linseed oil, palm oil and echium oil, respectively, into salmonid diets.

The successful substitution of fish oils with vegetable oils requires an understanding not only of what determines conversion of 18:3n-3 to 22:6n-3 but also of what determines the deposition of 22:6n-3 in tissue triacylglycerols, especially in relation to the deposition of less desirable dietary fatty acids such as n-6 PUFA. This necessitates understanding what determines levels of triacylglycerols in the fish, i.e. what determines its adiposity. This already is an area of interest to the industry which is concerned with the production of over - oily fish with poor processing characteristics and consumer acceptance due to the use of high - oil diets. We have some evidence that it may be possible in principle to select genetically for lean and fatty fish. This requires a non-invasive method of determining adiposity in the fish,

either by physical measurement or by a molecular marker. Both these areas are being investigated.

Studies investigating broodstock nutrition and egg and larval quality are underway in halibut jointly funded by the British Marine Finfish Association, The Crown Estates Commissioners, Trouw Aquaculture and Otter Ferry Seafish and in tilapia with Dr Dave Little (IoA), Dr Ram Bujhel of The Asian Institute of Technology, Bangkok and Agribrands.

The programme monitoring flesh quality in Scottish farmed Atlantic salmon was completed. This study, pursued by Ms Fiona McGhee and Dr Gordon Bell was funded by the Crown Estate Commissioners. Over a period of 6 years more than 1000 salmon steaks have been analysed for a range of flesh quality parameters including colour (Roche score), texture, lipid content, lipid class composition, fatty acid composition, vitamin E content, carotenoid pigment content (including the ratio of astaxanthin to canthaxanthin) and levels of thiobarbituric acid reacting substances (TBARS). A large database is now available. The main conclusion was that Scottish farmed salmon is a high quality product which provides high levels of essential n-3 HUFA to the consumer.

The Nutrition Group has taken part in the Roche ring test for carotenoid analysis for the past 3 years. This involves inter-laboratory analysis of samples prepared by Hoffman La Roche and distributed to over 40 participating analytical laboratories worldwide. The laboratory expertise is increasingly in demand for analyses of constituents of fish feed and tissues, mostly fatty acids, vitamins and carotenoid pigments. Ms Liz MacKinlay has been employed for the last 2 years to support the increasing level of commercial contract analysis being undertaken by the group.

Environment Group

Environmental Services

The increase in environmental awareness and consequent regulation in European aquaculture has caused an increasing demand in environmental assessment and monitoring work within the industry. This has meant a very busy time for the Environmental Services consultancy, which has had its best year so far in terms of financial turnover and contracts completed.

There were several staff changes with the Environmental Services during this year beginning with the loss of a long serving member of staff, Dr Mary Hennessey, who took up a post with Scottish Natural Heritage. Dr Hennessey was replaced by Ms Anna Moodie, though primarily to work on marine based contracts. Ms Moodie has an MSc in Environmental Management from Stirling University and is providing invaluable expertise in sample analysis, management and the potential for the use of GIS for coastal management. The Institute monitors nutrients in freshwater systems for most major fish farm operators in Scotland. This service continues under the direction of Dr Karen Robinson. Apart from routine freshwater monitoring several interesting studies have been undertaken within this environment. Of particular interest is a field investigation into the use of an anti-microbial as a bath treatment, including development of a dispersion model for environmental regulation.

Work in the marine environment continues to increase. Although many of the contracts involve statutory monitoring of sediments and water quality in the areas around fish farms, several modelling studies of the dispersion of waste material and full environmental impact assessments for new and existing developments were successfully completed. This work largely encompassed Scotland and Ireland

but some projects were based in the Mediterranean, including assessment of the environmental impacts of bass and bream culture in Sicily and tuna farming in Malta. The latter required the modification of existing waste distribution models, under development within the Environment Group, for use in wind driven hydrodynamic systems and with trash fish food waste.

The Environmental Services consultancy is increasingly looking for ways of collaborating more closely with the research side of the Environment Group. An excellent example of this was a project integrating the environmental quality expertise of the Environmental Services with work on biomarker indicators of effect by Professor Stephen George, to investigate the association between environmental quality and the causes of fish deaths at a farm site. This integration of resource and expertise will be more relevant in the future in a more holistic approach to assessment of environmental impacts by and on the aquaculture industry.

Environment Group Research

The waste dispersion models for fish farm discharges, being developed within the Environment and Systems Groups (in conjunction with Professor Lindsay Ross), progressed further during this year with the implementation of the dispersion algorithms into a GIS framework by Mr Oscar Perez. This allows its use for estimating effect and its application for a GIS structured coastal management plan. The model has also been adapted for use with seabass and tuna farming and though some final validation is required the model is showing excellent potential. Dr Song Chen has successfully obtained his PhD investigating the various parameters involved in modelling.

This year saw the completion of a highly successful EU CRAFT FAIR Project. This was undertaken in conjunction with three other academic and four industrial partners. This showed clearly that using adaptive feeding technologies will decrease waste input by approximately 23% in seabass culture. Further to this a new project has been started this year in Scotland looking at the environmental benefits of this technology for Atlantic salmon culture. This involves a NERC CASE funded PhD studentship, held by Richard Corner.

We have a successful project near completion by Ms Malene Felsing as part of a split centre PhD with the Nutrition Group of Fisheries Western Australia, based in Perth. This involves the almost unique situation of a small marine fish production system, totally under scientific control to investigate environmental impacts of cage wastes. This work has included investigating nutrient uptake within the environment, sediment trap studies, and fish exclusion experiments to investigate the removal of wastes by indigenous fish. The results of this project will be key in defining parameters for environmental management of fish cage production systems.

This year saw the beginning of a PhD project, undertaken by Mr Stephen Cross in British Columbia, the aim of which is to investigate the impacts of aquaculture activities on each other with a view to implementing effective integration of aquaculture practices. This project, in conjunction with Professor James Muir of the Systems Group, is of importance within this area due to new environmental management legislation in western Canada and has implications for integration of large-scale fish farming with aquaculture practices of the indigenous first-nation populations of the area.

Mr Matias Medina is in the final stages of his PhD project investigating the impacts of parasiticide treatments on zooplankton populations. This has been a very successful project and work has been undertaken in both laboratory and field situations, using mesocosms, to allow relation of the data to actual environmental effects.

Ecotoxicology

In the final larval season of Professor Stephen George's NERC-funded study on the effects of dietary quantity and quality on the robustness of larval flatfish to the toxic effects of pollutants which cause oxidative damage to cellular macromolecules, Stephanie Chew (MSc. student) was able to successfully manipulate the levels of the intracellular oxidant defence systems (glutathione, metallothionein and glutathione s-transferase) in plaice larvae 1-2 weeks post-hatch by means of dietary drug treatments using artemial enrichment oil as the delivery vehicle. To our knowledge this is the first time that this method of manipulation has been used. The study not only showed that the capacity of these defence systems could be externally manipulated and that expression of the GST-A and MT genes are regulated very early in development, but also proved the importance of these systems *in vivo*, since in larvae where protectant levels were reduced mortalities on pollutant challenge were greater, whilst in larvae overexpressing metallothionein they were reduced. These results were very significant in that they followed exactly those which we had obtained previously in fish cell culture, thus vindicating our assertion that *in vitro* methods are entirely valid for toxicological investigations and can be extrapolated to *in vivo* situations. These principles are in line with our strategy to reduce the dependency on whole animal experimentation and also show that in many situations *in vitro* studies are also much more cost and time effective.

The plaice larval rearing experiments have been useful, in that we have been able to obtain samples during different stages of both embryonic and larval development to establish the ontogeny of various enzymic systems for drug and pollutant metabolism and detoxification, metal homeostasis and oxidative defence. These studies have been facilitated by the use of cloned cDNA's as probes to determine expression of the genes, immunoassays for the proteins and the development of micromethods using multiwell plate readers for analysis of enzymic activities.

The question of inheritance of resistance traits for pollutant resistance in estuarine fish species still remains a major thrust area of Professor George's group. Estuarine pollution by persistent polyaromatic hydrocarbons (PAHs) and polychlorinated aromatic hydrocarbons (PCBs and dioxins) remains an ongoing problem that will not be alleviated for a long time by pollution control legislation. Mr Tom Dixon has successfully developed quantitative PCR procedures (using our newly acquired Real Time PCR instrument) for determining the expression of genes coding for the transcription factors (AhR and ARNT) and enzymes of the Ah gene battery (CYP1A, UGT1B1 and GST-A) which respond to exposure to these classes of chemicals. These systems are responsible not only for the activation of carcinogens such as benzo(a)pyrene (CYP1A) but also for their biotransformation and detoxification (UGT and GST). He has also completed experiments where family groups of artificially reared flounders (crosses of fish from estuaries with very different long term pollutant histories) were exposed to a commercial PCB mixture and is now using these new PCR methods to determine the inter-individual variability in response. We will also attempt to correlate these responses with potential population differences brought about by long term pollutant exposure of a population from the Mersey estuary.

The estuarine North American killifish remains our best model for heritable resistance traits and, in a NERC-funded short term study, Dr Phil Watts has prepared normalised cDNA libraries which we are using to constructing DNA microarrays for a study of dioxin-resistance in an adapted New Jersey population. Professor George has just secured significant 4 year funding under the EU 5th Framework initiative with partners in Birmingham, Haifa and Odense for a DNA microarray and proteomic study of pollutant effects on flounders which represents the first major initiative applying these technologies to fish studies.

Dr Baird's ecotoxicology research group has continued to develop its

key research focus on the impacts of low-level contamination on aquatic food webs through two EU-funded projects: the EC-INCO project TROCA (in Mexico and Brazil), and through the EC-Framework 5 TARGET project (field and laboratory studies in the UK and Europe). The TROCA project aims to develop a set of assessment methods based around the use of bioassays to assess feeding and life-history performance with local species. A demonstration of these techniques with colleagues from Portugal was carried out in Mexico, and laboratory studies to extend the approaches towards assessing the effects of applications of pesticide mixtures is currently the focus of PhD research. The TARGET project, which is developing a similar set of tools for use under the EC Water Framework Directive, involves a team of five researchers at Stirling. This team has been busy testing feeding bioassays using a range of aquatic invertebrates in both mesocosm experiments and in a series of field deployments at 20 sites within the UK. Results so far have been extremely promising, and the project continues to receive feedback on the work from a linked steering committee which includes representatives from SEPA, the EA and the Scottish Executive.

The collaborative research programme between Dr Baird's group and scientists from Environment Canada, supported by a formal agreement signed last year, has continued to support research on the effects of toxic exposure on the feeding behaviour of aquatic invertebrates and fish. Two NERC PhD students are currently supported (through CASE awards) under this scheme, and future collaborations in the area of the assessment of river sediment ecotoxicology are planned for the coming year.

Systems Group

Members of the Systems Group and their colleagues have been engaged in a range of active and productive outputs, involving UK and international programmes. The group also continues to support high demands in teaching and supervision, increasing amounts of which relate to the group's extensive work and reputation in international development. Staffing is virtually unchanged from the previous year; as numbers are limited, essential contributions have also been obtained from a range of external partners, and from our active group of postgraduate students.

An important element in the Group's profile is the DFID Aquaculture Research Programme (ARP), managed by Professor James Muir. With the successful bid to manage the next phase of this programme and the former Fish Genetics Research, a new and much expanded programme, the Aquaculture and Fish Genetics Programme, is now underway, with funding in place until 2005. The existing programme had made considerable progress, contributing to a range of international outputs at both practical field level, in terms of new cross-disciplinary approaches and methodologies, and in contributing to a range of international strategies. Within and outside the DFID programme a range of system-related work continues, with Dr David Little providing a key field co-ordinating role, linking with the Asian Institute of Technology (AIT) and other institutions, together with Stuart Bunting and a range of UK and international collaborators, research assistants and postgraduates. The departure of Dr Malcolm Beveridge from the Environment Group has removed one of the most valuable contributors within the Institute, though Dr Donald Baird and Dr Trevor Telfer continue to provide important support. Links with aquatic diseases and production systems are represented in particular by Dr Jimmy Turnbull, Dr Kim Thompson and Dr Margaret Crumlish. With the new genetics interests, greater opportunities now lie in collaboration with key researchers in the Genetics group, including Professor MacAndrew, Dr Penman and Dr Rana. More widely within the University, strong links continue with Professor James Young (Marketing Department), and

new associations have been developed with the Department of Applied Social Sciences and the Department of Economics.

The group's themes include Dr Janet Brown's Shellfish Group, Professor Ross's GISAP (Geographical Information Systems and Applied Physiology) Group, the Tropical Aquaculture programme, and the Fisheries Sector Marketing and Economics programme run by Professor Muir and Professor Young. Stirling Aquaculture also provides links across these areas. Thematic interests are summarised as follows:

Strategy, planning and development

With the completion of a number of PhD studies and external contracts last year, the GIS programme has provided the major part of this year's work in this area. Professor Lindsay Ross and his group have continued to develop advanced culture technologies, including GIS applications. During the year, work on stereo imaging systems with Silsoe Research Institute and Glasgow University was concluded, with promising results, several publications and a potential commercial product under development. Dickson Chan also completed his PhD thesis on a stereo imaging system for the estimation of biomass of free-swimming fish, which was part of the overall project.

Work on GIS modelling in support of the aquaculture sector has continued strongly and Abdus Salam completed his thesis on the potential of GIS-based modelling for aquaculture development and management in south-western Bangladesh. Professor Ross and Matias del Campo Barquin gave an advanced course in GIS for Aquaculture at the University of Temuco in Chile in January. Temuco is a major centre for aquaculture training in southern Chile and the 25 participants were drawn from the industry, ngo's and government departments.

Collaboration has continued with Dr Martinez's group at the Universidad Michoacana in Morelia, Mexico. Our British-Council supported work on developing a culture technology for the endangered whitefish *Chirostoma estor* is now moving ahead rapidly and a number of publications are emerging. In the last year, Alison Graham and Jordi Comas both completed theses in Mexico. Several staff exchanges are planned and we anticipate further productive output from this link.

With Professor Young of the Department of Marketing, Professor Muir and Mr Bostock continue a range of work on production and market system analysis for aquaculture and fisheries supply in Scotland, Norway, Iceland and in their external markets. The group's EU-funded study on organic aquaculture generated strong external interest, with a number of new concepts to take forward.

With FAO, Professor Muir continues to develop work on the identification and application of sustainability indicators in aquaculture, providing the major input to an Expert Consultation on this topic in September 2001. He also provided a keynote input on international aquaculture development to the Canadian aquaculture industry and policy groups in two meetings, in Prince Edward Island and Vancouver.

Aquaculture production systems

Dr David Little and his regional colleagues have contributed many of the current activities in this area, including:

- Fish seed quality in Asia: a collaborative project with the Asian Institute of Technology and five national institutions funded by DFID-ARP. Collaborative research is under way on a range of themes, with increasing impact amongst regional producers and institutions. Mr Angus MacNiven, a Stirling PhD student is based at AIT to co-ordinate field work.
- Farmer-managed irrigation systems and aquaculture: also funded by DFID-ARP this work is continuing in water-short areas of Karnataka State, India and the dry zone of Sri Lanka. Research Assistant Francis Murray has been based in the field; work has now attracted

further support from CARE Sri Lanka, with current plans for an extended project, involving resource and access rights.

- Aquaculture integrated within engineer-managed irrigation systems: continuing research with partners in the UK (University of Newcastle) and Sri Lanka (ABC, University of Peradeniya) and India (Tamil Nadu Agricultural University) funded by DFID-KAR. Lindsay Pollock is responsible for field research at both sites together with local partners.
- Aquaculture in eastern India: the final phase of an DFID-NRSP project in Bihar/West Bengal was successfully completed, and with Stirling MSc Anton Immink as project assistant, preparations have been made for follow-up activities with local and national institutions.
- Aquaculture in the peri-urban zone-the Calcutta wetlands: the project is now successfully under way, with Stuart Bunting and colleagues funded by DFID-NRSP. The project has already generated a range of important contributions.

Dr Janet Brown's programme in crustacean production is continuing through a programme of PhD studies, and with STAQ and other field projects. Nesar Ahmed's PhD project investigating social and economic consequences of small scale *Macrobrachium* farming in the Bagerhat region of SW Bangladesh, in association with the DFID/CARE 'Golda' project, was successfully completed during the year.

Bioecological bases of production systems

Dr Little's new project with Dr Kai Lorenzen of Imperial College, London, on the livelihood impacts of self recruiting species in Asia has now successfully commenced in three countries of Indochina, eastern India and Bangladesh. With the Environment group, Dr Beveridge's work on the use of periphyton in aquaculture systems was also successfully completed, with the addition of livelihoods studies. Coordinated by Dr Little with Pham Anh Tuan, an interdisciplinary team from Stirling (Jimmy Turnbull, Mags Crumlish) and Research Institute Aquaculture 1 (RIA 1) in Bac Nin, near Hanoi developed further their activities in cage culture in Tuyen Quang province, with the support of a British Council Link project.

Crustacean Research

Dr Brown successfully completed a NERC small grant on the determinants of individual growth rates in *Macrobrachium rosenbergii* which succeeded in showing that not only was it possible to tag the very smallest postlarvae but even tag pre-metamorphic larvae so that it is possible to have a population of newly metamorphosed postlarvae already tagged. We also demonstrated a link between the resting metabolic rate and dominance and plan to take this research forward. We will be assisted in this in that through the EU Large Scale Facility project we have established a research link with Dr Amir Sagi and Dr Isam Khalaila from Ben Gurion University, Israel which has led to our having a number of sex reversed *M. rosenbergii* under culture. They visited the prawn unit last year and the prawns that they took away to sex reverse were newly returned for on-growing through the visit of Mr Yaacov Avraham in September 2001. The outcome from breeding from these prawns will constitute part of the PhD studies of Mr Ibrahim Al Mohsen from Saudi Arabia.

System design

Work in this area continues together with Stirling Aquaculture, providing practical application and development in the commercial context. A new TCS scheme set up with Luca Montorio, and Alexander Sandison's of Shetland, has now made good progress in developing novel water treatment systems. Work on other systems continues, with Bart Vlaminck (STAQ technical manager) involved in a range of offshore cage culture innovations, and David Currie (STAQ associate) developing shrimp project designs. Stuart Bunting has completed his PhD work on the design of aquatic wetlands systems in association with aquaculture, and Wara Taparhudee is finalising his PhD on water sparing and aeration systems in intensive shrimp farms in Thailand.

External Facilities

The Institute's External Facilities at Howietoun, Buckieburn Freshwater Research Unit, Machrihanish Marine Environmental Research Laboratory and Stirling Aquatech all had excellent years financially and academically and were expanded with the formation of a new company, Machrihanish Marine Farms Ltd, in December 2000.

Howietoun

Smolt production increased by 5% to around 525,000 and is expected to increase further as new technology is adopted. Out of season smolts account for around 50% of production and have many benefits over normal spring smolts as they represent the fastest growing stock and allow our customers to benefit from year round harvesting. Our 28-day survivals after transfer to sea water at 99.8% are arguably the best in the industry and are testament to the care taken in the production process at our three smolt sites. Close attention to detail when transporting the smolts at their peak of readiness is the key to this excellent performance. Our relatively small production allows quality control and customer support, which is second to none in the Scottish industry. Consequently, the market for Howietoun smolts has been and continues to be very strong. We have expanded smolt rearing facilities at Howietoun this summer and are carrying larger stocks in anticipation of this increased demand.

Infectious salmon anaemia has not reappeared in the Scottish industry but the last 6 months have seen increasingly poor prices for farmed salmon globally. This has been largely caused by weak selling with far too many sellers in the market place, and it has been particularly galling for salmon growers comparing the very poor ex farm prices achieved with those for which the product is being sold by the retail multiples and others. The demand for farmed salmon is very strong and the on growing industry must urgently address these weak selling practices.

Globalisation of salmon farming continues unabated and the declining number of client companies is of great concern to the Institute and its commercial operations. However, we work closely with a number of large multinational operations and we expect this to increase as new aquaculture species, such as cod, emerge.

Howietoun is a founder member of Scottish Quality Salmon, the industry trade association, and Dr Robertson sits on its Council and chairs the Smolt Sectoral Committee. SQS has had a very busy time over the last 12 months presenting a professional image of a sustainable and well managed industry.

Brown trout sales had a very difficult year because of the disruptions in the market created by foot and mouth disease. During February and March 2001 deliveries were at a standstill, as landowners would not allow us to cross their land. It was very fortunate that Howietoun was situated above the Forth/Clyde line, as this area was declared provisionally free in April and deliveries started again. We had several cancellations and some customers delayed their deliveries until 2002 but ultimately sales were very close to target. Unfortunately foot and mouth still looms over our brown trout operation, as there is still a considerable overhang of production in England, which has still not been placed. Howietoun's reputation for quality and service and large and loyal customer base will hopefully see us through what could be a difficult year generally for restocking.

Buckieburn Freshwater Research Unit

Buckieburn has had a very successful year and the excellent facilities in the new building have been much appreciated by students, staff and the increasing customer base. A new office, laboratory, mess, toilet and changing area for staff and visitors has been designed and is expected to be complete and commissioned by March 2002. A

new procedure room to meet Home Office requirements has already been commissioned. The purchase of the site in 1998 has provided the stimulus for these recent developments.

A number of trials have been completed for feed companies, pharmaceutical companies and Scottish Quality Salmon, and Buckieburn now complements Machrihanish in carrying out contract research to GLP accreditation. Indeed several of the trials carried out at Machrihanish this year have had their initial phase at Buckieburn under the supervision of Dr Roy from Machrihanish. We have recently discussed opportunities for rearing of specific genetic strains of brown trout at Buckieburn, which is potentially a large area of work for the future.

However, the majority of work carried out at Buckieburn is in supporting the staff and students of the Reproduction and Genetics Group. This work is carried out by site manager, Mr Alistair McPhee who joined us in the spring, and stockman Jon Gardiner with support from Howietoun staff. The staff and students are largely focusing on photoperiod manipulation of salmon smolts and rainbow trout. The MAFF/BTA project on stocking density effects on farmed rainbow trout is now in its second year. This trial will provide benchmark data for fish welfare in the future.

Machrihanish

Machrihanish has had another record year in terms of contract and academic research and has become the major focus for cod farming research and production in Scotland.

In conjunction with Nick Fullerton from Fish Tech Ltd we successfully produced 62,000 cod juveniles for Lakeland Marine, 90% of the British cod juvenile production, and have initiated trials into cage rearing of cod at very small sizes, similar to that carried out with Mediterranean species. These trials, part funded by HIE and Highland Council and which are still ongoing, have been very successful, with growth and mortality very similar to that experienced in tank environments. This is a significant finding as it may open up an inexpensive and rapid development of juvenile cod production.

Work on cod maturation, an area of major economic significance to the cod farming industry, has been extensive and we have successfully prevented maturation of cod following extended exposure to simulated long days. However, more work is required to fine tune this technique as significant growth penalties were observed after extended periods on long days. A major collaborative project will start in 2002 to tease out the details of the most appropriate photoperiod regimes to prevent early maturation whilst promoting good growth. This work will be carried out by Andrew Davie, NERC PhD student and is designed to be applicable in cages throughout Scotland.

Nodavirus appears to be a most significant pathogen in juveniles of some marine fish species, notably bass and bream. Thus, the occurrence of the virus in one of our cod stocks last year was of great concern. However, mortality was only 2% and this provides some confidence that in cod the virus will not have a huge impact.

Sea lice infestations of salmon are still a major problem in Scotland but the licensing and granting of consents for emamectin benzoate is finally signalling the end of a very long and damaging battle. Research with Schering Plough, the supplier of emamectin, over a five-year period has thus come to fruition. Work on new lice chemotherapeutants is increasingly concerned with the use of these products in alternative species such as cod, halibut and sea bass. Janet Stone's experience with developing challenge models for lice on salmon has proved invaluable with new parasites such as *Clavella* sp., *Lepeophtheirus hippoglossi* and *Lernanthropus kroyeri*.

Trials for the development of vaccines for sea lice have continued and proved once again the success of the lice challenge model

developed by the Parasitology Group. This was also put to good effect in a trial assessing the effect of freshwater treatments on lice survival and reproduction after a three-hour exposure to fresh water.

In a new development for Machrihanish we have successfully developed freshwater facilities which has allowed us to carry out several trials on the efficacy and safety of Pyceze, a new fungicide for eggs and freshwater species, and we have developed new facilities for testing of antibiotics against bacterial problems of new species.

Machrihanish Marine Farms Ltd

Following acceptance by the University Court in December 2000 of a business plan for the setting up a new cod hatchery at Machrihanish, a new joint venture company was formed with Lakeland Smolts Ltd, a company owned by the Marine Farm group of Bergen. The new company's plan is to produce and sell around 1.2 million cod juveniles from purpose built state of the art facilities adjacent to the existing facilities at Machrihanish. Grant funding of around £400,000 has been awarded by FIFG and Argyll and the Islands Enterprise and £400,000 share capital introduced from Machrihanish and Howietoun reserves and Lakeland Smolts.

Building of the facilities commenced in August 2001 and is expected to be complete by August 2002, with the first production taking place in April 2003. Seven new staff will be employed in the operation. The company is being jointly run by Dr Robertson and Mr Richard Prickett of Marine Farm Technology Ltd. To date cooperation between the two organisations has been excellent and we hope that in addition to kick starting a new and very much needed industry for Scotland there will be a significant research element for the existing Machrihanish operation.

Stirling Aquatech Ltd

This company, in which we own 10% of the share capital, had a difficult but successful year and we have now reached agreement on sales of the remaining shares to Ewos, the majority owner. This will end our involvement with the Oban operation which started in 1988 and through which much knowledge and experience have been gained.

Stirling Aquaculture

Management support continues to be a central activity for Stirling Aquaculture (STAQ), the consultancy and project management arm of the Institute of Aquaculture. Support continued throughout the year to Acqua Azzurra in Sicily. STAQ manager Bart Vlamincq oversaw the expansion of the offshore cage site with a further 2 rafts of Dunlop (16 x 16 m) cages, taking the total to 24 offshore cages with a combined volume of 80,000 m³. This allowed production to be increased from 1000 to 1400 tonnes per annum. The hatchery was also substantially re-organised and a new oxygen control system installed. This reduced oxygen consumption per kilo of fish produced by 45%. Even greater efficiencies were achieved with respect to artemia consumption (one of the main operating costs), with requirements per million seabream fry cut by 75%. Meanwhile in Turkey, STAQ manager Trevor Meyer helped with the installation and commissioning of a new offshore site at Pinar Deniz, bringing our contract with the company to a successful conclusion. In addition to overseeing the start-up of the new site, Mr Meyer with the support of other Stirling staff, provided training, consultancy and collaborative research, leading to substantial improvements in grow-out survival rates and feed conversion efficiencies, and the practical elimination of a previously significant disease problem. Assistance was also provided with the hatchery, which was upgraded during the year with clear gains in production efficiency. A third management support project commenced in Libya, working with Farnoccean International and the General Aquaculture Development Authority (GADA) to

develop offshore fish farming of sea bream. Jonathan Grubb visited the site in November to assist with preparations and the deployment of cage moorings. Fry were supplied to the project from Acqua Azzurra just at the end of this reporting period.

Sector and market studies form another important component of our activities. The first of these was a study of the ornamental fish sector as a market for pharmaceutical products. This was carried out on behalf of an animal health company with Dr Eva Randall as primary researcher. Dr Randall also made an important contribution to a global study of opportunities for aquatic animal health products entitled "The Aquaculture Market", which is due for publication by Animal Pharm Reports (PJB Publications) in late 2001. Valuable specialist contributions were made by a number of Institute staff with John Bostock providing overall editorship of the report. Another study investigated the value of the Scottish label to the farmed salmon industry. This was conducted in partnership with the Department of Marketing and French consultant Marie Christine Monfort on behalf of Scottish Quality Salmon. The report focused on price issues and the value of various identifiers, including the Tartan Quality Mark and Label Rouge. STAQ also worked with the Department of Marketing on a study of the Scottish salmon sector for the Norwegian Export Council.

Our project with the Kings Lynn Fishing Industry Cooperative to investigate mussel spawning and recruitment in the Wash (East England) was bought to a successful conclusion, providing useful information for future management of the fishery. This involved STAQ researcher Ben Lowen, with scientific supervision and support from Drs Trevor Telfer and Janet Brown. Technicians from the Diagnostics and Water Quality laboratories provided additional support. Another commercially based research project continuing throughout the year was our TCS programme with Alexander Sandison & Sons Ltd in Unst, Shetland. This involves the employment of Luca Montorio, who splits his time between Shetland and Stirling, working on the development and optimisation of water recirculation technology at the Company's salmon hatchery. Results have been exceedingly promising and wider opportunities for exploitation are now being investigated.

In addition to the major projects, staff were kept busy with a range of shorter-term consultancy work. David Currie visited Indonesia and Thailand in support of a shrimp processing project. He also visited Turkey and Lebanon to conduct brief feasibility studies for private shrimp farming projects. Jonathan Grubb worked with staff in the Veterinary Diagnostic and Environment Group troubleshooting unexplained mortality problems at a Scottish salmon site. He also led an appraisal of management options for a salmon farming company faced with a complex disease problem potentially affecting several sites. John Bostock continued to provide occasional advice to the Treasury Solicitor and Argyll and the Islands Enterprise, whilst Professor Muir provided advice on risk assessment and development strategy to Western Isles Enterprise. STAQ also worked with Dr Bill Roy and Professor Richards on various insurance claim assessments and with Bob Bawden of Pisces Aquacultural Engineering on purging systems to prevent taints in tilapia.

STAQ continues to act as the UK National Network Leader for the EC funded Aquaflow project. This involves disseminating information on research projects to the aquaculture community, especially likely end-users of the research. A new round of funding commenced during the year, with the scope of the project extended to include non-EC funded as well as EC funded research. STAQ are also contributing to the EC funded GENESIS project, which commenced in July 2001, investigating the feasibility of integrated approaches to mariculture. European funding through Aqua TT also allowed the "Computers in Aquaculture" course materials to be updated, ready for future short-course initiatives.

One of the most memorable events of the year was the Scottish-Norwegian conference on "Sustainable Futures for Marine Aquaculture". This was held at the University Management Centre in June with primary sponsorship from the Norwegian Federation of Fish and Aquaculture Industries through the Royal Norwegian Consulate General. STAQ provided planning and management for the event, which involved around 60 participants from Scotland, Norway and Ireland. Presentations from invited speakers were complemented with participatory workshops and a very enjoyable social programme. STAQ was also represented at Acquacoltura International 2001 (Verona) by Trevor Meyer, and Professor Muir visited Indonesia to represent us at a workshop on sustainable marine aquaculture.

Promotional efforts during the year focused on the Aquaculture Technology Centre (ATC). STAQ acts as the "front office" for this grouping of commercial services, which have been strengthened through a European Regional Development Fund grant through the East of Scotland European Partnership. With Government, and hence University policy once more emphasising the importance of academic assets for regional commercial development, the ATC is likely to have an increasingly important role to play in supporting the Institute's commercialisation and knowledge transfer activities.

There were several staff changes during the year. Laure Demerson moved back to her native France to take up a post with UCAAB, whilst Ben Lowen moved to Canada and on to a PhD programme that builds on his work with mussel populations in the Wash. We wish both well in their new careers. Eva Randall completed two short-term contracts and remains an associate consultant for STAQ, whilst Paul Bulcock was welcomed to the STAQ office to provide research and other project support. Our team of associate consultants was further strengthened through closer links with Zarko Peric (fish health and marine hatchery specialist) who is based in Malta.

Stirling Aquaculture has always operated as a commercial entity within a competitive international environment with its key strength being an ability to combine practical aquaculture business experience with technical understanding gained from leading edge aquaculture research. The group remains well placed to provide this distinctive service, and convinced of its effectiveness and commercial value. At the same time it is also recognised that as the sector evolves, continued innovation in services will be required to ensure the needs of all potential clients can be met. STAQ is responding to these challenges and looks forward to another busy and exciting year.

Appendices

Appendix I

Advisory Committee

Professor C Bell	Principal of University & Chairman Scientific Director, Edinburgh Centre for Rural Research	Dr G H Gordon, OBE	Past Chairman, European Fish Farmers Association
Professor I D Aitken, OBE	Vice President of the Royal Society of Edinburgh	Professor R H Richards	Director of Institute (<i>ex officio</i>)
Professor Sir James Armour	University Secretary (<i>ex officio</i>)	Professor L G Ross	Dean of Faculty of Natural Sciences (<i>ex officio</i>)
Mr K Clarke	Managing Director, Lithgows Limited,	Dr P Sorgeloos	Artemia Reference Centre, University of Ghent
Mr H M Currie	Chairman CBI Scotland	Dr J Tarbit OBE	Former Senior Fisheries Adviser, DFID
Dr E Edwards, OBE	Vice President, Shellfish Association of Great Britain	Professor P N Wilson, CBE	Professor Emeritus, University of Edinburgh; General Secretary, Royal Society of Edinburgh
Dr Ph. Ferlin	Director, Institut National de la Recherche Agronomique	Mr N Yonge	British Trout Association

Appendix III

PhD Students 2000/2001

Mr N Ahmed, B.Sc., Bangladesh, (British Council/DFID/BAU)
 Mr M Z Ali, B.Sc., M.Sc., Bangladesh, (World Bank/Private)
 Ms E Alorend, B.Sc., M.Sc., France, (BMFA, NUTRECO)
 Mr A K Amirkolae, B.Sc., M.Sc., Iran, (Ministry of Culture & Higher Education)
 Ms P Armstrong, B.Sc., UK, (Technology Foresight Challenge)
 Mr G Arthur, B.Sc., UK, (North Atlantic Fisheries College)
 Mr A Asiain Hoyos, B.Sc., M.Sc., Mexico, (CONACyT)
 Ms B Banks, B.Sc., M.Sc., UK, (BBSRC CASE/SSGA)
 Ms B Basso Mercado, M.Sc., Mexico, (CONACyT)
 Mr A Bell, B.Sc., M.Sc., UK, (NERC/University Staff)
 Mr S Bell, B.Sc., M.Sc., UK, (Technology Foresight)
 Mr I Berrill, B.Sc., M.Sc., UK, (NERC CASE)
 Mr M Betancourt-Lozano, B.Sc., M.Sc., Mexico, (CONACyT)
 Ms C Boonphakdee, B.Sc., M.Sc., Thailand, (Government Scholarship)
 Mr J Botero, M.Sc., Colombia, (Colombian Government/INPA)
 Mr I Brierley, HND, B.Sc., M.Sc., UK, (EU)
 Mr C Brown, B.Sc., M.Sc., (Alkion Fish Farms)
 Mr S Bunting, B.Sc., UK, (Technology Foresight)
 Mr R Butler, B.Sc., UK, (MAFF Link)
 Mr A Campos-Mendoza, B.Sc. (Hons), Mexico, (CONACyT)
 Mr R Campos-Ramos, B.Sc., M.Sc., Mexico, (CONACyT)
 Ms P Carter, B.Sc., UK, (BBSRC CASE)
 Ms A-M Cato, B.Sc., M.Sc., UK, (Private)
 Mr D Chan, B.Sc., M.Sc., UK, (BBSRC/Silsoe)
 Mr J Chara, B.Sc., M.Sc., Colombia, (Colombian Government)
 Mr P Christoflogiannis, B.Sc., M.Sc., Greece, (Greek Government)
 Mr R Corner, HND, B.Sc., UK, (NERC CASE)
 Ms C Crichton, B.Sc., M.Sc., Canada, (EU)
 Mr S Cross, B.Sc., M.Sc., Canada (Private)
 Mr L M Del Campo Barquin, B.Sc., Chile, (Private)
 Mr R Del Rio-Rodriguez, B.Sc., M.Sc., Mexico, (CONACyT)
 Mr G Delgado Morales, B.Sc., M.Sc., Ecuador, (British Council)
 Mr J Deverill, B.Sc., M.Sc., UK, (Howietoun Silver Jubilee Studentship)
 Mr T Dixon, B.Sc., UK, (NERC)
 Mr M. T. Ezaz, B.Sc., M.Sc., Bangladesh, (Private)
 Mr A R Faruk, S.S.C., H.S.c., B.Sc., Bangladesh, (British Council)
 Ms M Felsing, B.Sc., M.Sc., Denmark, (Faculty of Natural Science Studentship)
 Mr M Freeman, B.Sc., B.Tech., UK, (BBSRC CASE/SSGA)
 Mr M Fuentes, B.Sc., M.Sc., Ecuador, (Chilean Government)
 Ms W Futter, B.Sc., M.Sc., UK, (BBSRC CASE/BTA)
 Mr K Glover, B.Sc., UK, (Norwegian Research Council)
 Mr C Gonzalez Vera, Lic., Mexico, (CONACyT)
 Mr J Good, B.Sc., UK, (EWOS)
 Ms D Guerrero Tortolero, M.Sc., Mexico, (CONACyT)
 Ms L Halfyard, B.Sc., M.Sc., B.Ed., Canada, (Private)
 Mr A Hamilton, B.Sc., M.Sc., UK, (BBSRC)
 Mr R B Hassan, B.Sc., M.Phil., Malaysia, (Government of Malaysia)
 Ms N Hastings, B.Sc., UK, (NERC)
 Ms A Holzer, B.Sc., M.Sc., Austria, (Austrian Academy of Sciences)
 Ms E Irving, B.Sc., UK, (NERC)
 Ms A N Isyagi, M.Sc., B.V.M., Uganda, (World Bank Lake Victoria Project)
 Mr S-C Jeng, B.Sc., M.Sc., Taiwan, (Taiwan Government)
 Mr M Khan, B.Sc., M.Sc., Bangladesh, (British Council)
 Mr R D Kim, B.Sc., Korea, (Supreme D)
 Mr J Y Kwon, B.Sc., M.Sc., Korea, (Private)
 Mr P Lewis, B.Sc., M.Sc., UK, (University of Stirling Studentship)
 Mr A MacNiven, B.Sc., M.Sc., UK, (DFID)
 Mr C Mahika, M.Phil., B.Sc., Tanzania, (World Bank Lake Victoria Project)
 Ms L Marshall, B.Sc., M.Sc., UK, (AVL and Biomar)
 Mr C Mazorra de Quero, Lic., Spain, (Technology Foresight Challenge)
 Ms R McWilliam, B.Sc., UK, (NERC)
 Mr M Medina Ginepro, B.Sc., Chile, (Chilean Government)
 Mr D Miles, B.Sc., UK, (Aquaculture Vaccines Ltd)
 Ms L Montorio, B.Sc., Italy, (Private, Alex Sandison & Sons Ltd.)
 Ms A L Morgan, B.Sc., M.Sc., UK, (NERC CASE)
 Mr D Morris, B.Sc., UK, (NERC)
 Mr F Murray, B.Sc., M.Sc., UK, (DFID)
 Mr J P Neary, B.Sc., M.Sc., Canada, (University of Stirling Studentship)
 Mr D Nhampulo, B.Sc., Mozambique, (Educational Trust/British Council)
 Mr M Peck, B.Sc., M.Sc., UK, (NERC)
 Mr E Perez Sanchez, B.Sc., M.Sc., Mexico, (BC/CONACyT)
 Mr O Perez-Martinez, B.Sc., M.Sc., Spain, (Marie Curie Fellowship)
 Ms N Petchsupa, B.Sc., M.Sc., Thailand, (Royal Thai Government)
 Ms K Plant, B.Sc., M.Sc., UK, (NERC CASE)
 Ms L Pollock, B.Sc., UK, (DFID)
 Mr D Riddell, B.Sc., M.Sc., UK, (NERC CASE)
 Mr A Salam, S.S.C., H.S.C., B.Sc., M.Sc., Bangladesh, (British Council)
 Mr N Sanchez-Perez, B.Sc., M.Sc., Mexico, (CONACyT)
 Ms S Sayeed, B.Sc., M.Sc., Bangladesh, (Commonwealth Scholarship)

Mr P Scott, B.Sc., M.Sc., Brazil, (Brazilian Government)
 Ms R Sharif, B.Sc., M.Sc., UK, (Moredun Research Institute)
 Ms N Sheriff, M.Phil, B.Sc., UK, (University of Stirling Studentship)
 Mr W Taparhudee, B.Sc., M.Sc., Thailand, (Royal Thai Government)
 Mr J F Taylor, B.Sc., M.Sc., UK, (Commercial Fish Farm)
 Mr N Taylor, B.Sc., UK, (Environment Agency & BTA)
 Ms A Treuner, Diplome, Germany, (DAAD/EU Project TROCA-WET)
 Ms E Turgut, B.Sc., M.Sc., Turkey, (Gaziosmanpasa University)
 Mr J Vargas-Vazquez, B.Sc., M.Sc., Mexico, (CONACyT)
 Mr I Vatsos, B.Sc., M.Sc., Greece, (Greek Government/Private)
 Mr G Von Hoegen, B.Sc., M.Sc., Germany, (Private)
 Mr M Wayland, B.Sc., UK, (NERC Case)
 Ms S Yuksel, B.Sc., Turkey, (Food and Agriculture International)

MSc by Research

Mr S Al-Khamees, B.Sc., Saudi Arabia, (Saudi Arabian Government)
 Mr E Gozogozoglu, B.Sc., Turkey, (Food and Agriculture International)
 Mr S Powell, B.Sc., UK, (University of Stirling)
 Mr R Serwata, Diploma in Animal Technology, UK (Private)

MSc Aquaculture 2000/2001

Ms S Chew, Singapore (Agri-Food and Vet)
 Ms M Clegg, UK (BBSRC)
 Mr J Comas Morte, Spain (Private)
 Ms C Coulon, France (Ministry of Agriculture)
 Ms S Dance, UK (SAAS)
 Mr V Defaux, France (Private)
 Mr A G Hartley Alcocer, Mexico (CONACyT)
 Mr A Hendry, UK (Private)
 Mr D Macleod, UK (SAAS)
 Mr V Papadopoulos, Cyprus (Private)
 Ms H Roussel, France (Ministry of Agriculture)
 Mr V Symiiridis, Greece (Private)
 Mr M Thompson, UK (BBSRC)
 Mr V Tsiaras, Greece (Private)
 Mr C Yanes-roca, Spain (Private)
 Mr G Zemianites, Greece (Private)

MSc Aquatic Pathobiology/Veterinary Studies 2000/2001

Ms I Cote, Canada (Private)
 Mr K Foyle, Ireland (Private)
 Mr C Komar, France (MERIAL, Private)
 Ms S Kueh, Singapore (Primary Production Dept.)
 Ms L Labrie, France (MERIAL, Private)
 Mr C McGurk, UK (Private)
 Ms E Ooi, Singapore (Private)
 Mr G Spiliopolous, Greece (Private)
 M N Steiriopolous, Greece (Private)

Appendix IV

MSc Aquaculture Theses 2000/2001

- Chew S. Growth and pathological consequences of pollutant challenge on plaice larvae of different nutritional status
- Clegg M. Sea lice and sea water composition
- Comas Morte J. The tolerance of *Chirostoma estor estor* to saline environments
- Coulon C. Physical structure and chemical properties of activated carbon: an investigation on the potential exploitation in biological fixed-film systems
- Dance S. Behavioural and metabolic variations in relation to growth rate in *M. rosenbergii*
- Defaux V. Analysis for demand for freshwater fish in Tamil Nadu
- Hartley Alcocer A. A comparison of the breeding performance of GIFT and Chitralada Nile tilapia strains
- Hendry A. Importance of aggression in confined conditions on spawning performance of mouthbrooders
- Macleod D. Identification of sources of off-flavour compounds in farmed trout
- Papadopoulos V. Growth rates of *M. volenhovenii*
- Roussel H. Pesticide impacts of moulting behaviour and development in the larvae of *Penaeus vannamei*
- Symsiridis V. Lipid and fatty acid composition and growth/survival of cod and/or haddock larvae using eggs from wild caught broodstock and eggs from hatchery-reared broodstock
- Thompson M. Single bay management in coastal aquaculture; development of strategies
- Tsiaras V. A nutritional study of an aspect of feeding or diet manipulation in pandora (*Pagellus erythrinus*) in Greece
- Yanes-Roca C. Assessing productivity of free-breeding tilapia in farmer-managed irrigation tanks in the Dry Zone, Sri Lanka
- Zemianites G. The development of a standard challenge method for *Lernanthropus kroyeri* (Crustacea: Copepoda) in sea bass

MSc Aquatic Pathobiology/Veterinary Studies Theses 2000/2001

- Cote I. Chemotherapy of 'white spot' caused by the ciliate protozoan *Ichthyophthirius multifiliis*
- Foyle K. Experimental reproduction and pathology of *Pasteurella salmonicida*, a new pathogen of farmed salmonids
- Komar C. Effects of water treatment on incubation of demersal, adhesive eggs of the bullseye puffer (*Sphoeroides annulatus*)
- Kueh S. Iridovirus of tropical marine fish
- Labrie L. Effect of methylparathion on the susceptibility of shrimp to bacterial challenge
- McGurk C. Development and characterisation of monoclonal antibodies to ISAV
- Ooi E. Molecular biological study of white spot syndrome virus
- Spiliopoulos G. Effects of parasitic gill infections on sea bass in Greece
- Steiroopoulos N. Detection of rickettsia-like organisms (RLO) in sea bass farms using IHC, IFAT and PCR

PhD Theses 2000/2001

- Ahmed N. Socio-economic aspects of freshwater prawn culture development in Bangladesh
- Deverill J. The post-stocking behaviour of hatchery-reared brown trout (*Salmo trutta* L.)
- Iving E. Ecotoxicology responses of the mayfly *Baetis tricaudatus* to dietary and water-borne cadmium
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- Scott C.L. Calanoid copepods and ice fauna in Arctic fjords and regions of the marginal ice zone around Svalbard: lipids; stage distributions; trophic interactions and life strategies
- Salam A. The potential of geographical information system based modelling for aquaculture development and management in south western Bangladesh
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Appendix V

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