2021

afbi AGRI-FOOD & BIOSCIENCES INSTITUTE

Science Impacts 2021

Leading | Protecting | Enhancing

Contents

Introduction

I am pleased to introduce the fourth in the series of AFBI Science Impacts in which we highlight some of our latest achievements and key outcomes.

I trust you will enjoy reading about the successes of AFBI over the last year.

The Agri-Food and Biosciences Institute (AFBI) is Northern Ireland's largest provider of agri-food science. As an arms-length body of DAERA, AFBI science plays a crucial role in providing the underpinning research and development, diagnostic and analytical testing, emergency response capability and expert scientific advice required to support the various work programmes of DAERA and the wider requirements of the agri-food industry.

This booklet reflects the excellence of our scientists through their ability to conduct highly relevant applied science, addressing local needs but also making a scientific impact nationally and internationally.

Science is increasingly multidisciplinary and frequently involves a range of organisations working together. To deliver many of the achievements within this booklet, AFBI is delighted to work alongside industry, government and academic colleagues to ensure that the work we do has direct relevance and to maximise both the impact and reach of the science work.

Against that backdrop of global and local challenges, the need for science has never been greater. AFBI is very well placed to contribute to meeting these challenges through our work which centres on our three key themes of leading improvements in the agri-food industry, protecting animal, plant and human health and enhancing the natural and marine environments. The achievements noted in this booklet provide testament to these goals.

Finally I wish to gratefully acknowledge the various funding bodies who have supported our scientific achievements and outcomes.

Josephine Kelly

Acting CEO

afbi

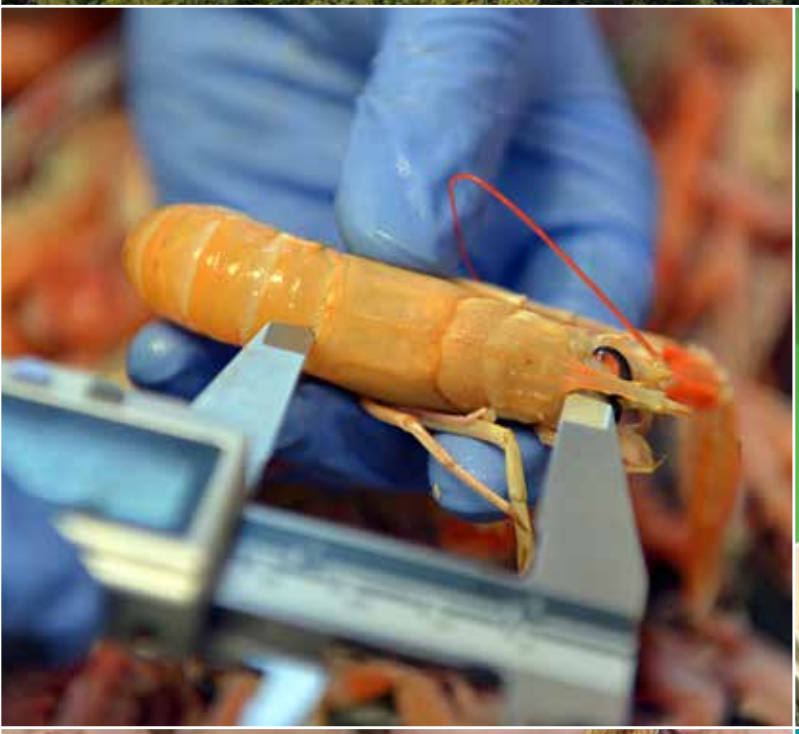
Who we are and What we do

AFBI's VISION

Advancing the local and global agri-food sectors through scientific excellence.

AFBI's MISSION

Enhancing industry innovation and informing government policy across the agri-food and rural sectors through excellence in scientific services, research & development and knowledge.



Key Metrics for AFBI in 2020

PROTECTING THE NI ECONOMY

In the previous 5 years to 2021,
AFBI have delivered on

3 MILLION

ANIMAL, PLANT AND FOOD SAFETY TESTS

In support of sales from the agri-food industry to the value of

£3.6 BILLION

TOTAL SALES

£1.1 BILLION

£2.5 BILLION

INFORMING POLICY

AFBI has delivered

95

EVIDENCE AND INNOVATION

Projects for DAERA

KNOWLEDGE TRANSFER

AFBI has delivered

1881

OUTREACH ACTIVITIES

Over the past 5 years

AFBI has delivered

44,000 **COVID-19 Tests**

in support of Health Authories

WORKING WITH OTHERS

AFBI works with partners across

35

COUNTRIES

AFBI have secured

£45 MILLION

OF EXTERNAL RESEARCH GRANTS AND CONTRACTS

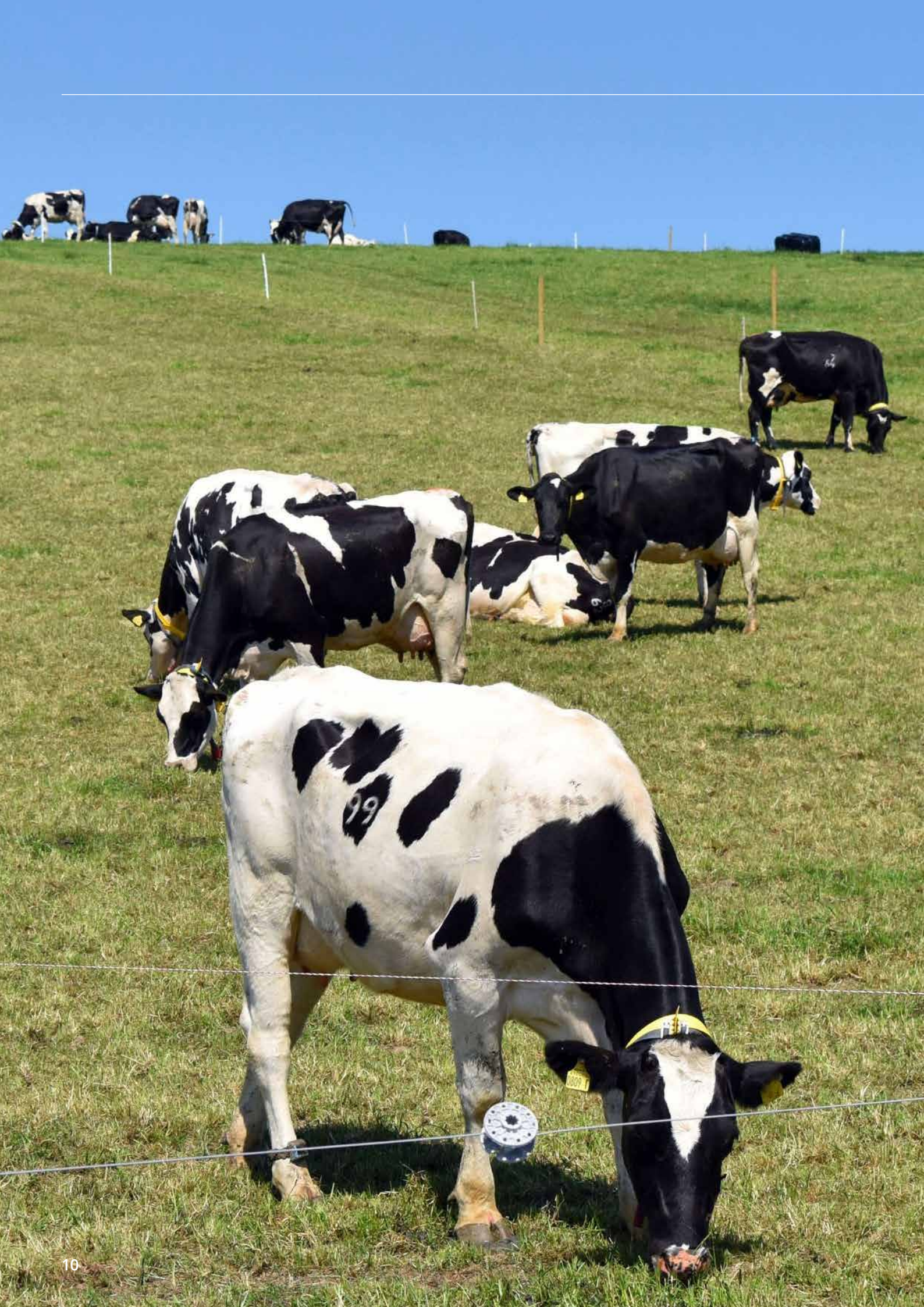
EXCELLENCE IN SCIENCE

AFBI has delivered

556

SCIENTIFIC PAPERS

Over the past 5 years



Section 1

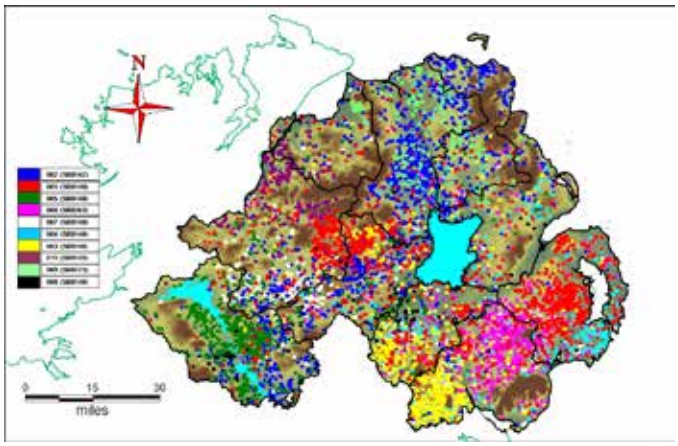
Leading improvements in the agri-food industry

Bovine tuberculosis – supporting the industry through a turbulent year

Research Leads: Dr Emma Campbell, Dr Adrian Allen, Dr Masoud Shirali, Dr Robin Skuce

Never before has science been so constantly in the public consciousness and under such scrutiny, highlighting the importance of altruistic scientific services and research in providing vital evidence and options for infectious disease control. However, despite sustained efforts, bovine tuberculosis (TB) continues to be the most costly, complicated, controversial and disruptive endemic disease in the UK and Ireland, impacting adversely on public finances, affected farming businesses and their families. Many of the same issues that are playing out in real-time with the COVID-19 pandemic are equally relevant to TB, such as lockdown, R, diagnostic performance, track and trace, aerosols, surfaces, super-spreading, asymptomatic transmission, new variants, messaging, behaviour change etc.

Despite the COVID-19 disruption, a small, dedicated, multi-disciplinary AFBI team continues to support the industry by providing accredited services for laboratory TB confirmation of field diagnosis, supplementary blood testing and pathogen track and trace. Our role also includes keeping up-to-date with relevant scientific developments and providing objective scientific evidence to stakeholders. As an example of 'thought-leadership' the following peer-reviewed Hypothesis and Theory article authored by AFBI scientists was published as a lead article in a Special Edition of Frontiers in Veterinary Science.



Geographical clustering of the ten most common strains of Mycobacterium bovis in NI, 2003-2008. The bovine TB problem presents as a series of micro-epidemics.

The article has been read 18,664 times to date by the international science/policy community and has been cited 37 times in other publications, placing it in the top 4% of articles read/cited in the whole *Frontiers in* series of scientific journals: Allen AR, Skuce RA, Byrne AW. Bovine Tuberculosis in Britain and Ireland - A Perfect Storm? *Front Vet Sci*. 2018 Jun 5; 5:109.

AFBI also undertakes DAERA-commissioned and externally-funded, collaborative research to provide evidence to inform policy- and decision-makers, stakeholders and the general public on TB risks and potential mitigations. Our research continues to develop new knowledge, providing scientific support and innovation to the TB control programme in these

unprecedented times. Below we highlight and discuss selected, recent TB research achievements.

Investigating TB exposure risks at pasture:

Substantial previous work has investigated potential routes of transmission when animals are housed, as well as investigating cattle movements, including to/from markets/shows and buying-in cattle. However, little was known about transmission in cattle while grazing. Most cattle in NI are grazed outside during the warmer months, where they may encounter potential sources of *Mycobacterium bovis* and become infected. Such sources may include

badger setts and latrines as well as contact with neighbouring cattle across a hedge/fence boundary.

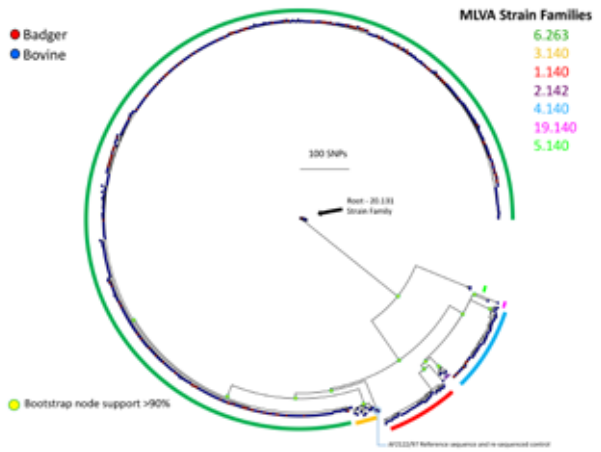
Novel epidemiological and ecological research conducted by AFBI, QUB and DAERA colleagues studied the time cattle spent in fields with badger setts or latrines and in fields beside neighbouring cattle. Farms (N=18) recorded their cattle grazing locations across an entire grazing season, the farms included both beef and dairy herds. The study found that fields with badger setts and latrines did not seem to be avoided when selecting fields for cattle grazing. This may be due to farmers not realising that they are a risk factor in the transmission of TB or they may not be aware that a sett or latrine was present in the field. This highlights the need to ensure farmers are educated fully on the risks involved in TB and what they can do on their own farm to minimise exposure to such risks. The final aspect of the study investigated how much time cattle spent in fields beside cattle from neighbouring herds. It was found that 18% of days were spent in such fields. Not only does this represent a risk for transmission of *M. bovis* but also other infectious diseases. These results can be used in education for farmers locally and to inform future epidemiological studies investigating TB transmission in NI.

Cattle genetics and TB:

It is biologically untenable that genetic variation in cattle does not contribute to the outcome of TB infection. Parallel genetics studies in Ireland and the UK indicated that there was exploitable, heritable genetic variation in resistance to TB, based on the TB test performance of the daughters of sires.

Heritability was estimated at 0.14, which compares favourably with the heritability of milk yield of 0.30. There are high and low TB risk dairy and beef sires. Consequently, it should be possible to breed selectively for enhanced TB resistance by favouring low TB risk sires, or avoiding high TB risk sires. To discover and map genetic variations associated with TB resistance, AFBI, collaborating with the Roslin Institute, delivered a large genome-wide association study (GWAS) in local dairy cows. TB case and control cattle were DNA typed at high density, providing a further (genomic) heritability estimate of 0.23, confirming the earlier findings. Several genetic markers were associated significantly with the TB case definition and further markers continue to be discovered.

Susceptibility to TB turns out to be a complex, multi-gene trait. However, selective breeding for improved resistance in the national herd is now feasible as a complementary control measure and the TBadvantage index, developed by AHDB and Scotland's Rural College, based on



Phylogenetic tree of M.bovis strain families circulating in the Co.Down Test and Vaccinate or Remove zone. 619 M.bovis isolates separated by 1,562 single nucleotide mutations

well-recorded TB test data, is now being implemented by industry and includes NI TB data.

The revolutionary technology of genomics can use DNA information on a large scale to predict the future performance of particular traits. Encouragingly, further genetic gain is now achievable via genomic prediction on this new TB trait and relatively resistant sires tend to have good Profitable Lifetime Index scores. AFBI undertook a further, targeted, case-control GWAS based on local dairy cows, funded by DAERA project 16-3-05, which has improved further the 'reliability' of the TB selection index. Detailed analyses by the Roslin Institute allayed initial concerns about relying on TB test data to make such genetic predictions. Provisional recent data from the AFBI GWAS are consistent with there being no significant genetic difference between TB reactors and cows that present lesions at routine slaughter; both phenotypes are TB cases and can be used in the predictions. AFBI wishes to thank herd-keepers who participated in the studies and contributed to the development of a new tool in the TB control toolbox. AFBI would recommend that herd-keepers exploit the new selection index, alongside other production indices and existing TB control measures.

Getting to know the enemy:

Genetic tests have been developed by AFBI scientists, which discriminate the TB pathogen at different geographical and evolutionary scales. These methods have essentially two applications: (1) to investigate important aspects of TB epidemiology using descriptive, analytical and disease mathematical modelling and (2) to inform TB outbreak investigations and contact tracings (track and trace). The pathogen population shows striking genetic structure, with different pathogen types clustered in space. Consequently, the epidemic is strongly driven by local risk factors and is, effectively, a series of local micro-epidemics. Cattle and badgers share the same pathogen types at a regional scale, consistent with inter-species transmission. In collaboration with the Universities of Glasgow and Edinburgh and using pathogen whole-genome sequencing (WGS) for the first time, we provided the first genetic evidence of an ongoing interaction with badgers at the farm scale, as well as evidence consistent with within-herd spread (amplification) in cattle.

Pathogen WGS improves resolution and enables a better understanding of disease transmission dynamics. We collected and sequenced 619 *M. bovis* isolates from historical (pre-2014) and contemporary (2014-2017) badgers and cattle in an endemic 100 km^2 study area in NI. We applied advanced statistics and family tree (phylogenetic) analyses and structured coalescent methods to investigate between-host (cattle-badger) transmission dynamics. We found eight major lineages of *M. bovis* circulating, only one was endemic in the region since the 1970s. The non-endemic lineages were likely imported by cattle movement, with most failing to seed foci of persistent infection. Within the endemic lineage we observed that the vast majority of genetic diversity in the pathogen population was found within cattle hosts.

Importantly, we observed that cattle-to-badger transmission was approximately three times more common than badger-to-cattle transmission. These data are consistent with badgers from this small study area being involved in disease dynamics, but playing a reduced role compared to cattle. These findings are crucial to the NI TB evidence base, but in stark contrast to those from a similar study conducted in Gloucestershire, GB, in which AFBI collaborated. In that study, of the transmissions detected between hosts (cattle and badgers), badger-to-cattle transmissions were ten times more common than cattle-to-badger transmissions, although cattle were still at slightly higher risk from other cattle in the Gloucestershire study. These contrasting data suggest that TB dynamics may be context-dependent and vary across the landscape, and that there may not be a single paradigm for TB control in all regions. Such local evidence has been highly-anticipated and is vital for TB decision- and policy-makers and stakeholders.

Conclusion:

Advances in biosciences are allowing AFBI to undertake studies that were inconceivable just a few years ago. New tools, big-data and evidence-based approaches are allowing AFBI to contribute to solving some of society's biggest real-world problems. DNA technology is revolutionising human medicine and similar advances are already rapidly changing the way AFBI diagnoses and understands animal disease. By developing capacity and capability AFBI is contributing to improved and more sustainable control of infectious diseases in livestock and is playing an important role in supporting local food production and livestock trade.

Testimonials:

AFBI's ongoing bovine TB research programme is crucial in monitoring the current programme and informing its future direction. A strong and internationally-recognised bTB research group is, and will continue to be, a key component of the NI bTB programme.

Dr Sam Strain, Scientific Advisor to TBEP (TB Eradication Partnership)

A comprehensive and well-targeted research agenda has provided the competent authorities with relevant evidence to reinforce the implementation of the available control and eradication measures.

EC Food and Veterinary Office Audit

We fully support and appreciate the work of AFBI in ongoing areas of TB research - the findings will be key to the development of a sound bTB eradication policy, which is based on the best possible scientific evidence.

Raymond Kirke, Senior Principal Veterinary Officer, TB Strategy, DAERA

Quality and relevance of research, leadership, reputation, resources: work is world-leading. Scientists are working at the forefront of their field internationally and their work has an important and substantial impact in the field.

External Peer-review Panel

Supporting UK agricultural policy development

Research Leads: , Dr Erin Sherry, Dr Siyi Feng, Dr Paul Caskie, Dr Myles Patton

Following Brexit, authority over agricultural policy returns to the UK and as agriculture is a devolved matter this means increased responsibilities for Northern Ireland and the other UK administrations.

AFBI economists were commissioned, by the devolved administrations, to investigate post-Brexit policy scenarios using the FAPRI-UK modelling system. The purpose was to evaluate the impact radical policy positions could have on farm gate prices, livestock numbers, crop areas, production volumes, and trade flows, in the expectation that the results would help inform the nature and pace of future policy reforms.

Two main avenues of enquiry were undertaken: the reduction or elimination of current CAP Pillar I 'decoupled' direct payments, and, alternatively the return across the UK (excluding Wales) of farm subsidies linked to the volume of production, referred to as 'coupled' support. Three future trade arrangements between the UK and EU were incorporated within the analysis. The main findings were:

The UK-EU trading framework in place when decoupled direct payments are eliminated, has a significant effect on production volumes and farm gate prices;

Reducing or eliminating decoupled direct payments to farmers has uneven impacts on production and farm-gate prices for the main UK agricultural commodities;

Agricultural commodities produced by farm sectors that are most dependent on subsidies for farm income, experience the biggest projected changes in farm-gate prices and production volumes, most notably beef and sheep meat (see Figure 1 for beef production and Figure 2 for sheep production);

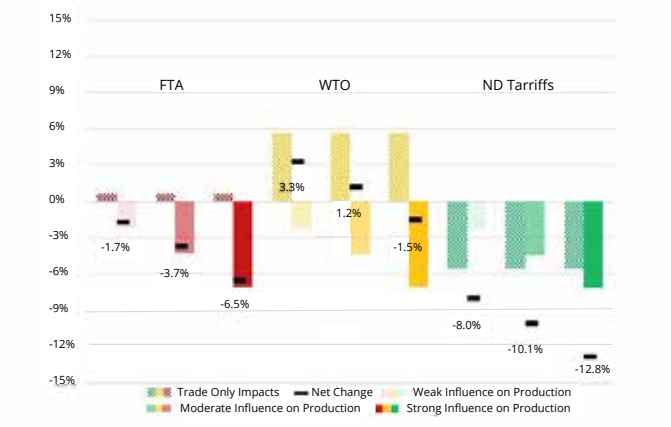


Fig 1. Projected changes in beef Production

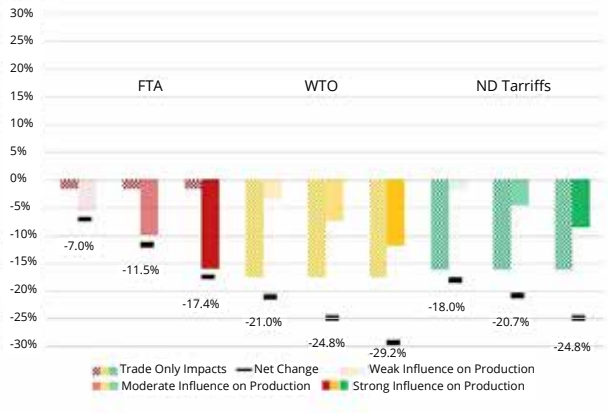


Fig 2. Projected changes in sheep production

Delivering the current farm budget using only coupled support payments works to maintain existing livestock numbers and crop areas, production volumes and farm gate prices, especially when introduced in conjunction with a Free Trade Agreement between the UK and EU.

This analysis has been discussed extensively with policy makers across the UK and industry representatives. It has made a significant contribution to the body of evidence used by policy makers within the UK's four agriculture administrations to prepare a range of papers and briefings.

Following an online workshop with key stakeholder, Dr Mike Johnston, Chief Executive at Dairy Council for Northern Ireland and Northern Ireland Director, Dairy UK, commented:

'The project report has been helpful in challenging our thinking, and in teasing out the issues around Pillar 1 payments to ensure the economic and environmental sustainability of farming businesses. The scenario approach adopted by the project is ideally suited for this type of work, and has been useful in stimulating discussion about future policy.'

The study was co-funded by DEFRA, Scottish Government, Welsh Government and DAERA.

Dairy sector productivity growth in Northern Ireland: trends and drivers

Research Leads: Dr Kehinde Oluseyi Olagunju, Dr Aurelia Samuel & Dr Erin Sherry

Increasing farm productivity is an essential element in sustaining the international competitiveness of the Northern Ireland dairy sector. Increasing farm productivity will likely also be a key goal if NI's future agricultural policy. Limits on the availability of factors of production such as land and labour, as well as changes in policy and market conditions, mean it is important to gain a better understanding of the sector's performance over recent years. Findings will help to maintain and improve its competitiveness in a changing national and international context, especially following Brexit.

Recent DAERA-funded research, carried out by AFBI Economics Research Branch, sought to examine productivity trends (as shown in Figure 1) and drivers for dairy farms in Northern Ireland. The study computed an aggregate dairy sector productivity measure as well as identifying significant factors impacting farm level productivity.

Findings show the dairy sector productivity improved (growth averaging 0.5% a year) between 2005 and 2016 due to output increasing relative to input. Drivers of productivity included increasing herd size, stocking density, and higher educational attainment, while increasing labour input per cow and purchased feed per cow tended to have a negative impact. The results show that capital investment improves productivity, although benefits tend to be delayed.

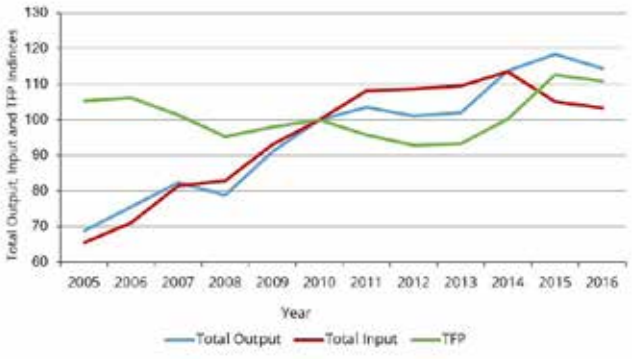


Fig 1. Northern Ireland Dairy Farm Sector Total Factor Productivity (TFP), Total Output & Total Input Indices (2010=100), 2005 – 2016

The study identified strategies and best practices to help dairy farms improve productivity. These included efficient management of inputs which may involve increasing labour or capital to achieve more from available land. For example, improving grassland management and investing in technology may help accelerate improvements in efficiency, competitiveness, and sustainability of the sector. Moreover, to maximise the gains from innovative dairy technologies an appropriate set of farmer skills and competencies is also needed. The research has been presented to the research community and policy stakeholders in the UK and beyond, and forms an important part of the evidence base used by policy makers to develop policy under the 'increased productivity' theme of the Northern Ireland Agricultural Policy Framework.

To further this objective, AFBI-Economics Research is currently developing a whole farm model to assess the impacts of policy, markets and farming factors on economic performance of the dairy sector.

Productivity growth is a key objective of DAERA's future agricultural framework. The analysis undertaken by AFBI-Economics as part of this project is making an important contribution to the development of policy by providing a comprehensive understanding of the drivers of productivity growth on local farms.

Paul Keatley, Department of Agriculture, Environment and Rural Affairs.

Grass and climate change: early June is now mid-May

Research Leads: Dr Eamonn Meehan and Prof Trevor Gilliland

Grassland scientists in the 20th Century had observed that perennial ryegrass variety heading dates fluctuated each year at official seed testing sites throughout the UK. Decades of grass variety evaluation trials at AFBI Crossnacreevy has generated an extensive data set of varieties' heading dates and dry matter yields for each year.

AFBI scientists analysed data from Crossnacreevy along with previously published work and noted that the heading dates of early heading varieties fluctuated the most from year to year whereas those of later heading varieties were more stable. Intermediate heading varieties were found to head, on average, in early June for the period 1969-1973 but by mid to late May in the period 2004-2013 likely as a result of warmer springs due to climate change. Heading dates, and therefore timing of silage harvest for optimal nutritional value was found to be earlier in general but less predictable from one year to the next. Knowing that grass maturity dates are more predictable for later heading varieties improves confidence in planning feed budgets for grazing herds in summer and for the extended grazing season.

Some grass varieties are more equal than others

Although perennial ryegrass varieties may often look or cost the same they are not all equal in terms of yield, quality or persistence.

When cattle eat grass most of each bite is water. Grass is normally around 19% Dry Matter (DM) and 81% water however this varies throughout the growing season and according to ploidy. Diploids normally contain about 19.4% DM and tetraploids 18.4%.

Bearing in mind that many factors will determine how much grass is eaten by cattle, if 100 cows each ate 70kg of fresh grass per day for six months those eating

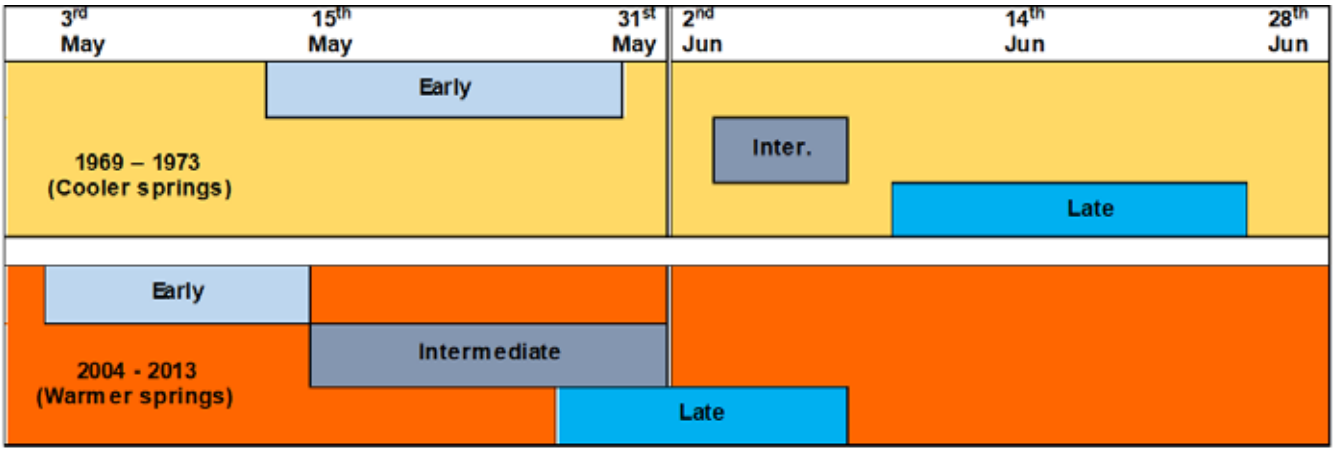


Fig 1 Range of heading dates for each maturity group at Crossnacreevy 1969-1973 and 2004-2013

Different varieties of plots of perennial ryegrass in a trial at Crossnacreevy.

the diploids (i.e. 19.4%) would consume 12.5 tonnes of dry matter (125kg per cow) more than those eating the tetraploids.

Differences also occur between the DM% values of heading groups of each ploidy and some varieties can have significantly higher or lower DM% than others in the same heading and ploidy group. Further work will be done in this area as a number of grass breeders and seed merchants have expressed interest in these findings which may provide a useful quality to distinguish amongst the better varieties.

Ultimately, perennial ryegrass varieties with more stable maturity dates and higher DM% will facilitate more precise grassland management and improve grass intakes, especially at the critical 'shoulders' of the grazing season.

Breeding for improved lamb performance: let's RamCompare!

Research Leads: Dr Aurélie Aubry and Dr Naomi Rutherford

Genetic improvement on commercial sheep farms is largely achieved through the purchase of breeding males. The adoption of estimated breeding values (EBVs) into flock breeding programmes can increase both animal performance and the rate of genetic gain within sheep flocks, which will also reduce their environmental footprint. However, at present it is estimated that only 40% of sheep holdings in the UK use EBVs to select new breeding sires.

'Loughgall rams': Sires of either a high or low EBV for muscling were evaluated

In collaboration with AHDB and Sheep Ireland, AFBI Livestock Production Sciences Branch have been evaluating the effects of using recorded sires of either a high or low EBV for muscling on their progeny. This involved monitoring the performance of more than 840 lambs (from the AFBI herd) from birth to slaughter, using existing and novel techniques such as ultrasound scanning, CT scanning, saleable meat yield and instrumental meat quality. Importantly, this project also collected novel data using the CIEL individual feed recording system at AFBI Hillsborough, to investigate the relationships between net feed efficiency (NFE) in growing lambs and their sire EBVs as well as other factors (diet and breed type). Whilst previous research typically used conserved forages and concentrates, this project generated novel data on individual intakes and NFEs from lambs under zero grazing conditions,

The benefits of selecting for high muscling EBV in a breeding programme were clearly seen in the progeny performance, with lambs having a greater average daily gain (ADG) from birth to weaning. As a result,

lambs from a high EBV sire reached target slaughter weight 10 days earlier, which equates to a saving in feed costs of £1.69 per lamb. CT scanning highlighted differences in body composition, with lambs from a high EBV sire having a greater muscle weight and lower fat weight. However, differences in feed conversion ratio (FCR) were not observed. All sires used in this study were performance recorded and differed only in one EBV (muscling). Therefore, if using similar high EBV rams in a commercial farm and comparing them with an unrecorded stock ram, a greater variation in FCR and lamb performance could be expected.

This project improved the understanding and awareness of EBVs within the industry, and provided valuable information for NI producers to improve performance recording and make best use of breed selection tools. This research also generated new knowledge on feed efficiency, which will support the development of new EBVs for NFE as part of future research programmes; a trait which has the potential to greatly improve production and resource efficiency and in doing so reduce the carbon footprint of lamb production.

Use of EBVs by farmers when selecting rams remains low in Northern Ireland. The findings of this project will help increase confidence in the use of EBVs as well as providing valuable information to enable the creation of new EBVs for commercial traits.

Jason Rankin, General Manager, AgriSearch.

This study was funded by DAERA, AgriSearch and Dunbia, and carried out in partnership with AHDB and Sheep Ireland.

Hillsborough lambs: individual feed intakes were recorded at AFBI Hillsborough to evaluate feed efficiencies

Food Futures: using a holistic, multi-actor approach to enhance the sustainability of livestock production systems

Research Leads: Dr Aurélie Aubry and Dr Steven Morrison

Quantifying and enhancing the sustainability of agri-food production is key to sustain and build markets locally and internationally. The Agri-Food Quest 'Food Futures' project aims to develop a reporting tool to capture, credit and drive positive behavioural change among livestock farmers and their stakeholders, in order to enhance the sustainability of Northern Ireland agri-food production.

Under the pillars of Economic, Environmental and Social sustainability, a set of more than 250 indicators, combined into 30 scientifically robust metrics, have been identified following literature reviews and consultation with stakeholders from the food supply chain as well as scientists from a range of disciplines. The data needed to inform these metrics were obtained from 31 dairy and beef/sheep farms across Northern Ireland, by integrating:

1. data from existing benchmarking and soil sampling schemes, and
2. new data by surveying these ambassador farms.

Results so far indicate that there is a significant potential to enhance further the sustainability at farm level. For example, only 45% of the study farms assess and minimise soil compaction and only 42% of the fields sampled are at optimum pH, 74% of farmers have developed a long term farm business strategy that is reviewed regularly, and 60% feel that they only occasionally have the right work/life balance. Metric polygons have been developed to visualise the overall performance of each farm (see an example in Figure 1 on next page), as well as summary tables using a traffic light system to suggest key actions to improve overall performance.

The project is also developing advanced metrics informed by collecting new, cutting edge data, to better quantify the effect of activities that have the potential to enhance sustainability for example through increased carbon sequestration. The AFBI BovIS dairy and beef greenhouse gas calculators were used to estimate the carbon footprint of each farm. The use of GPS soil data and lidar technologies are also being explored.

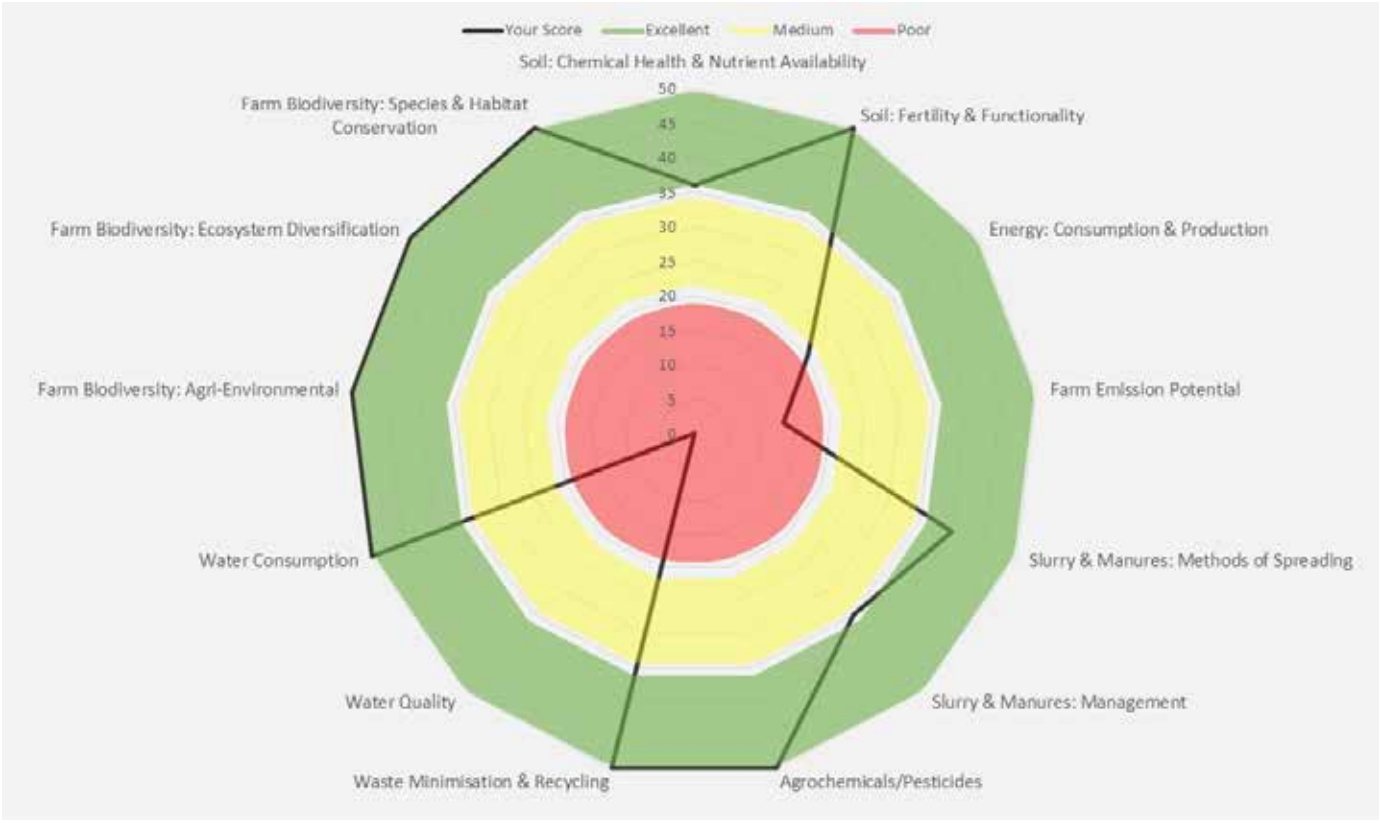


Fig 1. Metric Polygon showing a farm's environmental performance against the ideal score for each metric.

Through multidisciplinary collaboration with QUB, machine learning techniques are being used to integrate multiple indicators within one SMART tool that can provide an overall rating of sustainability to the consumer. This new knowledge will be used to inform a decision support tool, made available to all stakeholders as on online dashboard, to select areas of interventions most likely to enhance the overall farm sustainability. The commercial value and application of this tool are key to this project, as it has the potential to provide customer assurance by identifying and supplying sustainability driven markets and high integrity food systems.

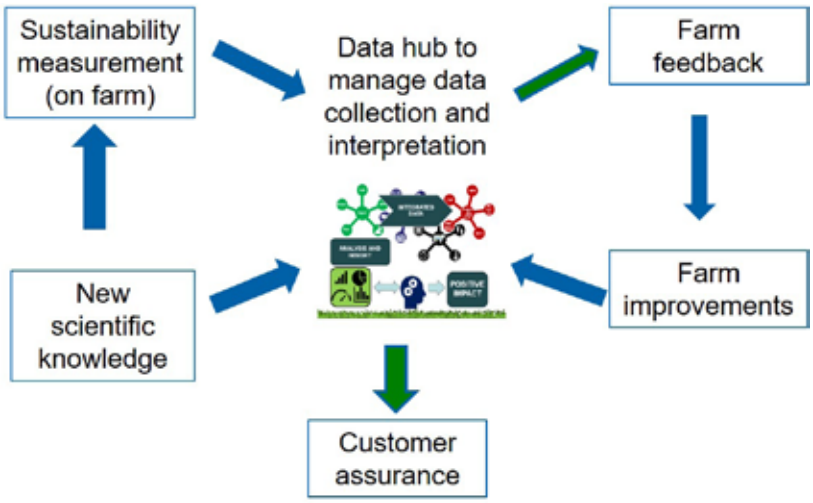


Fig 2. The project is adopting a multi actor approach to develop a smart platform to enhance the sustainability of agri-food products.

The study was co-funded by Agri-Food Quest (flagship project) with support from industrial partners.

Sustainable broiler production through phosphorus nutrition

Research Leads: Dr Christina Mulvenna and Dr Elizabeth Ball

Phosphorus (P) is an essential nutrient in animal nutrition. However, monogastric animals such as pigs and poultry are particularly inefficient in the use of plant derived P as they lack the ability to naturally digest plant P due to extremely low gastrointestinal levels of the enzyme phytase which is needed to release the P in plant ingredients. As a result 60 - 80% of P in feedstuffs is inaccessible to these animals and lost via excreta, which in turn can have detrimental effects on soils and water systems. Often diets are supplemented with inorganic-P to meet animal dietary requirements, which ultimately increases dietary costs and adds to the environmental impacts.

Plant ingredients contain a level of endogenous phytase that can improve P utilisation of the diet but this endogenous phytase is often destroyed during the diet-making process and therefore exogenous enzymes with the ability to withstand the diet-making process, have been developed. Previous research has suggested that the addition of exogenous phytase to monogastric diets can reduce P excretion by improving P utilisation, therefore reducing the need for inorganic P supplementation. There is also evidence to suggest that 'super-dosing' of this enzyme may have further beneficial effects although this is yet to be fully understood. Current efforts to switch to home grown alternatives such as dried distiller grain solubles (DDGS) and rapeseed meal (RSM) to reduce the use of expensive, imported soyabean meal have been shown to be successful in maintaining performance. However, the effects of phytase addition to these alternative, more sustainable diets are yet to be fully investigated.

Working with partners across the UK and Europe on the "PEGaSus" project (Phosphorus efficiency in *Gallus gallus* and *Sus scrofa*): Bridging the gaps in the phosphorus value chain", AFBI investigated

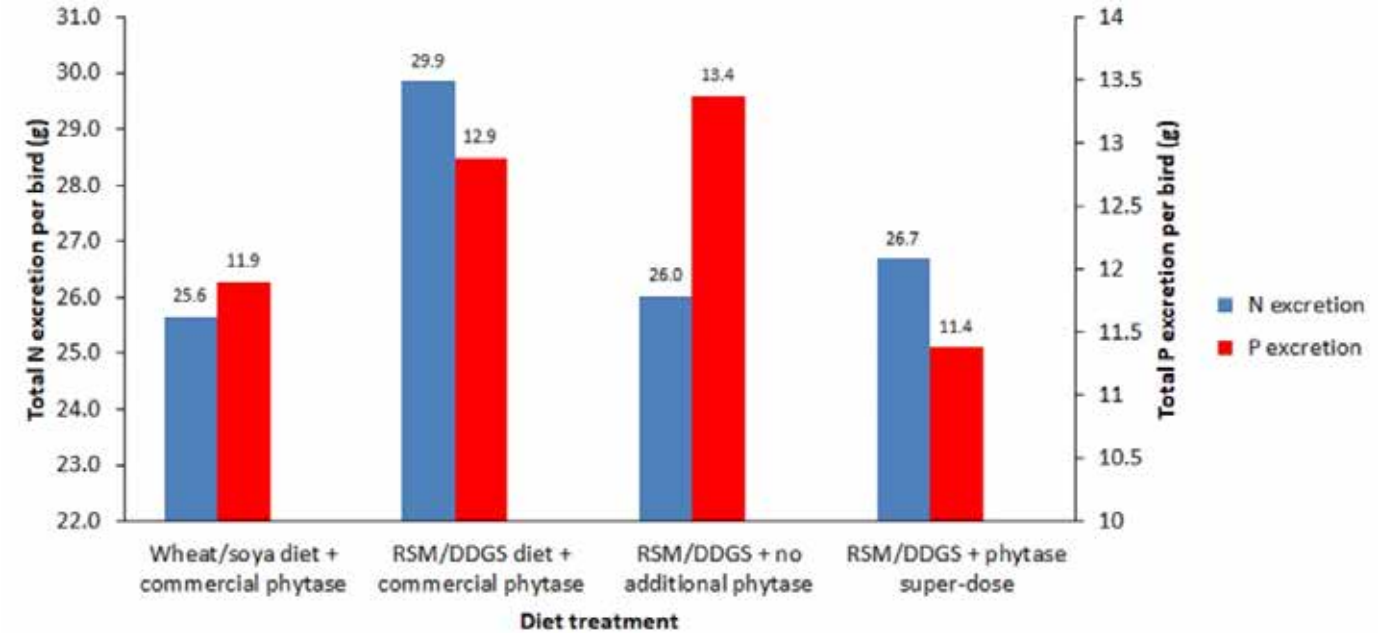


Fig 1. The effect of dietary treatment on total Nitrogen (N) and Phosphorus (P) excretion of broilers to reach target weight of 2.2 kg.

the use of alternative by-product diets (with varying levels of nutrient availability and phytase content) compared to traditional, wheat-soya diets for broilers. The ultimate goal was to assess the ability of phytase to increase P utilisation, maintain growth performance and in turn, reduce diet costs and environmental impact of production. As part of this study, broilers were offered either a traditional wheat/soya diet (with commercial phytase), a RSM/DDGS diet (with commercial phytase) or a reduced nutrient RSM/DDGS diet with either no commercial phytase or a phytase super-dose. The reduced nutrient RSM/DDGS diet was formulated to a lower energy, crude protein and P level and was designed to be more sustainable and less expensive.

While birds offered the traditional, wheat/soya based diet performed best throughout this study, phytase super-dosing improved the growth performance of birds offered low specification RSM/DDGS diet, equivalent to those of birds offered the high specification RSM/DDGS diet. Total N excretion was lowest for birds offered the traditional wheat/soya diet, while reducing the nutrient specification in the RSM/DDGS diet reduced N excretion (by 12%) due to lower N intake.

This work has also found that phytase super-dosing can reduce total P excretion from broilers offered the 'sustainable' RSM/DDGS diet by 15% (Figure 1).

When formulating broiler diets, consideration should be given to the balance of reducing N and P excretion, optimising animal performance, the availability and sustainability of dietary ingredients and the cost of diet production. The use of phytase at commercial and super-dosing levels shows potential as a useful tool to improve performance of broilers offered a more sustainable lower cost diet and to reduce N and P excretion. From the results of this study, phytase super-dosing of a lower cost reduced nutrient diet would enable the effective use of more sustainable protein sources and could reduce overall N and P excretion from broiler production in Northern Ireland by approximately 400t and 90t per annum respectively.

The study was co-funded by ERA-NET SusAn and Department of Environment, Food and Rural Affairs.

Protecting animal, plant and human health

Section 2

CoVID-19 – AFBI's response to support Government and society

Provision of COVID-19 testing services to the Health Authorities

AFBI's Veterinary Sciences Division has a substantial diagnostic capability and infrastructure for the testing and surveillance of animal diseases. These platforms and expertise are particularly important when an emergency arises, and for AFBI the emergency is normally of an animal nature. However, as we are all very aware 2020 brought forward a societal emergency which would have overwhelmed the normal structures for disease testing and surveillance of our human population.

As such, through working closely with QUB, Almac and the Department of Health, AFBI's animal testing and surveillance platforms were quickly re purposed and mobilised in May 2020 at the request of Minister Poots to assist the Northern Ireland Health Service in providing CoVID-19 testing. Our ability to quickly repurpose high throughput PCR testing work streams for animal disease testing enabled test workflows for CoVID-19 to be brought online within a matter of a few weeks. The team involved with the testing was drawn from a number of AFBI Branches as well as incorporating research

L-R: DAERA Minister, Edwin Poots, DoH Minister Robin Swann with AFBI Directors, Josephine Kelly and Alastair Douglas at the announcement of COVID-19 testing at AFBI

Dr Ken Lemon- AFBI virologist outlines the testing process to DAERA and DoH Ministers

scientists from Queens University Belfast (QUB) as part of the consortium approach between AFBI, QUB and Almac. To date AFBI have tested almost 44,000 samples, all within tight turnaround times of a few hours from receipt to report. Additionally, the test method being used by AFBI can identify CoVID-19 virus variants such as the Kent strain and this information has been reported back to the Department of Health, assisting in the epidemiological monitoring of the virus within the province.

The resultant impact of the work undertaken by AFBI has been to address the surge capacity that was forecast throughout the pandemic within the CoVID-19 testing programme. AFBI's input has significantly supported the clinical laboratories within the Northern Ireland Health Service and in doing so has enabled the Northern Ireland CoVID-19 testing programme to meet the demand for testing over the past year.

Investigating pestivirus (Bovine Viral Diarrhoea and Border Disease) in sheep in Northern Ireland

Research Leads: Dr Emma Campbell

BVD is a major cause of poor cattle health and financial loses within the Northern Ireland cattle industry. Estimated costs due to BVD on farm can be up to £552 per cow per year and the impact of an outbreak will depend on whether the herd is vaccinated or if it is naïve to BVD. Animal Health and Welfare Northern Ireland (AHWNI), implemented a voluntary Bovine Viral Diarrhoea (BVD) eradication programme for cattle in 2013 that moved to a compulsory phase in 2016. This is an industry led programme incorporating stakeholders from the main dairies, meat processors and tag suppliers across NI.

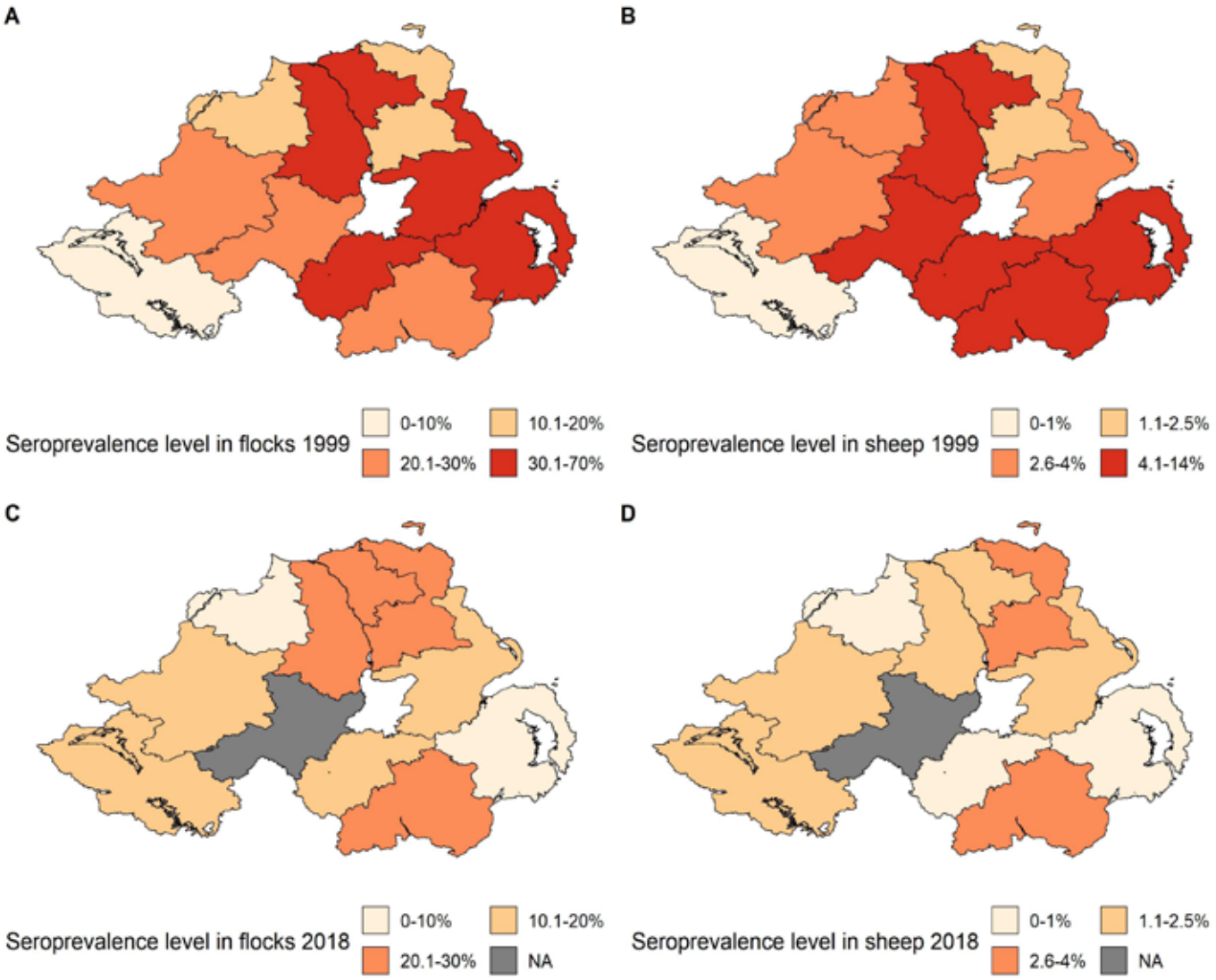
During the first full year of the compulsory programme 0.66% of calves tested positive for BVD, this has reduced to 0.3% of calves in the 12 months prior to September 2020. Working towards eradication in NI cattle herds will reduce financial loses, improve cattle health and welfare and help continue trade with other countries. To successfully eradicate a disease all potential routes of transmission need to be understood and addressed.

BVD can cause diarrhoea, pneumonia, decreased milk production, reproductive issues, increased susceptibility to other diseases, and death. Reproductive issues include abortions, congenital defects, birth of small weak calves and production of persistently infected (PI) calves. PI calves act as a reservoir for BVD and can shed high volumes of virus, infecting other animals within the herd. A PI calf may initially appear healthy but will likely develop severe disease which causes extreme diarrhoea, weight loss and ulcerated lesions. Most of these animals will eventually die or be euthanised but they still present a severe threat to the herd whilst secreting virus.

BVD is a member of the Pestivirus family of viruses which also includes Border Disease Virus (BDV) which primarily infects sheep. Both viruses have been found in cattle and sheep, therefore an infected sheep could act as a viral reservoir which may hinder the successful eradication of BVD in NI cattle herds.

In 2018 AFBI's Disease Surveillance and Investigation Branch in collaboration with AHWNI investigated the prevalence of pestivirus in sheep in NI and determined which of the pestiviruses, BVD or BDV was the major circulating pestivirus in NI sheep. Of the 3,372 sheep tested, 56 (1.7%) tested positive for pestivirus antibodies which equated to 33 (17.6%) of the 188 sheep flocks having at least 1 antibody positive result.

A 1999 study conducted by AFBI also looking for the presence of pestivirus antibodies in sheep and reported an animal



Apparent prevalence of pestivirus in DVOs across Northern Ireland in sheep flocks in a) 1999 and b) 2018 and sheep (animals) in c) 1999 and d) 2018.

level prevalence of 5.3% and a flock level prevalence of 30.4%. Therefore, there has been a reduction of 3.6% at the animal level and 12.8% at flock level between 1999 and 2018.

Further testing of the pestivirus antibody positive samples identified BVD rather than BDV to be the major circulating pestivirus in sheep in NI. The prevalence maps show a large decrease in both animal and flock prevalence in the Newtownards and Armagh areas between 1999 and 2018. The Ballymena and Fermanagh areas were the only areas to show an increased animal and flock level prevalence between the two studies.

The prevalence maps can be used to easily visualise the geographical distribution of pestivirus in sheep across NI.

Overall, since 1999 the prevalence in sheep and flocks has reduced, this is most likely from the introduction of the BVD eradication programme removing PI calves which act as reservoirs of infection across the farm and infecting both cattle and sheep on the premises.

By conducting surveillance studies like this, AFBI are able to inform stakeholders of the current level of exposure on farms, identify areas hindering the removal of a disease and demonstrate the benefits of implementing an eradication programme.

Optihouse: optimising the housing environment for calf performance and health

Research Leads: Dr Gillian Scoley; Dr Steven Morrison; Aaron Brown (PhD Student)

Calf rearing is one of the most labour intensive activities within dairy farms. Recent AFBI research has highlighted major loss in calves during the first weeks of life, with mortality rates up to 6%, a figure which has not decreased over the last number of decades across the UK. Additionally, morbidity concerns have been highlighted by a recent report from the Royal Veterinary College in the UK which indicated that more than 40% of calves on commercial farms suffer pneumonia, which has an average financial cost of £43 per calf. Aside from the immediate costs of treatment, ill health in early life can cause delayed growth rates which leads to delays in breeding and calving age and a depressed level of milk production, overall resulting in a major loss in production efficiency.

Calf mortality and morbidity are predominantly a function of three areas: housed environment, husbandry and nutrition. However, little is understood about the true impact of the housed environment in the early life of the calf, and it's interaction with nutrition, health and genetics, something which the Optihouse project aims to address. Optihouse is research project funded by the Department of Agriculture and Rural affairs (DAERA) which incorporates research teams from AFBI Hillsborough and Queen's University Belfast, the CAFRE Dairy Advisory team and a group of international veterinary, academic and industry experts. One of the main elements of the project has been to gain a better understanding of the conditions in calf rearing houses within Northern Ireland. This understanding will help identify the influence of key factors, linked to poor environmental conditions and failure to deliver expected growth, such as building design, hygiene practices and calf nutrition.

In the first stage of the project, AFBI alongside the CAFRE Dairy Advisory team completed assessments focused on calf housing and rearing systems on 66 dairy farms across Northern Ireland. Detailed information on management practices, animal health and performance and the physical characteristics of the rearing house including ventilation and hygiene assessments were recorded. Additionally, the AFBI research team collected samples from the calf house environment. This included feed, water from drinkers and swabs from bedding and feeding equipment. The samples were then analysed for indicators of potential disease causing organisms including total viable bacterial counts (TVC), coliforms and E.coli.

One of the key findings from this analysis highlighted the need for better hygiene with regard to water quality. Water is a driving factor for concentrate intake and therefore is essential for rumen development. Providing calves with clean drinking water and maintaining high levels of hygiene for drinking facilities is therefore vital. However, currently, there are no set standards for

drinking water quality in calves as there are within the pig and poultry sectors. When the drinking water samples collected within the calf houses were compared with the Red Tractor Pig standards, only a small proportion of the samples met the standards.

Preliminary results from samples taken from calf feed and feed preparation equipment have also indicated a high level of bacteria, thus putting young calves at high risk of ill health.

These initial results stress the fact that much opportunity exists to improve hygiene on farms, leading to a positive impact on calf health and performance

Outputs from the Optihouse project are expected to have a number of positive impacts for both policy and industry, these including:

- Clear, proven knowledge support material relevant to NI from which producers, advisers and policy makers can make informed decisions on calf housing
- Reduced incidence of calf ill health, therefore, reduced concern regarding antimicrobial resistance and improved public image with respect to livestock production
- Improved farm yard planning, which may have positive impacts on the performance of other livestock groups and overall labour efficiency
- Improved marketability of livestock produce through enhanced image. This is as a result of delivery of optimal environmental conditions for the calf to support efficient feed conversion, high welfare standards and high levels of calf health

Benefits are already being seen with Don Morrow, CAFRE stating:

"Having been involved with the Optihouse project from the start, CAFRE advisors have found the initial findings extremely useful in promoting better calf house design and management. They have been used in Business Development Group meetings and featured in CAFRE webinars for dairy and beef calf rearers. Optihouse provided excellent local data on the importance of providing a clean, dry well ventilated environment for new born calves and we are finding an increased focus on this area of management by farmers as a consequence. We look forward to the delivery of the full project findings."

The study was co-funded by Yearly in-kind contribution from AgriSearch

Optihouse

Reducing antibiotic use through a selective approach to dry-cow therapy

Research Leads: Dr Anna Lavery and Dr Aimee Craig

Historically, standard practice on the majority of dairy farms has been to treat all cows with antibiotics at dry-off. However, milk somatic cell counts (SCC) have decreased in recent years providing an opportunity for farms to reduce antibiotic use by utilizing selective dry-cow therapy (SDCT). The impact of SDCT on performance and udder health was examined in a two year study within the dairy herd at AFBI Hillsborough.

In this study, cows were considered to be at 'high risk' of infection if they had a SCC >200,000 cells/ml, or a mastitis case during the three months prior to drying-off. These cows were treated with conventional dry-cow therapy (CDCT) (intramammary antibiotics and teat sealant). Cows with SCC < 200,000 cell/ml and no mastitis cases during the three months prior to dry-off were identified as 'low risk'. These cows were treated with either CDCT, or SDCT (teat sealant only).

Treatment did not affect milk yield or composition. 'High risk' cows had an average SCC of 281,000 cells/ml, while 'low risk' cows managed on CDCT and SDCT had an average SCC of 86,000 cells/ml and 83,000 cells/ml, respectively (Figure 1). 'High risk' cows had on average 0.6 cases of mastitis/cow in the

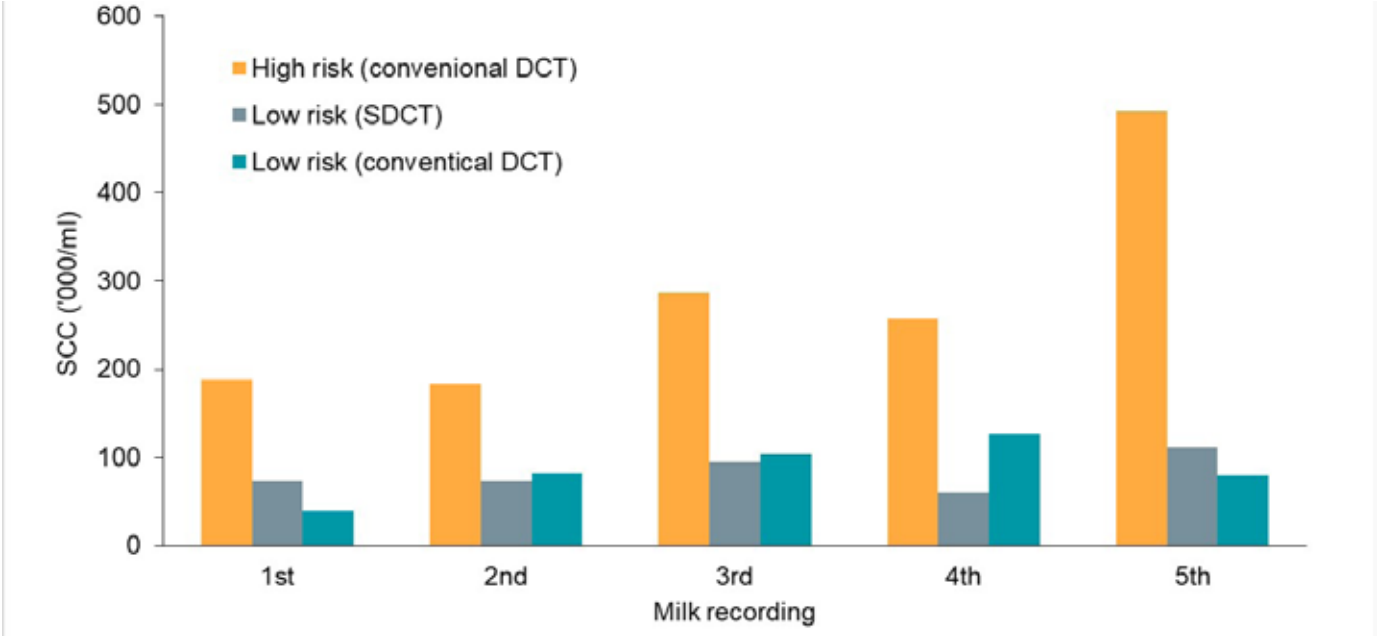


Fig 1. Average somatic cell counts ('000/ml) during first five milk recordings post-calving for 'high risk' cows that received antibiotic plus teat sealant, and for 'low risk' cows subject to either SDCT (teat sealant only) or conventional DCT (antibiotic plus teat sealant).

subsequent lactation, while 'low risk' cows had on average 0.2 cases of mastitis/cow, irrespective of treatment. These findings suggest that SDCT can be adopted with 'low risk' cows with no negative implication for udder health during the subsequent lactation.

SDCT provides an opportunity for the NI dairy industry to dramatically reduce intramammary antimicrobial use. For example, there are 2,500 dairy farms in NI containing 313,000 dairy cows. If 70% of NI farms adopted SDCT, and 50% of cows within those farms did not receive antibiotics at dry off, then this would reduce antibiotic dry cow course use within Northern Ireland by 35%.

Commenting on the impact of this research, Jason Rankin from AgriSearch said:

Farmers are under increasing pressure to reduce the use of antimicrobials. Dry cow therapy represents a significant proportion of the antimicrobials used by dairy farmers. This study has demonstrated how dairy farmers can use SDCT to significantly reduce the use of antimicrobials, without adversely affecting milk production or udder health, which will go a long way in helping the sector meet its targets to reduce antimicrobial use.

This project was co-funded by DAERA's Research Challenge Fund and carried out in partnership with AgriSearch, Animal Health and Welfare Northern Ireland, LMC and Farm Vet Systems.

Finding a solution to respiratory disease in cattle

Research Leads: Dr Ken Lemon and Prof Louise Cosby

Bovine respiratory disease complex (BRDC) is one of the most economically important diseases for the Agri-Food industry being the main cause of cattle mortality from 1 month to 2 years of age. The economic impact results not only from mortality but also from the expense of treatment and 'hidden' costs such as weight loss, reduced reproductive performance, low milk yields or carcass blemish and the impact of this on market price reduction. These factors also all lead to an inflated carbon footprint.

Within BRDC, the initial viral infection normally predisposes calves to secondary bacterial and further viral infections. The known viruses contributing to BRDC are bovine respiratory syncytial virus (BRSV), bovine herpes virus type 1 (BoHV-1), bovine parainfluenza-3 virus (BPI3V), bovine viral diarrhoea virus (BVDV) and bovine coronavirus (BCoV). There is also mounting evidence that a newly described virus, Influenza D virus (IDV), is contributing to BRDC. IDV infects cattle, pigs and small ruminants and was first detected in North America in 2011. However, cattle have been shown to be the main viral reservoir. IDV had not been previously reported in the UK.

During the winter of 2017/2018, AFBI carried out PCR molecular testing on 104 cattle with confirmed respiratory disease and 9 were found positive for IDV (8.7% prevalence), Viral RNA was present in both the upper and lower respiratory tract and pathological changes in lung tissues were observed alongside signs of concurrent bacterial infections.

DNA sequencing revealed that Northern Irish isolates are similar to viruses from the Republic of Ireland and Italy (Figure 1). The presence of IDV in respiratory disease samples further supports a role for this virus in BRDC.

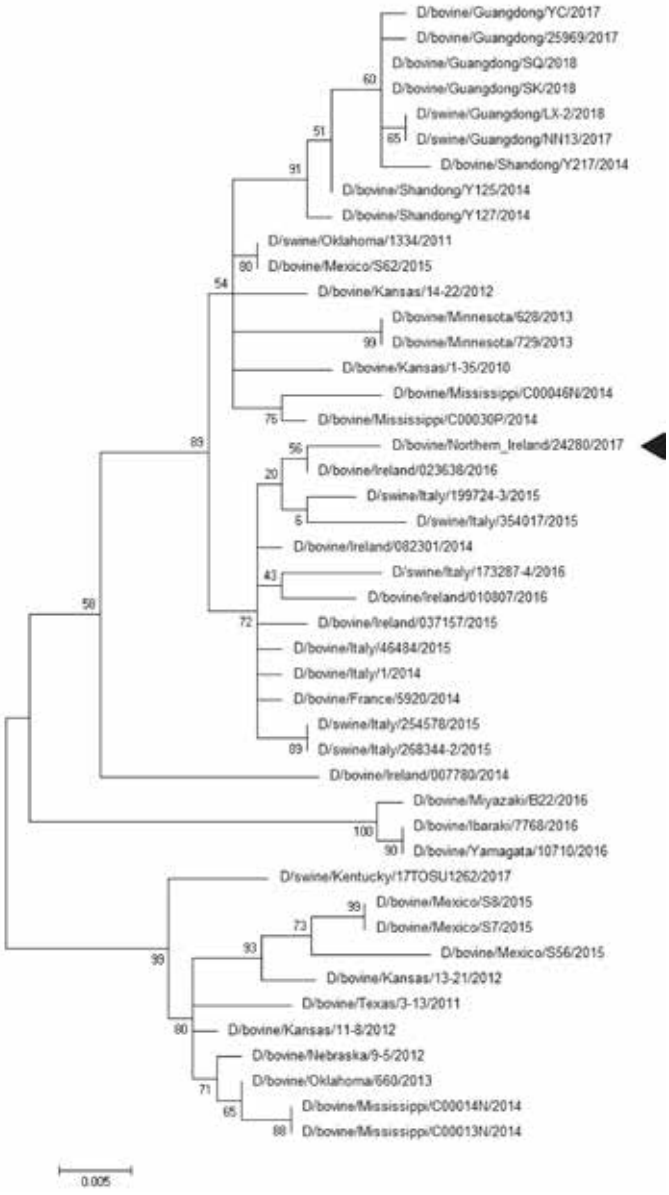
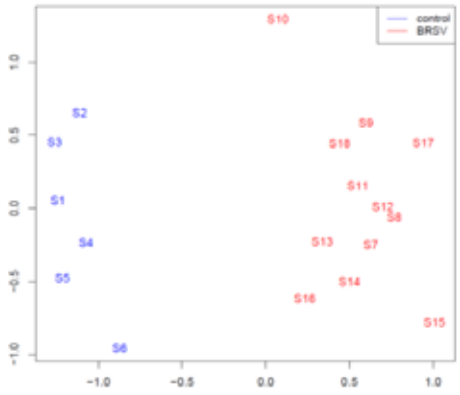


Fig 1. Phylogenetic tree of IDV segment 4 (HEF) at the nucleotide level

Identification of Genes and Pathways Involved in the Host Response to Bovine Respiratory Syncytial Virus (one of major viruses involved in BRD)



Multi-dimentional scaling (MDS) plot

1. Over-represented gene ontology terms results

Materials and Methods Go-term	Description	p-value (corrected)
GO:0006952	Defense response	3.91E-20
GO:0006955	Immune response	3.91E-20
GO:0002252	Immune effector process	5.81E-19
GO:0002376	Immune system process	8.76E-18
GO:0009607	Response to biotic stimulus	1.65E-16
GO:0006950	Response to stress	1.99E-16
GO:0051707	Response to other organism	4.6E-16
GO:0043207	Response to external biotic stimulus	5.99E-16
GO:0098542	Defense response to other organism	6.55E-16
GO:0009605	Response to external stimulus	2.76E-15
GO:0009615	Response to virus	1.8E-13
GO:0051607	Defense response to virus	2.32E-12

- Clear separation between infected and control calves based on log2 fold changes
- 934 differentially expressed genes (DEG) ($p<0.05$, FDR<0.1, fold change >2) between the BRSV infected and control calves.

Johnston et al. Sci Rep. 2019 Oct 14;9(1):14736

teagasc

University of Missouri

Fig 2 . Identification of genes and pathways involved in the host response to Bovine Respiratory Syncytial Virus

Two highly prestigious and competitive US-Ireland R&D Partnership Programme grants with combined value of > $2million have allowed AFBI to begin to understand what determines an animal's susceptibility or resistance to a particular 'BRDC' virus and also when and how bacteria and other pathogens contribute to the disease following virus infection. The grants support AFBI's scientists to collaborate with laboratories in the TEASGASC (RoI) with Drs Sinead Waters and Bernadette Earley, the University of Missouri (USA) with Professor Jerry Taylor and the USDA/ARS/US Meat Animal Research Center in Nebraska, with Dr Tara McDaneld, on this important challenge for cattle production. AFBI, TEASGASC and US laboratory work components are funded by DAERA, DAFM and the USDA, respectively.

To date we have identified genetic biomarkers and molecular pathways (Figure 2) of BRSV in cattle mainly relating to their immune response. This is also the first time that this type of information has been collected from circulating whole blood samples, allowing healthy cattle to be screened. We will also examine how the respiratory microbiome (community of micro-organisms) changes following the initial virus infections in cattle. Similar genetic and microbiological studies at AFBI will follow for other BRDC viruses.

Overall, the studies of BRDC at AFBI will inform future breeding programmes, design of novel diagnostics and improved vaccine design. Novel recombinant BRSV vaccines have already been produced in collaboration with Queen's University Belfast (BBSRC funded) and will shortly enter into a clinical trial in cattle at AFBI. Efforts at AFBI are now also underway to develop a vaccine to protect livestock from IDV as part of a major DAERA funded Evidence & Innovation project.

Should these vaccines prove successful, they will contribute significant to increasing the profitability of cattle production as well as reducing its carbon footprint.

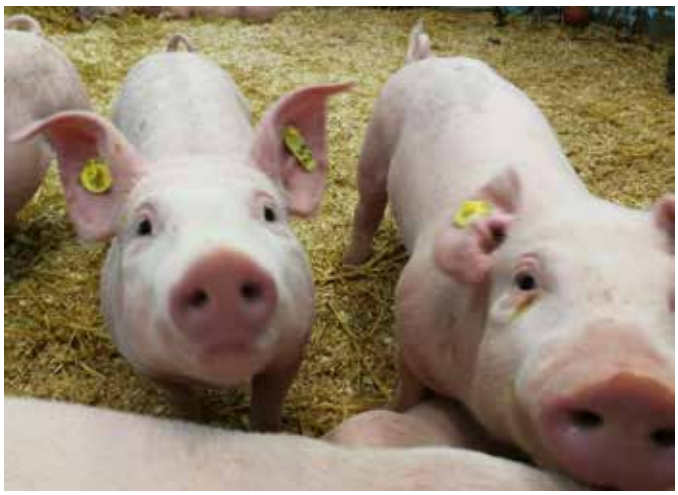
Investigation into the effects of fatty acids on the immune response and gut microbiome in pigs.

Research Leads: Dr Robyn McKenna, Dr Victoria Smyth, Prof Louise Cosby

Post-weaning enteric disease is one of the principal causes of economic losses in the pig industry worldwide. At weaning piglets are abruptly exposed to a number of stressors which have implications for their health and performance at this vulnerable stage. The factors involved in weaning, namely abrupt maternal separation and transition to solid feed, have severe implications on feed intake, gut development and ultimately growth.

In the past, the livestock industry has used in-feed antibiotics as a means of counteracting the deleterious impact of weaning and avoiding enteric disease. However, in light of anti-microbial resistance, since 2006 the EU have regulated the clinical use of antibiotics and banned their exploitation as animal growth promoters due to concerns of residual contamination within the food chain. This directive has since propelled an interest in the development of sustainable, nutritional alternatives capable of alleviating consequences associated with weaning.

Fatty acids have long been a subject of interest in both human and animal nutritional health with research showing that they can improve body function and play an important role in gastro-intestinal health. AFBI's work, in collaboration with industry, has demonstrated that fatty acid



supplementation throughout a pig's life can have sustained positive effects on growth and performance output as well as health status. Using a range of field trial studies and in vitro techniques we established that not only do dietary fatty acids exert positive effects on growth performance and production parameters in pigs, but they also have significant physiological relevance in the support and maintenance of intestinal barrier function as well as influencing the systemic immune response. Furthermore, fatty acids were found to play a role in modifying the diversity of viruses present whilst also altering the balance of bacteria, thereby reducing the viral challenge faced by young piglets and establishing an environment that favours the growth of commensal species such as *Lactobacillus*

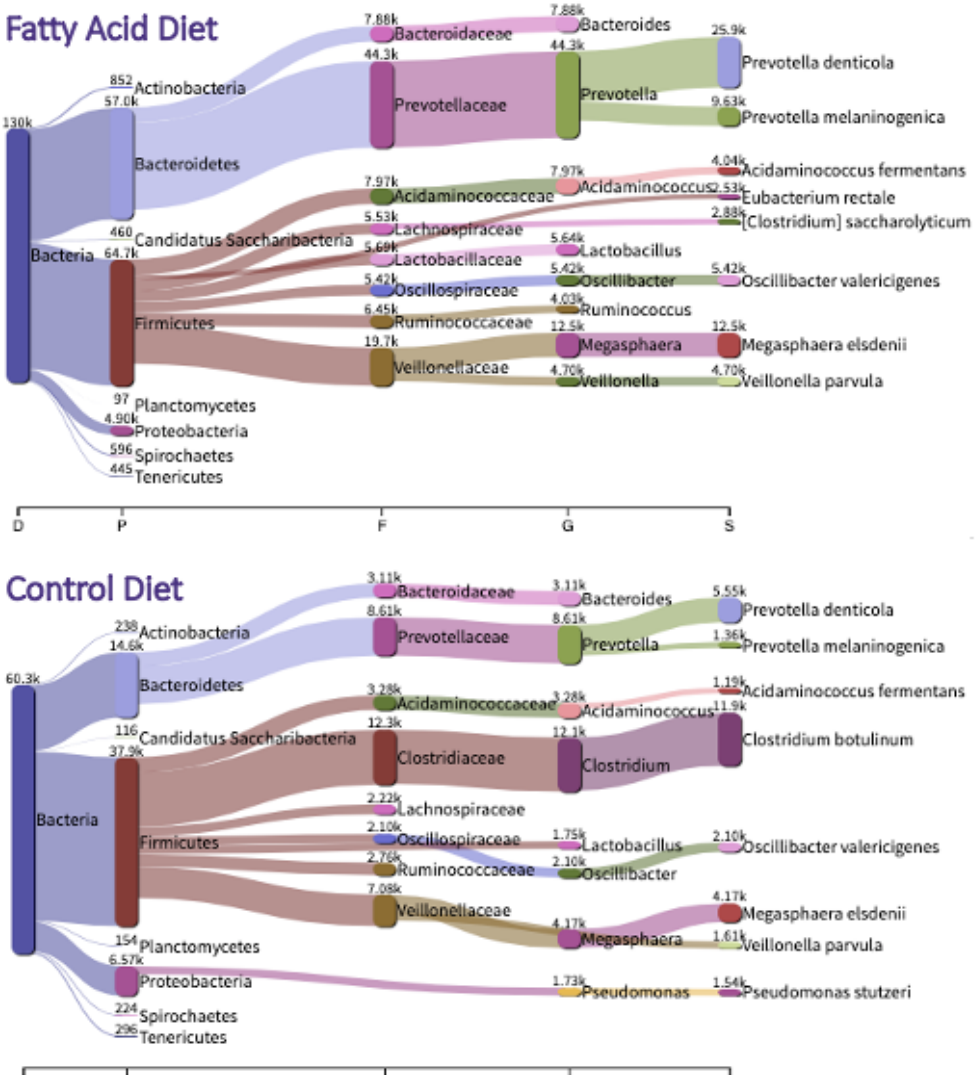


Fig 1. Fatty acids play a part in modifying the bacterial profile in the gut microbiome

(Figure 1). We also found the fatty acids to have a significant anti-viral effect against porcine rotavirus.

Through our research we have demonstrated the value of a proprietary blend of fatty acids as a wholesome porcine feed supplement and safe alternative to Anti biotic growth promoters. Our findings offer advantages to animal health and welfare as well as benefits that will reverberate through the supply chain and help improve the performance and sustainability of the agri-food sector in Northern Ireland which is both agriculturally and economically significant to the region.

"Being involved with AFBI regarding the work on fatty acids brought a whole new dimension of science to the work. AFBI profiled the gut biome, measured virus diversity and measured immune function. This level of science allowed us to understand how the fatty acids were working within the animal leading to commercial focus in how best to use fatty acids for the benefit of the animal and the producer. The benefit of working with AFBI is the breadth of scientific disciplines that are covered within one institute, this allows cross fertilisation in terms of knowledge and techniques thus widening the scope of any research."

Violet Beattie, Technical Project Consultant, Devenish

The study was co-funded by DAERA and Devenish Nutrition

Diversity and Pathogenicity of Chicken Astrovirus

Research Leads: Dr Victoria Smyth

Dead-in-shell chicks due to embryonic CAstV infection during "White Chicks" disease

Northern Ireland has a strong poultry farming industry of both meat and eggs and AFBI scientists provide significant support to this sector, both here in NI and further afield, through research and diagnostic testing.

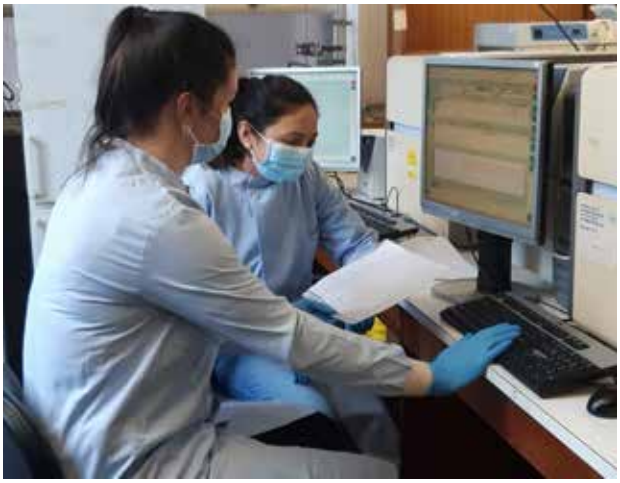
The Avian Virology Unit within AFBI's Veterinary Sciences Division at Stormont uses existing and new technologies to identify and solve challenges faced by the poultry industry. The unit also regularly designs new molecular diagnostic tests for the detection of more difficult viruses. This was the case for chicken astrovirus (CAstV), a species of virus that is ubiquitous around the world mainly affecting very young chickens and embryos causing embryo deformities, growth problems and mortality. It has a genome made of RNA which makes it prone to acquiring genetic mutations during replication in infections, which makes designing diagnostic tests more difficult. It also means that many diverse strains of CAstV are in circulation, some that cause disease while many other strains do not and there is no simple way to distinguish these pathogenic strains from benign strains except through diagnostic testing and research.

AFBI scientists used the knowledge gained from various studies of the complex CAstV genetics to design several new diagnostic tests including a pan-CAstV quantitative molecular test that detects and quantifies all known strains of CAstV and a serology test that detects antibodies against certain CAstV strains in blood serum. Both of these tests are now commercialised. Use of the range of novel CAstV tests designed at AFBI has placed us at the global forefront of discovering the diversity of diseases caused by specific strains of CAstV, and for publishing a strain classification system that has been widely adopted.

While cleaning and disinfection is routine and highly effective in poultry houses, CAstV is known to be more resistant and so a collaborative study with the local poultry industry examined levels of CAstV in poultry houses before and after cleaning and disinfection using the quantitative molecular CAstV test and found that some traces of CAstV still existed after cleaning, which could put the next batch of chicks at risk of disease. Revised cleaning and disinfection protocols were devised and testing for the presence of CAstV showed these were more effective at clearing CAstV strains from the houses.

Through commercial diagnostic testing of serum and tissue samples from Finnish

flocks suffering from a devastating hatchery disease called "White Chicks", AFBI was the first laboratory to identify the cause as CAstV and then used another AFBI-designed molecular CAstV test to identify the particular strain responsible. It was found that the virus entered the eggs from the parents and caused damage to the embryo, resulting in embryo death or chicks too weak to hatch. Losses averaged 30% in a two week period across flocks but some affected farms lost as much as 69% of their chicks. The AFBI-designed serological test showed that hen sera from 13 flocks were CAstV negative before the white chicks disease problem and positive soon after. White Chicks disease has become a big problem in large poultry producing countries such as USA, Brazil and Canada.



Virology Labs in AFBI Stormont

AFBI has also shown CAstV strains to be the cause of a devastating kidney disease in young broiler chicks, which resulted in 10-40% mortality in affected Asian flocks and so designed a novel molecular test specifically for this challenging strain, which shortens the time required for diagnosis confirmation and can be used on virus-inactivated samples sent on special cards in the post rather than fresh or frozen tissues by specialised couriers. This is much more convenient for global customers on other continents.

Recent research performed in AFBI's Avian Virology Unit with a visiting veterinarian and PhD student from Nigeria showed CAstV to be present in all pooled samples made from 160 runted and poorly Nigerian chicks and also in 83% of pooled tissue samples from 97 day old turkey poults that were weak and poorly. It was the only virus consistently found out of half a dozen common poultry viruses that were tested. Sequencing from a representative sample of the chicks and poults found that they all had the same strain with some minor mutations as would be expected. This is strong evidence that this particular strain of CAstV is causing the runting and weakness because if it wasn't the cause then we would expect to see diverse strains circulating in the flocks as is usual. This exciting preliminary study is potentially the start of solving a problem in Nigeria that was previously thought to be due to egg damage by handling.

These chicks and the earlier ones described would benefit from the protection of a CAstV breeder vaccine given to the adult hens that would invoke antibody production in the parents. These antibodies would prevent vertical transmission of CAstV into the eggs, thereby protecting the embryos from the virus and also give maternally-derived antibody protection to the vulnerable chicks for the first week or so post hatch against possible CAstV infection from their environment. AFBI is now working on a potential CAstV breeder vaccine to protect embryos and chicks.

Commenting on AFBI's work, Margaret Hardy, CEO and Chief Veterinarian at St. David's Poultry Team Dungannon, said,

"The innovative work undertaken at AFBI to identify and quantify avian viral challenge in combination with their local knowledge of the poultry industry here in Northern Ireland means that we remain at the forefront in producing quality food at the highest standards of welfare, sustainability and commercial competitiveness."

The study was funded by DAERA.

Rapid identification of avian influenza in Northern Ireland in 2020

Research Leads: Dr Valerie Harkin, Dr Michael McMenamy and Dr Ken Lemon

Suspicion of a notifiable epizootic disease in Northern Ireland, such as avian influenza or Newcastle disease must be identified rapidly to inform the correct response. These viruses pose a major threat to the 26 million birds in the local poultry industry which could result in severe financial loss. In the case of avian influenza there is also potential for impact on human health.

Fig 1. Locations of epizootic suspect cases associated with or presenting during H6N1 outbreak January to March 2020.

In early January 2020 AFBI received a poultry submission with suspicion of infection with a low pathogenic avian influenza. Mortality was at 3%, with 6,500 birds at risk and increasing to 24,000 birds in total in the poultry unit. AFBI's Virus Molecular Diagnostic Laboratory (VMDL) rapidly assessed the submission to rule out the possibility of highly pathogenic H5 and H7 avian influenza strains as any zoonotic potential of the virus. Sequence analysis suggested the subtype was a H6N1 and this was confirmed by further analysis at the Animal and Plant Health Agency (APHA), Weybridge. This initial case was soon followed by others on a second site with 375,000 birds. Further cases from other sites continued to be submitted from the 4th Jan to 23rd March with a total of 27 suspects.

Figure 1 shows the locations of the suspect cases. In total, 15 of the cases investigated were confirmed as H6N1. Further analysis at APHA suggested that the virus had been initially introduced from a wild bird source, with likely onward spread from a single event.

Overall AFBI's successful response in support of the industry resulted from effective and efficient coordination across multi teams within the Veterinary Science Division as well as continual interaction with colleagues in DAERA.

The study was funded by DAERA.

Wider effects of plant pathogens and pests

Research Leads: Dr Colin Fleming, Dr Archie Murchie, Dr Thomas Fleming

Plant pests and diseases cause immense damage to agriculture, forestry and horticulture, with approximately a third of food produced worldwide being lost to pests and diseases. However, generally less attention is given to their secondary impacts on the wider environment, economy and society.

A recent AFBI study identified the wider impact that plant pests and disease can have on Northern Ireland's national infrastructure and in turn on Northern Ireland's society. For example ash dieback infection (see figure 1.) can damage ash trees generating debris which falls on road, rail and electricity networks, as well as commercial and domestic property. This can result in significantly higher costs for maintenance, health and safety felling, clearing fallen branches, unblocking drains and water courses and ensuring stability of embankments.

Medical and veterinary problems can also result from plant pests and diseases. Fungal plant and bacterial pathogens can cause respiratory and skin problems and serious infections in immunocompromised patients.

Fungal mycotoxins are of particular concern, causing acute and chronic symptoms when consumed in contaminated animal or human food.

Fig 1. Ash dieback infection results in structural damage to trees

Fig 2. New Zealand Flatworm

Fig 4. Froghopper

A current health threat is the oak processionary moth, an insect recently detected in Britain and the Republic of Ireland. This non-native species can cause human skin irritation and respiratory problems, including asthma.

Perhaps the most significant problems arising from the introduction of new plant pests and pathogens is their long-term effect on ecology and ecosystem services. There is clear evidence that plant pests and disease can significantly degrade all aspects of the ecosystem services in both urban and the wider environment. Plant diseases such as ash dieback have the potential to remove a whole tree ecosystem with all the native insects and birds that go with it. This can have unforeseen and lasting changes to our landscape, as Dutch elm disease had in the 1970s.

Fig 3. AFBI Entomologists present at knowledge transfer events

An invasive pest, the New Zealand flatworm (Figure 2) feeds on our native earthworms. In field situations, it reduced key earthworm species such as *Lumbricus terrestris* by 75% leading to water-logging, loss of grass yield and a decline in native earthworm-feeding birds and mammals.

Grassland and Plant Science Branch in AFBI work to maintain Northern Ireland's plant health biosecurity. Whilst we seek to manage the pests and diseases we already have in as sustainable a manner as possible, great emphasis is also placed in preventing new pests and diseases from gaining a foothold. Thereby we aim to protect the forestry and agriculture sectors from loss, but also to safeguard our natural landscape, flora and fauna.

"The scientific advice and research provided by AFBI is crucial to maintaining Northern Ireland's high plant health status"

Diane Stevenson, DAERA Plant Health Policy

The study was funded by DAERA.

Impact of industrial production system parameters on chicken microbiomes: mechanisms to improve performance and reduce *Campylobacter*

Research Lead: Prof Nicolae Corcionivoschi

Few studies have explored how commercial poultry production system parameters affect the chicken gut microbiome and certain pathogens within it such as *Campylobacter*, the leading cause of human foodborne bacterial gastroenteritis.

This study examined how three different farming systems are important for performance and pathogen reduction. Chickens from production systems Normal (N), Higher Welfare (HW) and Higher Welfare with Omega-3 (O) were sampled and the microbiome profiled and investigated at days 7 and day 30.

The normal production system produced a significantly different microbial composition than the other systems. Dominant genera from each production system were identified and analysed along with farm meta data. Bacteria of the genus *Alistipes* played a more prominent role in the gut microbiome of chickens from the normal production system, with *Eisenbergiella* playing a more prominent role in the other two production systems.

This study explored how production system parameters affect the chicken gut microbiome

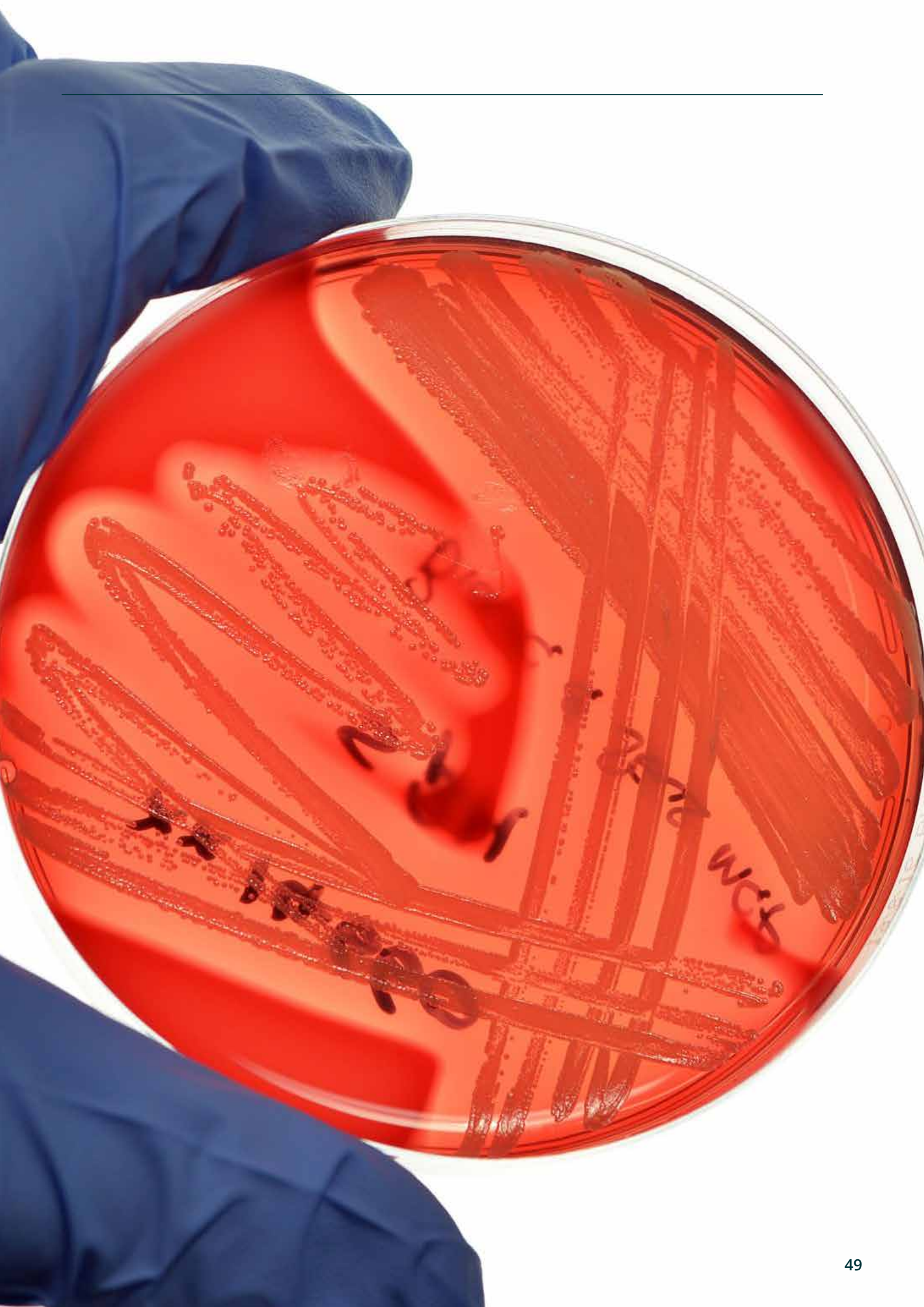
Eisenbergiella bacteria play active roles in energy metabolism and nutrient uptake. Campylobacter was linked to increased microbial diversity and environmental pressure on microbial community structure.

Key industrial production system parameters were identified, e.g. stocking density (birds per m^2), which when increased displayed a reduced ability to influence the chicken microbiome using extrinsic parameters. Overall, parameters between production systems (whether constant or variable) have an impact on microbial diversity which subsequently influences feed breakdown and hence instigate competitive exclusion of certain genera. These findings demonstrate that distinct microbial communities arise from different production systems and offers clues as to how these may be influenced in the future.

Research on the topic of Campylobacter is hugely important for animal and human health. Our work in collaboration with the AFBI team is extremely important in developing knowledge and transferring it back to industry, delivering the benefits for both bird health and human health which has long term benefits for health of our society and remaining at the forefront of scientific discovery in this space.

Justin Coleman - Agri Business and Live Production Services Director.

The study was funded by Moy Park.



Enhancing the natural and marine environment

Section 3

Accounting for the carbon sequestration potential of common land uses in NI

Research Leads: Dr Rodrigo Olave, Dr Dario Fornara, Dr Aurélie Aubry

Carbon sequestration by living biomass and soil has the potential to compensate for greenhouse gas (GHG) and carbon dioxide (CO2) emissions from livestock production systems and to substantially reduce their carbon footprint.

Within farmed landscapes, woodlands, hedgerows and grassland soil, have the potential to store large volumes of carbon and thus transform the land into a carbon sink, capable of offsetting GHG emissions, not least methane emissions from bovine livestock, and direct and indirect CO2 emissions linked to tillage, fertiliser application and other energy-using farming activities.

Quantifying, modelling and predicting the carbon sequestration potential of biomass and soil at farm and landscape scales has been a major focus of AFBI research in recent years.

Researchers in AFBI have sought to evaluate the carbon sequestration potential of woodlands and hedgerows with farmed landscapes by determining their rates of biomass (carbon) accumulation (Figure 1).

The research suggests that forests and hedgerows store considerable amounts of carbon, but that the potential for carbon storage varies considerably depending on species composition and management practices. There is evidence that hedgerows actively managed by cutting and shaping store more carbon than those that are not managed, and that forests and woodland need silvicultural interventions such as pruning, thinning and harvesting to optimise their carbon storage.

Fig 1. Hedgerows in AFBI farms sequestered 117.4 g C/m hedge on an annual basis which is usually trimmed back and added to the soil through decomposition of hedge litter (Blair, 2020.)

AFBI scientists (Blair, 2020) have found that if properly managed, hedgerows could add an additional ~90 tones C/farm, equivalent to 0.7 tonnes C/ha/yr which compares favourably with the average rate of carbon sequestration of densely planted conifer forests (mainly Sitka Spruce) of between 2.9 and 3.5 tonnes C/ha/yr based on a time series of forest sites in Northern Ireland (Olave & Fornara, Unpublished data) (Figure 2).

Fig2. Destructive sampling of conifers in Fermanagh, Northern Ireland, (Olave & Fornara, unpublished data, DAFM/DAERA, 2019).

Agricultural grasslands can also act as significant carbon sink, with their carbon sequestration potential dependent on the complex interaction of different environmental (i.e. soil type) and management (i.e. nutrient fertilization) factors.

Evidence from a long-term permanent grassland experiment in NI shows that grassland soils can sequester between 0.35 tonnes C/ha/yr in unfertilized grassland and 0.86 tonnes C/ha/yr in grassland receiving high application rates of cattle liquid manure.

AFBI research has also shown that under cool and humid Irish climate conditions, soil C stocks in managed grasslands continue to grow for decades and are resilient to intensive management interventions, such as ploughing, and are vital for the delivery of multiple ecosystem services.

To make the above research on C sequestration useful to farmers, AFBI have developed the BovIS greenhouse gas (GHG) calculators to calculate the carbon footprints of dairy and beef farms, expressed in terms of GHG emissions per kg of milk or meat produced.

These calculators are using the latest science from AFBI and other international research groups. They offer the option to include or to exclude carbon sequestration from grasslands and changes in land uses.

A sequestration value of 0.7 tonnes C/ha/yr has been adopted for permanent grasslands, based on the afore-mentioned research.

Recent research at AFBI involving more than 100 NI dairy farms indicate that their carbon footprint is reduced by up to 32% when including carbon sequestration from grasslands, depending on their land use management.

In order to better account for the overall reduction in the carbon footprint when taking into account all carbon sinks, the AFBI GHG calculators are being updated using refined carbon sequestration values and to include the effect of trees and hedgerows present at the farms.

Importantly, these calculators have a user friendly platform accessible by individual farmers or advisors to calculate their own carbon footprint and carbon sequestration potential.

Improving phosphorus sustainability in NI agricultural grasslands: the role of arbuscular mycorrhizal fungi (AMF)

Research Lead: Dr Dario Fornara

Global rock phosphate reserves are steadily declining, while phosphorus (P) losses from intensively fertilised agricultural soils continue to increase and contribute to water quality problems. These undesirable trends together with rising global food demand urgently call for more sustainable use and cycling of P within land-based farming sectors.

In Northern Ireland, ruminant livestock production systems, especially dairy enterprises, are characterised by sizeable P surpluses and low P use efficiencies (PUE), with significant amounts of P applied in fertiliser and manure retained in soil as 'legacy' P. Although farm-gate P surpluses are now routinely assessed on many farms, the biochemical mechanisms controlling long-term changes in ecosystem P budgets within grassland, are poorly understood and could be very context specific.

A better understanding of these mechanisms is needed to enable the development of practical strategies for improving PUE and helping to ensure the sustainability of ruminant livestock production well into the future.

An important knowledge gap, is the extent to which continuous applications of manure P to grassland soils affect the distribution of P within both the soil and the soil-crop system, and the role of arbuscular mycorrhizal fungi (AMF) in this process. Plants have evolved different strategies to optimize nutrient acquisition from soils, including the formation of arbuscular mycorrhizas, which are associations of plant roots with fungi that acquire soil nutrients. The presence of AMF is beneficial for P acquisition by plants especially when P is not immediately available for plant uptake. It is not clear, though, how this positive relationship between AMF and plant P uptake might be affected in agricultural grasslands receiving significant P inputs as manure.

Using a long-term grassland experiment (established in 1970) at AFBI research farm in Hillsborough the effects of long-term P fertilization on PUE and AMF abundance was investigated in soils receiving either inorganic P (NPK) or organic P (cattle or pig slurries). It was found that 47 years of repeated organic P applications increased soil P availability (Olsen P) and total soil P stocks by up to 1600% and 400%, respectively, compared to unfertilised-control soils, and that soils retain

up to 62% of the total P added as pig slurry compared to just 48% of the P added as NPK chemical fertiliser.

P fertilization significantly affected rates of AMF root colonization (%), which decreased in soils receiving increasing applications of organic P in cattle and pig slurries. Plant PUE increased with greater AMF root colonization, which remained high (i.e. 50-to-75%) even after 50 years of continuous 'normal' agronomic P inputs (~30 kg P ha/yr). AMF abundance, however, decreased when P applications were greater than recommended.

The study demonstrates that maintaining low-to-moderate P application rates (up to ~30 kg P ha/yr) to NI grasslands improves soil health, allowing AMF to function naturally. In turn, healthy soil AMF communities reduce the need for added P by 'mining' P from the pool of legacy soil P and making it available for crop uptake.

Overall, low-to-moderate P fertilizer inputs to NI grassland soils should: (1) increase P Use Efficiency, and (2) make grassland systems more P conservative thereby reducing the risk of P loss from soil to water bodies.

The take-home message from this long-term study, is that working with nature (e.g. maintaining healthy AMF communities in soils) is crucial to improving the P use efficiency of grass-based ruminant production systems, and making them more sustainable for the long-term.

The Schematic diagram which shows the annual amount of (1) P added to soils (i.e. P inputs), (2) P retained in soils (i.e. P soils), and (3) P up-taken in plant biomass (i.e. P plants) averaged across 47 years since the grassland experiment was established in 1970. 'Low P inputs' (left) include average cattle and pig applications at 29.6 kg P ha/yr while 'High P inputs' (right) include average cattle and pig applications at 115.5 kg P ha/yr. 'P gains' refer to 'extra' P in the system that is not accounted for based on annual P inputs. 'P loss' refer to 'missing' P whereby the annual amount of P in the system (soils + plants) is lower than that added through fertilization. Yellow arrows' width indicates (qualitatively) the potential role of AMF in mobilizing P for plant uptake'.

This study was funded by DAERA.

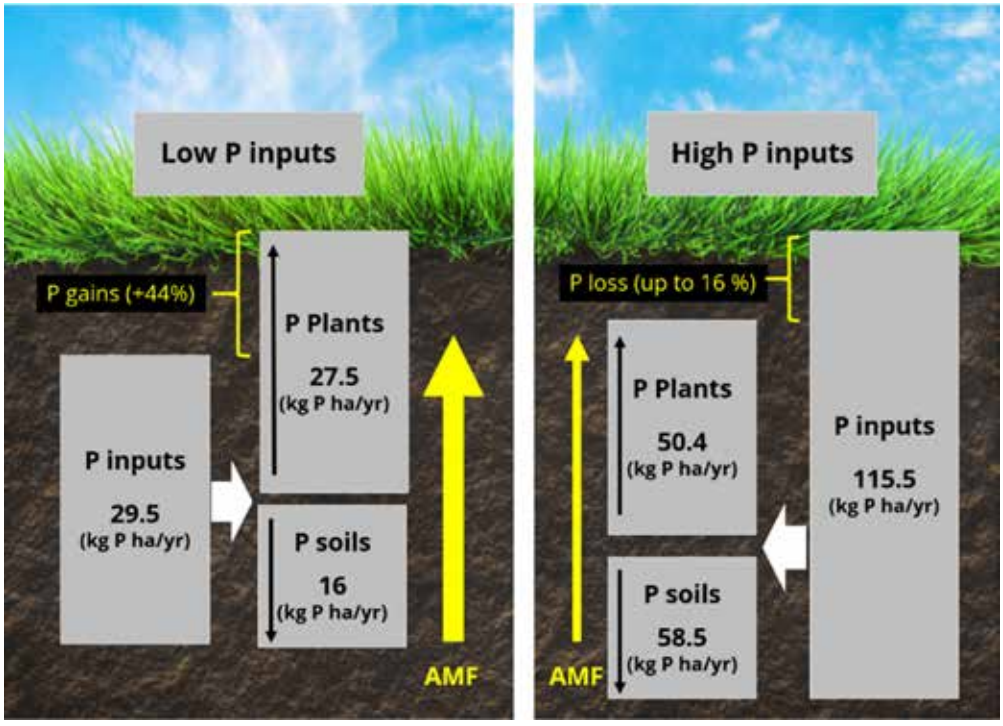


Fig 1.:Soil P dynamics

Source to Tap: safeguarding drinking water sources in cross-border Irish catchments

Research Leads: Dr Phoebe Morton, Dr Rachel Cassidy and Dr Donnacha Doody

Despite complex and costly processing at water treatment works, the herbicide 2-methyl-4-chlorophenoxyacetic acid (MCPA) is sometimes still found above the drinking water limit of 0.1 µg/L after treatment. This is a particular problem on the island of Ireland as soft rushes proliferate on waterlogged grasslands, reducing forage production and jeopardising subsidy payments. MCPA is one of just a few pesticides available to control rushes, and hence is frequently used, but can make its way into watercourses as a result.

The EU-funded (INTERREG VA) Source to Tap project focusses on water quality and is trialling measures in the cross-border Derg catchment, which supplies water to ~30,000 people, to reduce MCPA concentrations in the source waters through a financial incentive scheme encouraging farmers to change practices. With an investment of £1 million on mitigation measures and best practice guidance, Source To Tap provides a unique opportunity to demonstrate the cost effectiveness of targeted intervention within catchments. The key question being addressed is whether it is more cost effective to tackle MCPA pollution at source or to remove it from the river water at the water treatment works.

As part of the Source to Tap project, a three-month AFBI-led spatial sampling programme, in which grab samples were taken weekly at 11 locations across the Derg catchment, identified MCPA hotspots. The highest concentration was over 9 µg/L. These data informed Source to Tap of the sub-catchments which the financial incentive scheme needed to target initially. Additionally, MCPA was monitored every 7 hours at the drinking water abstraction point near the water treatment works. To date (2018-2020), 29% of these samples exceeded 0.1 µg/L of MCPA, with the highest concentration over 4 µg/L (Figure 1). An AFBI-led literature review on the state of knowledge about MCPA, which achieved recognition for being in the top 10% of downloaded papers from WIREs Water

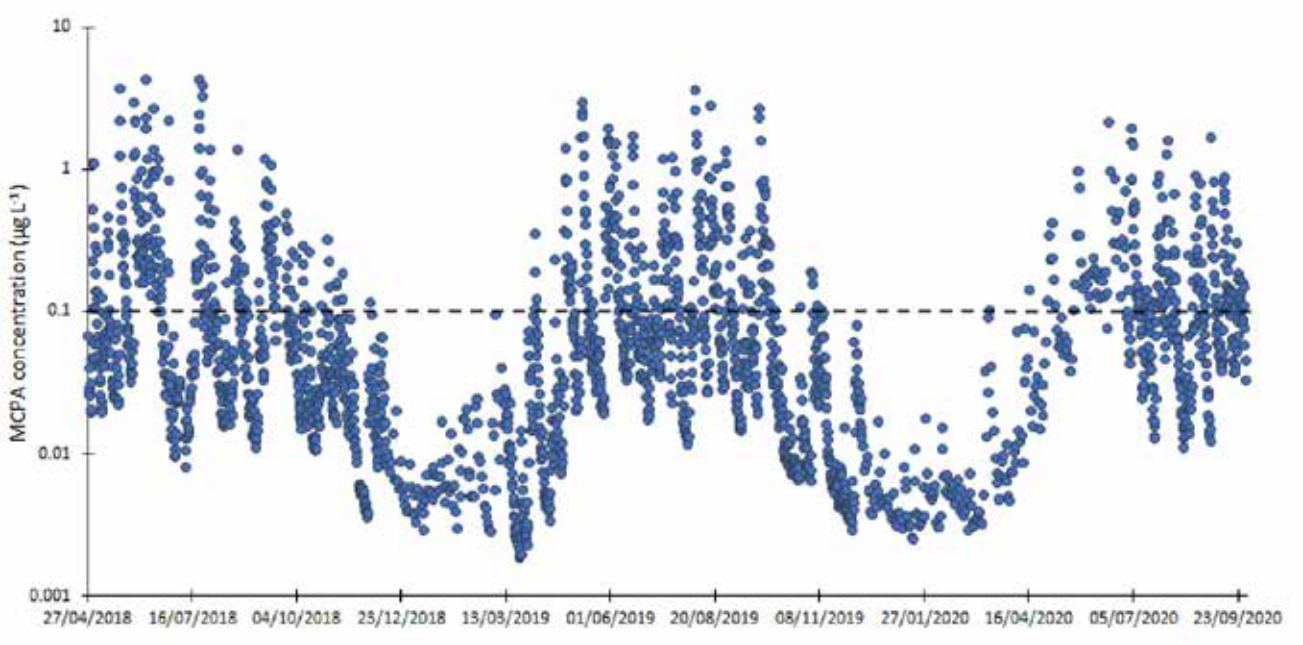


Fig 1: MCPA concentrations at the drinking water abstraction point on the River Derg (dashed line is the treated water limit).

journal, highlighted this 2500-sample high resolution dataset as one of the best of its kind globally.

Further monitoring, combined with a cost-benefit assessment with AFBI's economists, will demonstrate the incentive scheme impacts and cost-effectiveness. Additionally, Source to Tap has demonstrated the willingness of farmers to engage and has invested in improvements on many farms. It has also established links between farmers and water companies on both sides of the border. However, most importantly, the data gathered has been used to develop a tool to help water companies to identify MCPA risk periods, which will assist in the management of levels in drinking water.

AFBI have played a key role in the Source to Tap project, sharing and redoubling the efforts to protect drinking water from the effects of herbicide usage across drinking water catchments in Northern Ireland and Ireland. The approach taken by AFBI has meant that the project, not only has an enviable and relevant data set, but also an understanding of the retention / release of herbicides in drinking water catchments and furthermore, intelligent innovative ideas for affordable mitigation against herbicides in drinking water. NI Water is committed to working with AFBI for the good of public health protection and environmental improvement.

Dymphna Gallagher, Head of Drinking Water Regulation, NI Water

The project is supported by the European Union's INTERREG VA Programme, managed by the Special EU Programmes Body (SEUPB).

Evaluating scenarios for achieving the Water Framework Directive Phosphorus Targets in the Blackwater

Research Leads: Dr Russell Adams, Dr Donnacha Doody

Under the Water Framework Directive (WFD) freshwaters are required to obtain "Good" or better chemical status in terms of phosphorus (P). However, in Northern Ireland (NI) only 38% of our waterways achieve this status. AFBI science is monitoring some of these water systems and also applying models to aid future policy development aimed at improving water quality in NI. Models are important tools for exploring a range of future scenarios to address the impact of land use practice on aquatic ecosystems.

One such example of this is in the Blackwater catchment where models were used in the Interreg funded CatchmentCARE project, to demonstrate the impact of different farming practices on the water quality. The work focused on the sub-catchment of the Oona Water, a tributary of the Blackwater River and with an area of approximately 100 km^2. Key characteristics of the Oona Water include pastoral farmland (dairy, beef and sheep), small settlements mostly connected to septic tanks and the waterbody is currently classified as having "Moderate" status.

River Blackwater

The CRAFT (Catchment Runoff Assessment Flux Tool) was used in this study to explore phosphorus (P) dynamics (temporal variations in concentration and annual export) under the existing land use in the Oona (Baseline). The Baseline indicated that the P concentration required for "Good" status was only achieved for 39% of the period in the Oona. A comparison of the current observed soluble reactive P (SRP) concentrations to those necessary for "Good" status (i.e. 50 µg/L), demonstrated that a 60% reduction was required.

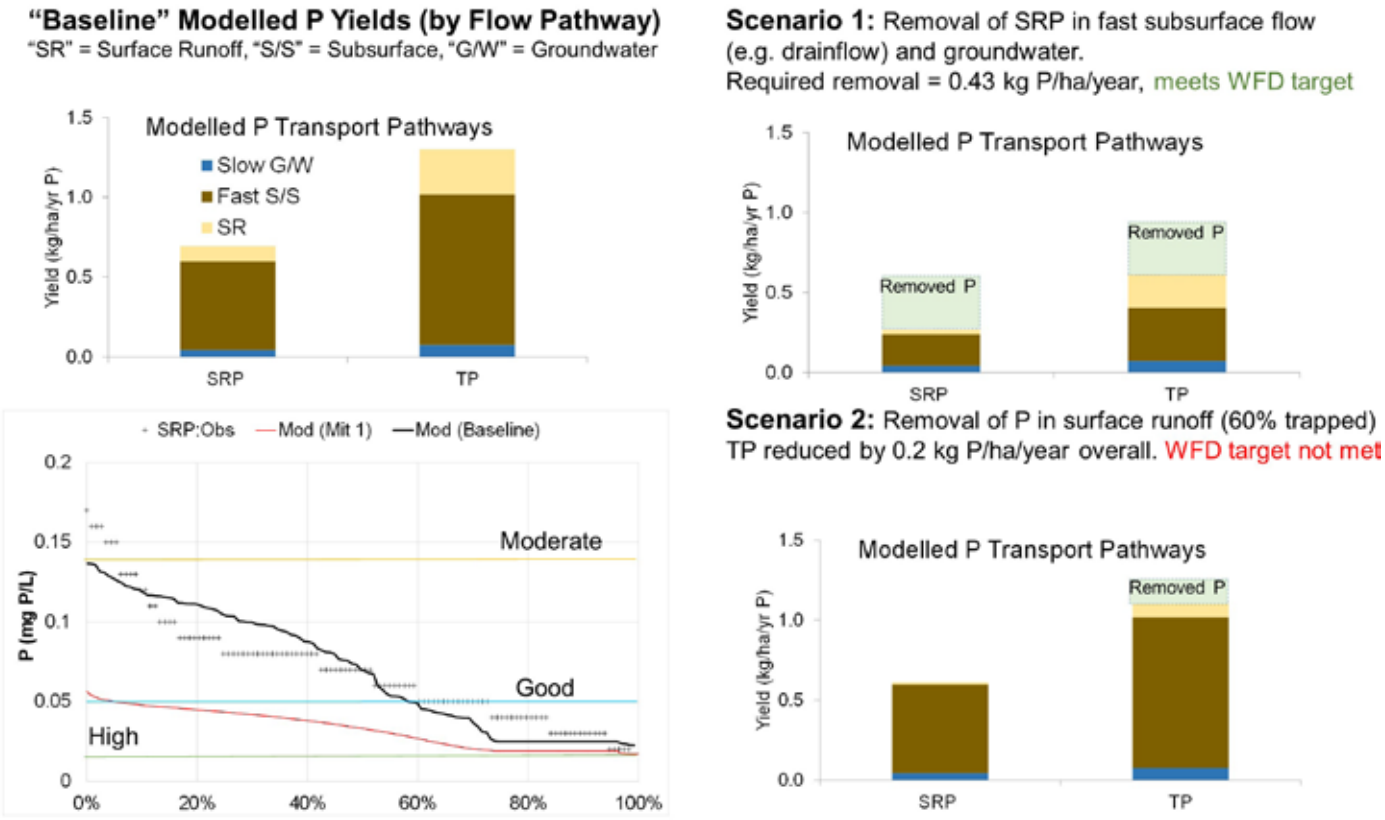


Fig 1. Plots of (top left) Baseline P export from Oona catchment (2005-17); (top right) P export (Scenario 1); (bottom right) P export (Scenario 2); (bottom left) Concentration-duration curves for Baseline and Scenario 1 ("Mit 1") with observed data shown by black crosses. WFD status thresholds indicated by horizontal lines.

Subsequently, two mitigation scenarios were investigated using the CRAFT: (i) mitigating SRP in fast near-subsurface flow, and (ii) targeting sediment P losses in surface runoff.

The results show that Scenario 1 was most effective, reducing SRP export by 61% and achieved "Good" status in the Oona Water catchment for 87% of the period (red line labelled "Mit 1" in lower left pane). However, a combination of Scenarios 1 & 2 would achieve the best environmental outcome in the catchment and provide more flexibility to land mangers on the sorts of mitigation measures they could adopt.

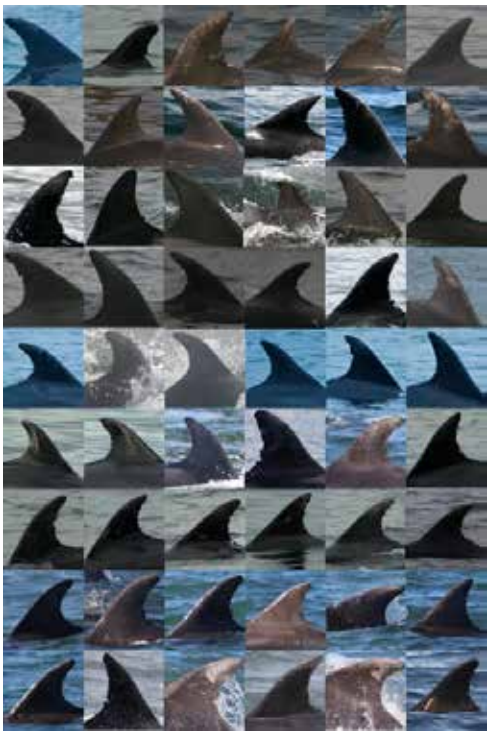
The use of the CRAFT is just one example of how AFBI is using models to inform the development of future agri-environmental policy in Northern Ireland

The project was supported by the European Union's INTERREG VA Programme, managed by the Special EU Programmes Body (SEUPB).

Using social media for animal tracking - photo-identification of bottlenose dolphins – a citizen science approach.

Research Leads: Dr Catherine Gibson, Dr Suzanne Beck

The bottlenose dolphin *Tursiops truncatus* is one of the most recognisable cetaceans worldwide and frequently encountered around the British Isles. Previous research has focussed on areas with resident populations and relatively high numbers of animals. A number of Marine Protected Areas (MPAs) now exist to facilitate the conservation of resident populations. However, where the animals exist in low numbers and in wide ranging groups, they are unlikely to benefit from these fixed designations. Furthermore, the interchange between highly mobile communities is likely to have direct implications for future management.



Images of the 54 well marked individual dolphins around the coast of Northern Ireland & Donegal.

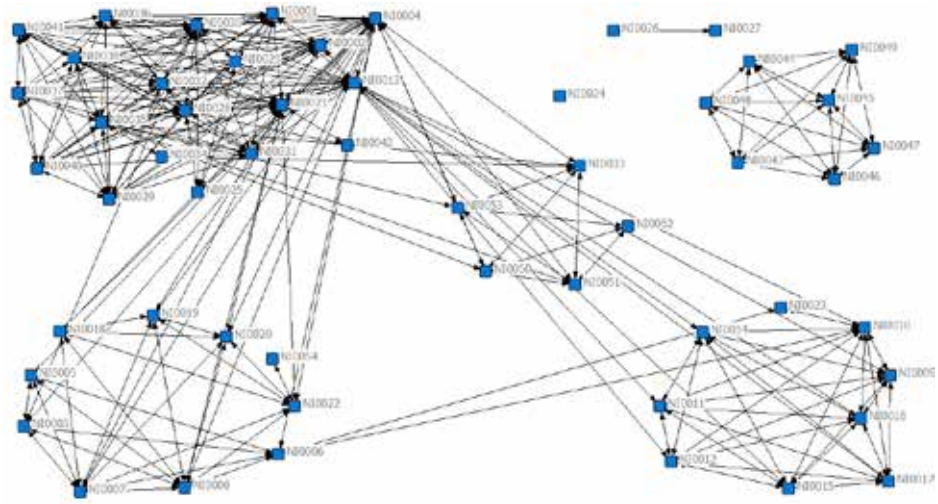
Individuals sighted around the coast of Northern Ireland likely form part of a wide-ranging coastal population, known as the Irish Coastal Community. Research has struggled to effectively monitor these occasional visitors and our understanding on the importance of Northern Irish waters has been greatly constrained by the lack of dedicated effort.

Fortunately, social media and photo sharing sites have rapidly become popular channels for the general public to 'post' information on biological events, including exhilarating encounters with the bottlenose dolphin. Through this digital society, an opportunity now exists to gather large volumes data, potentially extending the spatial and temporal scope of cetacean studies.

This research programme first sought to investigate social media as a data resource for photo-identification studies and provide a preliminary assessment of bottlenose dolphins in the north of Ireland. Photo-identification is a method of mark and recapture. During a dolphin sighting a portion of the population is 'captured' by photography. Individuals are identified from the photographs based on distinctive markings. This method is repeated over time and individuals are re-identified or new individuals added to the population sample. This information can estimate population size and make further

inferences such as whether the individuals form part of a resident population and their social structure.

Three sites were investigated; Facebook (www.facebook.com), Twitter (www.twitter.com) and the photo sharing site Flickr (www.flickr.com). A photo-identification protocol was devised to remove poor quality images from the dataset while still allowing less than perfect images of well-marked individuals to be retained in the dataset. This approach known as data mining resulted in 117 encounters of bottlenose dolphins between 2007 and 2016. From this, 54 well-marked individuals were added to the first Northern Ireland Coastal Bottlenose Catalogue.



Social network of all individuals photo-identified around the north coast of Ireland. Nodes represent individual bottlenose dolphins, lines between nodes represent that the individuals have been photographed associated together in a group or aggregation. The strength of social ties are represented by the thickness of the lines between individuals using the Half Weight Index (HWI).

Encounters were reported in every year of the study period, and distributed throughout all calendar months with a notable peak during the summer. Successful inter annual re-sightings were concentrated along the north coast, highlighting a potential 'hotspot'. This stretch of coastline, spanning from Malin Head, in County Donegal to the Giants Causeway in County Antrim, forms a key region for future study of this coastal bottlenose community.

Our research highlighted data collection via social media as a cost-effective and scientifically valuable method in the photo-identification of coastal cetaceans. It is especially suited to research on these low density and wide-ranging animals. AFBI have continued data mining via social media to further our knowledge on this charismatic community, in particular investigating the connectivity between neighbouring communities. This Citizen Science based approach aims to provide a broader regional context to our locally encountered dolphins, and form a basis for future collaborative management.

The data and knowledge gathered through citizen science has developed our understanding of the spatial distribution of these top predators around our coast, and in doing so will help AFBI develop ecosystem management strategies for marine resources such as fisheries and aquaculture. In particular, the conservation needs of this wide-ranging bottlenose community will be incorporated into the North-Coast Ireland and North Channel regional management plan. This cross border management strategy is being developed under the AFBI led MarPAMM project, funded by the INTERREG VA Programme. The work will also contribute to the UK Marine Science Strategy and the OSPAR Commission Assessment on coastal bottlenose dolphins.

Full citation: Gibson, C.E., Williams, D., Dunlop, R. and Beck, S., 2020. Using social media as a cost-effective resource in the photo-identification of a coastal bottlenose dolphin community. Aquatic Conservation: Marine and Freshwater Ecosystems, 30(8), pp.1702-1710.

Science supporting new coastal development policy

Research Leads: Dr Christian Wilson, Dr Adam Mellor, Dr Matt Service

Global climate change is driving a long term rise in the sea level around the coast of Northern Ireland. This will be accompanied by an inevitable increase in the exposure to erosive wave energy. There is a growing recognition that adaptive management approaches are necessary to deal with changing environmental pressures such as flooding and coastal erosion.

In this context the absence of primary legislation in Northern Ireland covering coastal management is an anomaly, and AFBI are providing DAERA and DfI with clear science to support this policy gap. Work undertaken by AFBI is addressing a broad array of coastal monitoring, mapping and modelling activities, including: installing offshore wave monitoring hardware (real-time data and forecasts available at http://wavenet.cefas.co.uk/Map), detailed coastal surveys, modelling groundwater, mapping habitats and erosion risk assessment using machine learning and satellite data.

These elements are being used to develop a narrative which informs the policy options that enhance the long term resilience of both the natural and built environment. It is becoming ever clearer that the mere provision of data, information or knowledge by scientists is no guarantee of successful "real world" use or application, and AFBI are active in developing the Coastal Change Assessment Partnership Project (CoChAP) to address more complex societal issues.

Wave monitoring buoy being deployed from RV Corystes

Solutions to complex socio-ecological issues must include the broader social, economic and political context within which the science will be used. This activity runs parallel with AFBI research looking specifically at the future climate impacts on valuable coastal wetland habitats.

"The information provided by AFBI has removed supposition and introduced fact to show that action needs to be taken to form a coherent strategy to mitigate the effects of the sea on the coast. A number of departments within the government can use this report to inform decision making."

Billy Carlile, Chairman, Ards Peninsula Coastal Erosion Group

Map of modelled groundwater depth in pilot study area.

The study was co-funded by the European Maritime & Fisheries Fund, managed by DAERA.

Foundations of ecosystem-based fishery management in the Irish Sea

Research Lead: Dr Mathieu Lundy

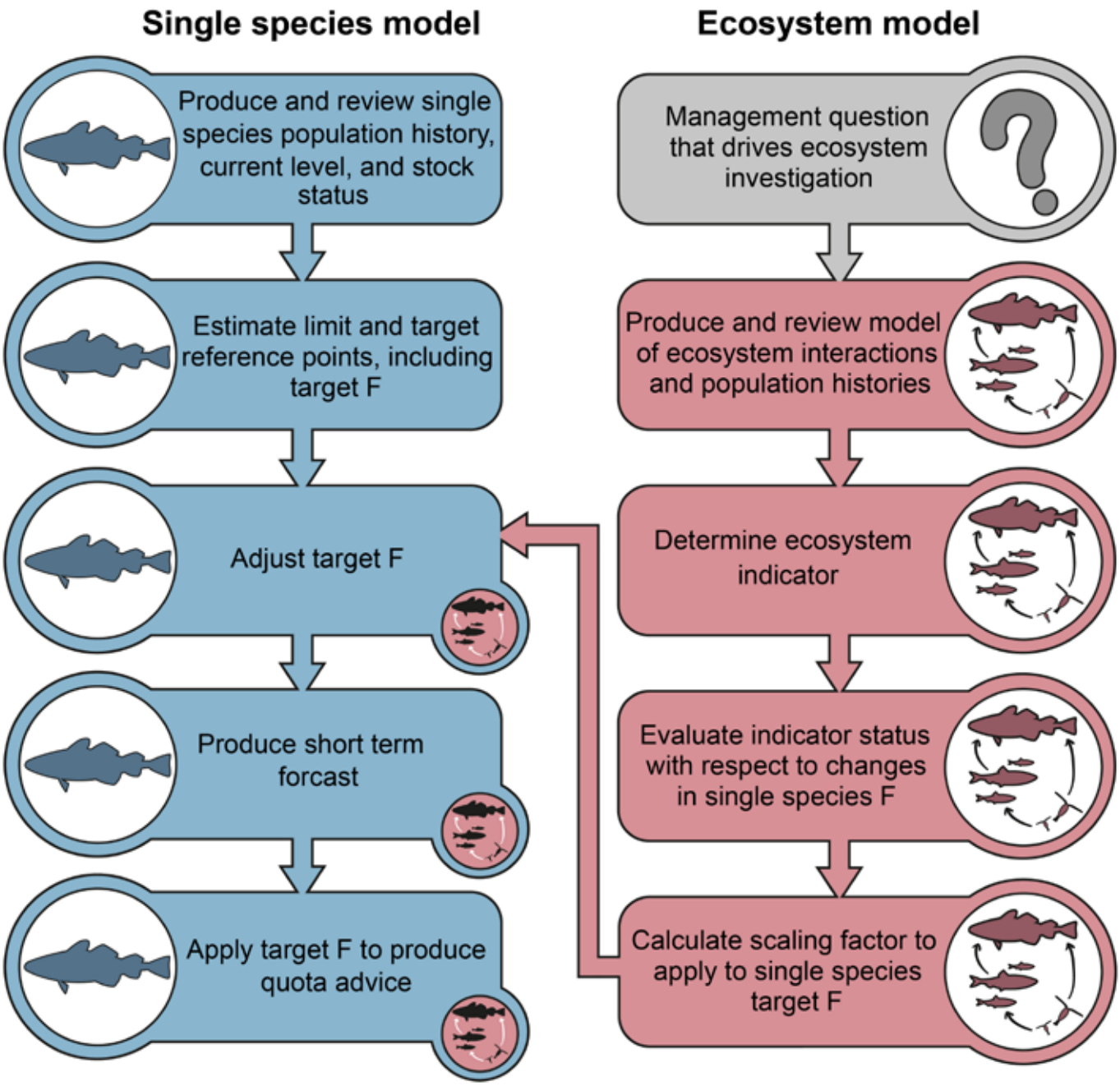
Integrating ecosystem information into fisheries management is acknowledged as key target achieving sustainable fisheries management. Whilst many nations have formally committed to Ecosystem-Based Fisheries Management (EBFM), progress toward these goals has been slow, due to the complexity of the system processes and knowledge gaps.

AFBI scientists have been working toward developing these methods completing assessment of Irish Sea fish and shellfish stocks and develop foodweb models incorporating environmental parameters. Through the International Council for Exploration of the Seas (ICES) coordinated Ecosystem Based Approach to Fishery Management for the Irish Sea (WKIrish) workshop series, AFBI fishery scientists, along with international partners, have developed a framework allowing the incorporation of ecosystem information into fishing opportunity advice.

The fisheries of the Irish Sea have shown dramatic changes over the last 50 years, with declines in finfish fisheries and increases in shellfish fisheries. Since the early 2000s, fishery management measures in the Irish Sea have been focused on the recovery of cod stocks. These included closed seasons, closed areas, technical measures and reduction in fishing quotas. Despite these management measures, recovery of some stocks has not been observed.

The work of WKIrish contributed to identification of key ecosystem drivers for stock production, for example sea temperature, plankton abundance and foodweb structure. The interdisciplinary approach of WKIrish combined the expertise of ecological modellers, stock assessors and stakeholders. AFBI scientists provided the key understanding of the assessment process and ecosystem function to allow integration within current management systems to provide policy advice.

The proposed solution sets out that target levels of fishery catches can be modified, within existing sustainable ranges for individual stocks, using indicators of ecosystem condition. This is turn provides a fishery catch advice process that will be responsive to wider environmental changes, taking into consideration the entire food web and environmental conditions to maximise fishing opportunity whilst prompting environmental sustainability. The WKIrish process is now to be used as an example in



Flow chart outlining the steps in advice giving involved in the proposed method, with the input of the ecosystem modelling to the single species advice highlighted. (Howell et al., 2021)

other sea regions. The work was developed with fishery stakeholder engagement and input from the outset and in doing so has uplifted the understanding of the challenge and potentials solutions for the fishing industry. Overall the outputs and analysis have provided a fundamental context to support an understanding of the status of Irish Sea fish stocks for industry, policy makers and scientists.

Reference:

Howell et al., (2021) Combining Ecosystem and Single-Species Modeling to Provide Ecosystem-Based Fisheries Management Advice Within Current Management Systems. Frontiers in Marine Science. https://doi.org/10.3389/fmars.2020.607831

The study was funded by DAERA.

Updating the nitrogen excretion rate for dairy cattle in Northern Ireland

Research Lead: Dr Tianhai Yan

The previous Northern Ireland's Nitrates Action Programme Regulations adopted a value of 91 kg/head/year for nitrogen (N) excretion from dairy cows. This value was determined based on a dataset that was collated from 26 total diet digestibility studies with 568 lactating dairy cows undertaken at AFBI Hillsborough from 1990 to 2004, using an annual average milk yield of 6,206 kg per cow in Northern Ireland at that time.

During the last 15 years, however, the dairy industry in Northern Ireland had experienced changes (e.g., derogations for nitrate and improvement in cow genetic merit) that had improved the production efficiency of dairy cows. In particular, there were research findings showing that the average milk yield had increased by over 1,000 kg, and that the proportion of N excretion over N intake had decreased. It had also been recognised that the crude protein content in dairy cattle diets had reduced, in light of the legislation to reduce the environmental impact of modern-day milk production systems. However, in order to drive the higher milk yield, dairy cows have to consume more feed, and hence have more protein intake, which has a direct effect on N excretion. Hence, it was of utmost importance to evaluate if the N excretion rate of 91 kg/head/year determined using total diet digestibility data of 1990-2004 was still valid to be applied to the current dairy herds in Northern Ireland.

Using a similar methodology to the one that was used to determine the N excretion rate of 91 kg/head/year, a dataset was collated from 12 total diet digestibility studies with 388 lactating dairy cows undertaken at AFBI Hillsborough from 2005 to 2015 and used to develop regression equations to predict manure N excretion for the current dairy herds in Northern Ireland.

A comparison of the two datasets showed that the '2005-2015' dataset had higher milk yield and feed intake than the '1990-2004' dataset. The dietary protein content was lower for the'2005-2015' dataset, but dietary metabolizable energy concentration was similar between the two datasets. The '2005-2015' dataset had higher N intake, faeces N and milk N, but lower urine N and

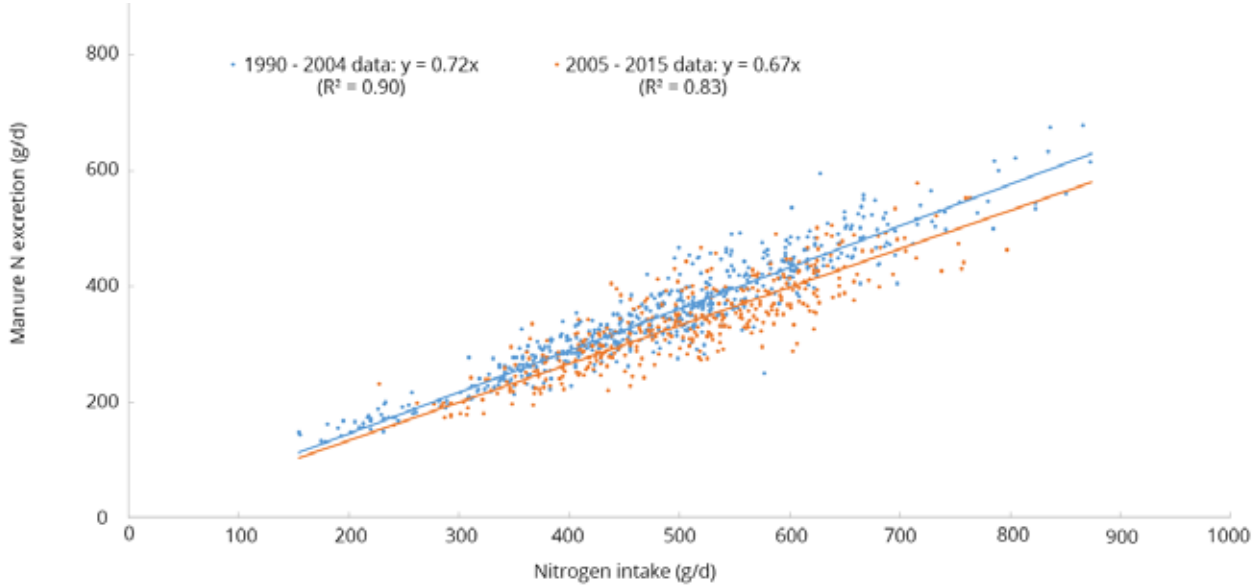


Fig 1. The relationship between N intake and manure N output

total manure N than the '1990-2004' dataset. Consequently, the '2005-2015' dataset had higher proportions of milk N over N intake, and lower proportions of urine N and total manure N over N intake (Figure 1). These observations implied that the current dairy cattle herds (represented by the '2005-2015' dataset) could be producing less manure N per unit of milk produced; necessitating an amendment to the N excretion rate determined using the '1990-2004' dataset.

The statistical modelling based on the '2005-2015' digestibility dataset showed that total N intake was the prediction variable of the best-fit equation for total manure N excretion of dairy cows. However further work was required to establish the relationship between milk production and N intake on a yearly basis, which facilitates the calculation of manure N excretion for average Northern Ireland cows per year. A best-fit relationship was thus developed for prediction of N intake based on annual milk yield and live weight of dairy cows. This equation was established using a dataset of 476 lactating dairy cows in 8 whole lactation studies undertaken at AFBI Hillsborough from 2006 to 2013.

The developed prediction equations were then used to calculate average manure N excretion (kg/head/year) for dairy cows in Northern Ireland from 2013 through 2017. The inputs for the prediction equations were collated from DAERA statistical reports. Manure N excretions were predicted to be 100, 102, 101, 98, and 101 kg/head/year for 2013 through 2017, respectively, with an average value of 100 kg/head/year for average dairy cows producing milk of 7,220 kg/head/year. This represented a 10% increase on the previous value of 91 kg/head/year. This N excretion value of 100 kg/head/year was reviewed and approved by DAERA stakeholder groups, and it was adopted in the new Northern Ireland's Nutrient Action Programme (NAP) Regulations for the period 2019-2022.

Overall, as a result, although the efficiency of production increased, the uplift in milk yield drove a higher intake and therefore a higher output of nitrogen. This higher output is now reflected in the value of 100 kg/head/year in the most up to date NAP regulations. This is important for both industry and policy makers as it provides a robust evidence base to design and implement future plans and strategies to address the environmental impact of dairy production.

The study was co-funded by DAERA, AgriSearch.

Key Services

Section 4

AFBI's Cattle Health Scheme

The AFBI Cattle Health Scheme is a Cattle Health Certification Standards (CHeCS) licensed scheme that is available to NI farmers to improve the health of their herd through a structured approach. It is available through AFBI's Veterinary Services Division (VSD) which has provided diagnostic services to farmers in Northern Ireland and beyond for over 30 years and has established a close working relationship with private veterinary practitioners and the farming community at large. AFBI's veterinary staff have recognised expertise in the diagnosis and control of the diseases covered by the scheme noted below. Testing is conducted to the highest standards, being monitored by external quality assurance schemes and/or performed to accredited standards (ISO 17025, ISO 9001). The scheme is delivered according to the Cattle Health Certification Standards (CHeCS) rules.

CheCS is the regulatory body for Cattle Health Schemes in the UK and Ireland. It is a non-trading organisation established by the British cattle industry for the control and eradication of diseases by a set of standards to which all licensed Cattle Health Schemes must adhere. These standards ensure that herd health status in one licensed scheme is equivalent to that in all other licensed schemes in the UK and Ireland. Close collaboration by CHeCS with other countries ensures that licensed schemes in the UK and Ireland are as good as any in the world. CHeCS is owned by the British Cattle Veterinary Association, the National Beef Association, Holstein UK and the National Cattle Association (Dairy). It received startup funding from the Milk Development Council (DairyCo) and the Royal Association of British Dairy Farmers (RABDF) provides administrative back-up.

The scheme provides approaches for the monitoring, control or eradication of five of the most important endemic infectious diseases affecting cattle:

- Bovine viral diarrhoea (BVD)
- Johne's disease
- Infectious bovine rhinotracheitis (IBR)
- Leptospirosis
- Neosporosis

Scheme membership will provide access to rapid, cost-effective results, backed by expert advice, helping to improve cattle health and profitability. Benefits include:

- Improved disease control
- Improved profitability
- Protection against accidental introduction of other diseases
- Certification of cattle health status

Herd owners can test for any or all of the diseases at the same time. The programmes may be used as a framework for routine monitoring, for disease reduction, disease eradication and for certification of freedom from the disease in question.

Further information about the AFBI Cattle Health Scheme can be found at https://www.afbini.gov.uk/articles/afbi-cattle-health-scheme

Seed quality assurance in Northern Ireland

Seed is one of the most important yet potentially one of the most variable of all agricultural raw materials. AFBI conducts research and technical activities involved in the quality control of seed and varieties enabling the agricultural industry to obtain a supply of quality seed of proven varietal performance.

The Official Seed Testing Station (OSTS) for Northern Ireland at AFBI, Crossnacreevy implements the Seed Marketing Regulations (Northern Ireland) 2016 and carries out Seed Testing and Certification duties on behalf of DAERA. Seed Certification ensures that seed sold by merchants has varietal authenticity and is capable of producing healthy weed-free crops.

The OSTS is responsible for the technical aspects of certification of cereal crops being grown to produce certified seed through registered growers in NI. This requires in-field inspection of the growing crop to confirm varietal identity, detect varietal and species impurities, wild oats and other noxious weeds, and any loose smut within the crop. In parallel, quality tests including seed purity and germination testing are conducted at the OSTS laboratory before and after seed processing by the merchants. Certified cereal seed grown in Northern Ireland and available locally must meet minimum standards (Table 1).

Policy/Industry Impact

As a whole the agri-food industry turns over more than £4.5 billion every year and a recent survey indicated that total production of barley, wheat and oats has increased significantly due to improved yields. High quality certified seed ensures that crops sown in NI establish well and maximally contribute to profitable and sustainable yields. The OSTS significantly supports these important goals.

Table 1. Minimum standards required for certified seed in NI according to DAERA NI Seed Regulations 2016

	C2 SEED	
	MINIMUM	HIGHER VOLUNTARY STANDARD (HVS)
Germination	85%	85%
Analytical Purity	98%	99%
Number of weed seeds in 500 g (Minimum), 1000 g (HVS)	10	4
Number of wild oat seeds	0	0

UHPLC-QTof-HRMS – a state-of-the-art analysis platform

techniques, based on high-resolution mass spectrometry (HRMS), employ theoretical/empirical mass spectra libraries that provide high-throughput screening for a wide range of compounds. HRMS-based platforms, i.e. quadrupole-time-of-flight (QTof), can be applied using a number of testing strategies including targeted screening, (semi-)untargeted screening and profiling of physiological markers.

The Chemical and Immunodiagnostic Sciences Branch (CISB) within AFBI carries out analysis of agri-food samples for the presence of chemical contaminants e.g. residues of veterinary medicines, natural toxins and other unauthorised substances. The work of the lab provides commercial companies and government alike with assurances and safe guards with regard to food and feed safety matters.

Complex sample matrices are analysed using state-of-the-art, accredited methods based on liquid chromatography-tandem mass spectrometry (LC-MS/MS). Furthermore, CISB develops and validates new assays in response to emerging or changing demands.

The possibility of shifting analyses from a target-oriented approach towards a non-targeted approach, has recently been demonstrated.

Targeted procedures such as LC-MS/MS monitor samples for only a limited number of pre-defined analytes however new

Policy/industry impact

QTof instrumentation has the potential to revolutionize contaminant analysis however, the full power of the technology and the scope to move from current methodologies has yet to be established. Method sensitivity in complex test matrices must firstly be demonstrated as sufficient to fulfil legislative requirements.

If applicable, the new approach would be suitable for both monitoring and surveillance purposes, providing the agri-food sector with meaningful data in respect of low level existing and/or emerging contaminants present in animal produce. This knowledge would be useful in supporting both existing markets and competing for new global ones.

The platform also opens up opportunities beyond food and feed safety, including areas such as antimicrobial resistance, environmental and exposure studies etc.

Protecting plant breeding IP through maintaining plant breeders rights

Plant breeding in agriculture plays a vital role in increasing the productivity by developing varieties with improved yield, nutritive quality and resilience to pests and diseases. It is pivotal to the food supply chain which contributes 7 % of gross value added to the UK economy (£109 billion).

Breeding a variety can take up to 15 years, requiring significant investment from a breeder. However, once released it can be reproduced by others and thus deprive the breeder from benefiting from their investment. Therefore sustained and long-term breeding are only worthwhile if this investment is adequately protected.

This is achieved through the International Convention for the Protection of New Varieties of Plants, an international framework adopted by 76 countries for the protection of intellectual property rights of plant breeders.

Policy/industry impact:

The Plant Testing Station at Crossnacreevy is a CPVO Entrusted Office that evaluates Plant Breeders' Rights for grass and clover species on behalf of the Animal and Plant Health Agency for the United Kingdom. Since 1966, the Plant Testing Station at Crossnacreevy has been providing this service to plant breeders and every year evaluates over 50 new grass and clover candidate varieties.

AFBI continues to protect the plant breeding industry into the 21st century, allowing them to introduce new varieties to the UK and global market. This enables UK agriculture to feed a growing population in a sustainable manner; have greater resilience to adverse weather conditions and rapidly adapt to emerging pest and disease risks in an era of climatic change.

The study is funded by APHA, grass breeders and DAERA.

Ongoing AFBI science making an impact

Section 5

RePhokus – phosphorus substance flow analysis of the Northern Ireland food system

Research Leads: Dr Donnacha Doody, Dr Erin Sherry

Sustainable management of phosphorus (P) is vital for the resilience and security of the Northern Ireland (NI) food system, and the delivery of valued ecosystem services (ES) such as clean water and biodiversity. Phosphorus is a key nutrient required for crop and livestock production, but the global reserves of phosphate rock (PR) from, which fertilisers and feeds are derived, are a finite critical resource. The UK has no PR, and NI agriculture is entirely dependent on P imports in fertilisers, feeds and foods, which are becoming increasingly volatile in cost.

Policy/industry impact:

Stakeholder engagement with industry and policy makers is central to the ethos of the Rephokus project. The importance of stakeholders was emphasized recently during the development of a substance flow analysis (SFA) of P in the Northern Ireland food system (Figure 1).

An SFA is an analytical tool used to quantify the stocks and flows of any material within a defined system and provides a visual tool by which to engage with stakeholders. The SFA was developed based on the best available data/information on the P stock and flows in NI in 2017. Where data were not publically available, the Rephokus team worked with agri-food and government stakeholders to identify data sources and/or avail of their expert input. This resulted in a draft SFA model (Figure 1) which formed the basis of further engagement with stakeholders to identify pathways to sustainable P management in NI.

During a stakeholder workshop, in February 2020, a range of future SFA scenarios were presented and discussed with stakeholders, focusing on identification of the levers/ barriers and actions required to achieve each scenario.

The input of stakeholders was recorded and formed the basis of a report published in October 2020, which also detailed the full stakeholder engagement process and the results from the SFA analysis.

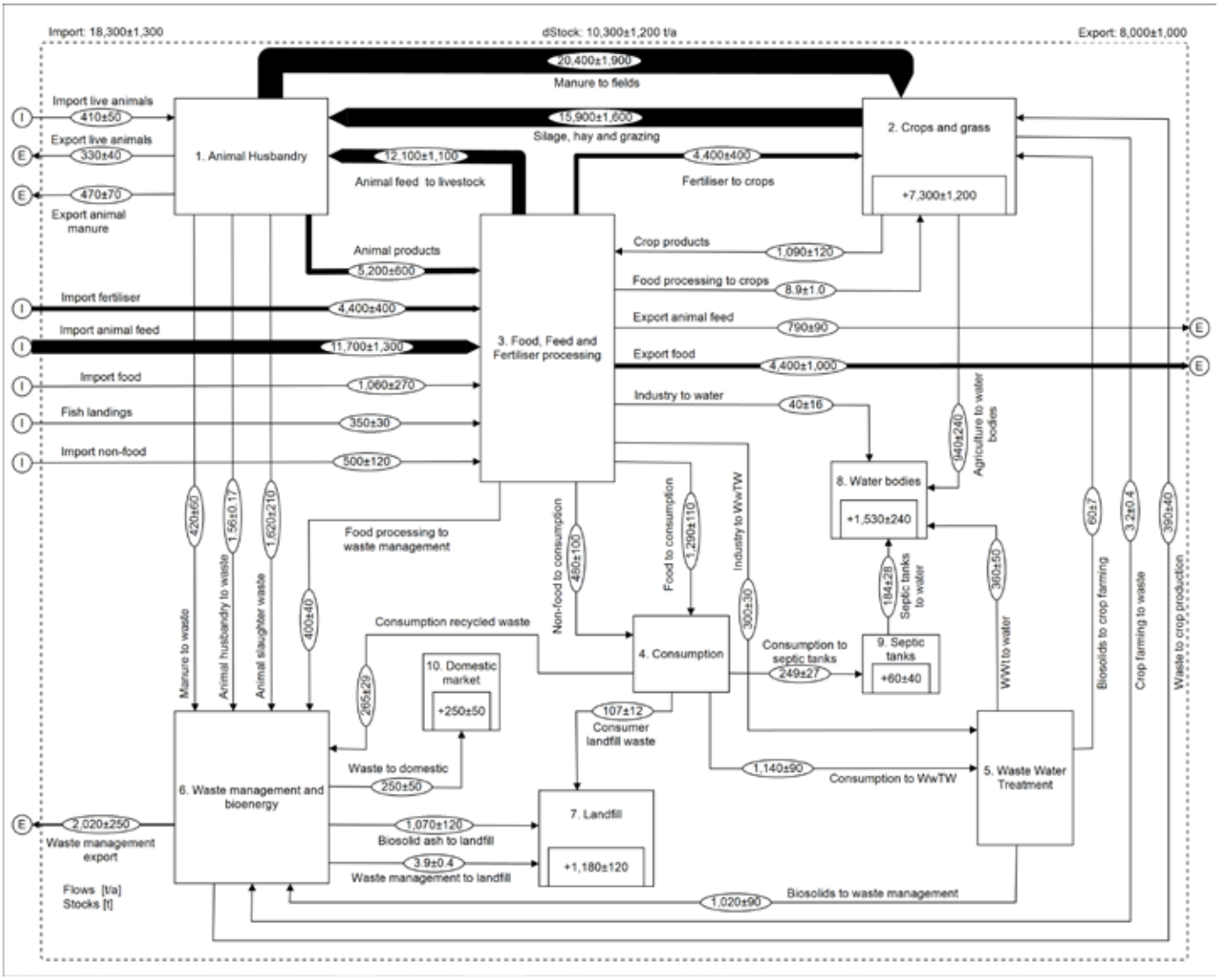


Fig 1: Substance Flow analysis (SFA) of the NI food system

The report can be found at: https://www.afbini.gov.uk/publications/rephokus-report-oct-2020.

This project brings together a strong interdisciplinary collaboration between researchers in global phosphorus (P) sustainability science, food system vulnerability, catchment science, environmental engineering, adaptive capacity and economic modelling.

Other institutes involved in the project are Lancaster University (LU), University of Leeds (UL), Centre for Ecology and Hydrology (CEH) and University of Technology Sydney (UTS)

Source of Funding: This project is co-funded by the UK research council (BBSRC, ESRC & NERC) and the Scottish Government.
Rephokus Project Website (http://wp.lancs.ac.uk/rephokus/)

RePhoKUs

InnoVar: next generation variety testing for improved cropping on European farmland

Research Leads: Dr Lisa Black, Dr Gareth Burns. Project Manager, Dr Hazel Brown.

Summary

AFBI is the lead partner and project coordinator for InnoVar and was fundamental in leading the development of the project proposal. InnoVar will develop next generation variety testing by combining cutting edge phenomic, genomic and machine learning methodologies to achieve greater efficiency in variety testing processes and on-farm variety selection.

Policy/industry impact:

This high profile and cutting edge project has showcased the ability of AFBI to lead large scale international projects using novel technology from world-renowned experts.

InnoVar will generate harmonised field data at unpreceded levels across Europe, facilitating data-driven decisions which will influence policy makers at an international, national and farm level on issues ranging from emerging plant diseases & pests, soil health, farm productivity and climate change.

The same data will be used to calibrate machine learning models and design decision support systems for growers.

AFBI plays a key role in ensuring the views of a diverse range of stakeholders are represented. This will maximise the impact, uptake and legacy of project outputs and raise AFBI's profile internationally. Horizon scanning will ensure that requirements of plant variety testing of the next generation are met and will pave the way for AFBI's involvement in emerging technology and 'omics' methodologies.

Our partners and funders

InnoVar has 21 partners from 11 countries across Europe bringing together a wide range in expertise including crop science, bioinformatics, genomics, phenomics and computer science.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 818144.

"InnoVar is unashamedly ambitious with its goals and objectives, with the potential to revolutionize the testing of varieties"

Sam Brooke, BSPB.

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION' HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT N. 818144

Reducing nitrogen excretion from dairy cows through dietary manipulation

Research Leads: Dr Conrad Ferris, Dr Anna Lavery

Nitrogen use efficiency (NUE) by dairy cows is generally low, with only 20 – 30% of nitrogen (N) consumed typically being converted into milk N. Most of the remaining N is excreted in urine and faeces, and this creates a number of environmental challenges.

For example, when faeces and urine mix, ammonia gas is produced, and if deposited on sensitive habitats can cause loss of biodiversity. Similarly, N in the form of nitrous oxide (a potent greenhouse gas) can be lost from manure during storage, or following land application, while N losses from soils via leaching causes eutrophication of waterways. Nitrogen (in the form of protein) is also expensive, so low NUE represents a financial loss for farmers. While NUE is determined by a range of factors, offering dairy cows lower protein diets provides a real opportunity to reduce N excretion, and consequently N losses to the environment.

Policy/industry impact

This major four year research programme seeks to provide DAERA, CAFRE, the livestock feed sector and local dairy farmers with clear information on opportunities to reduce nitrogen excretion from dairy cows through dietary manipulation. The programme includes a number of diverse components, encompassing a review of existing scientific literature, an examination of best practice in Europe, modelling of existing AFBI datasets relating to NUE, an evaluation of proxies for NUE (for example, milk urea), and three full lactation studies examining 'lower protein' diets, each incorporating measures of ration digestibility and analysis of the rumen microbiome (the latter in partnership with QUB). The project also involves an economic analysis of the use of lower protein diets, and an active programme of dissemination of outcomes. This project has the potential to contribute to the adoption of lower protein diets within the Northern Ireland dairy sector, with a subsequent reduction in nitrogen excretion from dairy cows, and ultimately lower nitrogen losses to the environment.

Our partners and funders

This project is being funded by the DAERA E&I programme, and by co-funding by John Thompsons and Son Ltd and Trouw Nutrition Ltd. A number of aspects of the project, especially in relation to understanding the rumen microbiome, are being undertaken in partnership with Queen's University Belfast.

Lackan bog - sensitive habitat

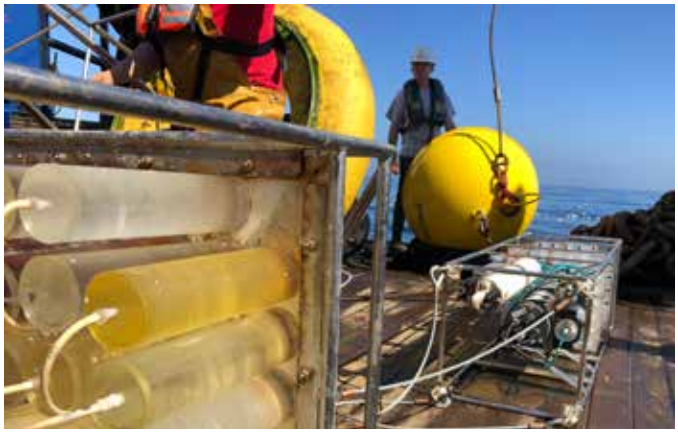
Collaborative Oceanography for Managing Marine Protected Areas and Species (COMPASS)

Research Lead: Dr Adam Mellor

Enhancing the management of Marine Protected Areas (MPAs) supports the sustainable use of our marine resources which is critical for a range of interests from fisheries to climate change. The EU funded COMPASS project is building cross-border capacity for monitoring and managing MPAs across Ireland, Northern Ireland and western Scotland.

To achieve this, the project partners have co-developed a state-of-the-art network which monitors oceanographic conditions, records marine mammals, and tracks migratory fish. The project has developed coupled environmental models for the region whose outputs will be delivered alongside the observational science through an improved and connected data infrastructure.

The COMPASS network of oceanographic buoys is now delivering coherent data from both existing and new locations across the region and is developing our knowledge into areas such as ocean acidification. The projects has already published the first hard evidence of northerly migration trajectories of salmon smolts, whilst the acoustics and modelling work have reported on topics such as the world's biggest ever recorded beaked whale stranding event, and is currently assessing the effect of the COVID-19 lockdown on ocean noise. The science and data generated is being made accessible through the development of a common data sharing infrastructure, as there is increasing recognition between stakeholders that the potential impact of the science is affected by the ability to access, share and use information. Connecting the science as well as the policy across the region has been critical - engagement with the relevant government departments, academics, NGOs and other stakeholders is essential to developing the sustainable management of our shared marine resources.



Deployment of CTD sampler from the RV Corystes

The study was funded by INTERREG, managed by the Special EU Programmes Body (SEUPB).

Interreg
EUROPEAN UNION
Northern Ireland - Ireland - Scotland
European Regional Development Fund

New technology deployed for aquaculture management

Research Lead: Dr Heather Moore

AFBI have been working with DAERA/NIEA and NIW to investigate the water quality of inner Dundrum Bay and the implications for shellfish quality.

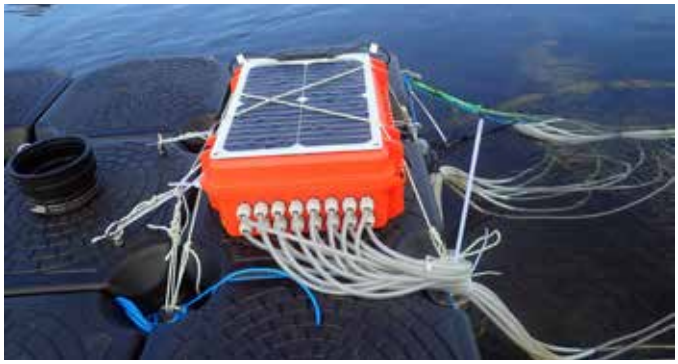
This has been supported by a collaboration with European partners as part of the EU Horizion2020 GAIN project. During early August a new in situ water quality monitoring buoy was deployed at the entrance the Bay adjoining the Irish Sea. This instrument logs water quality every 20 minutes and can be monitored in real time through a telemetry system.

Crucial to this work is the need to understand how shellfish feeding changes in response to water quality. FAEB working with the University of Essex, School of Life Sciences have deployed a novel technique to monitor mussel feeding in the field.

Magnetic sensors harmlessly attached to the outside of the mussel shells sense the open of closing of the shells as the animals filter the water in the bay (NB an individual mussel can filter around 1.5l of water every hour across their gills as they sieve food and other particles from the water).

Once attached to the mussels they were returned to the water and the sensors fed to a data logger deployed on a small pontoon floating in the bay. This work will enhance our understanding of the factors that controls the feeding of cultured shellfish and improve that management of this valuable industry.

Below: Setting up the monitoring equipment to monitor shellfish feeding changes in Dundrum Bay.



The Living With Water Programme

Research Lead: Dr Matt Service

Inadequate wastewater infrastructure means that currently the Greater Belfast area cannot develop or expand economically without growth in its wastewater capacity. AFBI are working with Northern Ireland Water in the Living With Water Programme (LWWP) to deliver a Strategic Drainage Infrastructure Plan (SDIP) to ensure continued economic growth and compliance with environmental targets for water quality in and around Belfast Lough.

AFBI is applying an Ecosystem Approach to modelling the entire Belfast catchment to inform the SDIP. This project is being developed with input from multiple agencies in Northern Ireland, and brings together a strong interdisciplinary collaboration between ecosystem modellers, waste water engineers and environmental regulators.

Living With Water Programme
Strategic Drainage Infrastructure Plan

AFBI are delivering a suite of connected models that are integrated under the System for Understanding Carrying Capacity, Ecological, and Social Sustainability (SUCCESS) framework which includes:

- Catchment models for rivers and streams discharging directly into Belfast Lough.
- A three-dimensional hydrodynamic model of Belfast Lough to model pollutant dispersion.
- An ecosystem model that describes biogeochemical processes in the Lough and accounts for ecosystem services provided by aquaculture and wild benthic species.

To understand the interactions between wastewater and our environment, these models take inputs from urban drainage area models to fully represent nutrient and bacteria loadings. This framework delivers a system that moves beyond an engineering solution to an integrated ecosystem approach. This programme provides more robust predictions for sustainable strategic infrastructure investment as well as tools for understanding wider environmental processes in areas such as land use, freshwater catchments and the coastal marine environment.

This project is funded by Northern Ireland Water.

Marine Protected Areas Management and Monitoring (MarPAMM) – progress in 2020

Research Lead: Dr Naomi Wilson

The Marine Protected Areas Management and Monitoring (MarPAMM) project started in December 2018. This project will use the wide experience of a novel partnership to deliver four models designed to support the conservation of habitats and species that underpin Marine Protected Area (MPA) designations across Northern Ireland, Republic of Ireland and Western Scotland.

These include two models for seabirds and seals, coupled with underwater noise assessments, a seabed-dwelling species, a benthic habitats model and a coastal processes model. Together with models produced by sister INTERREG VA projects (COMPASS and SeaMonitor) and existing datasets, the new models will provide the sound scientific evidence base required for marine management plan development for MPAs.

Six MPA management plans will be delivered by the project, using a cross-border, collaborative focus and extensive stakeholder engagement.

Progress in 2020.

Despite the impact of COVID on access to sites for fieldwork and cruise schedules, MarPAMM has progressed by delivering coastal erosion modelling on the Dundrum Bay area, using data over the past century in combination with satellite derived

bathymetry data to model shallow water topography changes as a result of storm and weather.

Work is also reaching completion on a Seabird climate change model looking at the impact of various climate related variables on key seabird species distribution and abundance within the MarPAMM region (Northern Ireland, Republic of Ireland and Western Scotland).

When COVID restrictions permitted, cruises to collect data for benthic modelling and acoustic data collection for underwater sea noise impact on seals and marine mammals were carried out.

The underwater noise data will be utilised in a collaboration with JONAS, an Interreg Atlantic project to enhance the seal distribution map they are developing and will share with the MarPAMM project.

At the end of 2020 a synergy webinar event took place with collaborative presentations from staff in MarPAMM, COMPASS and SeaMonitor along with panel discussions with panellists from DAERA, NPWS and DHPLG to answer questions relating to the current projects and the legacy that the cross project research and outputs will bring to future conservation and scientific outputs in the region.

Work is steadily progressing on cross border work in NI/RoI with AFBI leading the effort to engage and map out feedback and input from stakeholders who have valuable contribution to the Marine Protected Area/ MPA management plans MarPAMM are developing for the North Coast – North Antrim, County Down – County Louth areas as well as Carlingford Lough.

Our partners and funders.

This project brings together a strong interdisciplinary collaboration between scientists in AFBI, Marine Scotland Science, Scottish Natural Heritage, Scottish Association for Marine Science, Ulster University, University College Cork and BirdWatch Ireland.

This project is funded by the INTERREG VA programme, managed by the Special EU Programmes Body (SEUPB).

Investigating the role of robotic milking in dairy production systems in Northern Ireland

Research Leads: Dr Debbie McConnell, Dr Stephanie Buijs

Creating a labour efficient working environment is essential to building sustainable farm businesses and ensuring an attractive industry for new entrants. Robotic milking technology, whereby a cow voluntarily visits an automatic milking machine, is a technology attracting increased interest within the N.I. dairy sector, with approximately 10% of the national herd currently managed within robotic milking systems.

Independent information is needed to assist farmers in adapting to robotic milking which itself requires a paradigm shift in both cow behaviour and farmer management techniques. In particular, identification of new metrics and performance indicators which influence the performance and profitability of robotic milking systems within N.I. are required. Standard metrics for milking parlour dairy systems are not easily transferable to robotic systems and subsequently no agreed method of benchmarking physical performance of robotic systems has been achieved.

In addition, best management practices for the integration of robotic milking to grazing systems for N.I. farms remain unknown. Successfully combining robotic milking and grazing will be essential to assist farms in lowering overall costs of production whilst simultaneously reducing the environmental footprint for dairy production.

Policy/industry impact:

This project will assist farmers improve farm profitability and reduce the environmental footprint in robotics through the development of strategies to integrate grazing and robotic systems, lowering overall feed costs, and by identifying key performance targets for commercial business which will be based on optimising farm performance and achieving good return on investment.

The programme of work will also seek to improve resource use efficiency on farm by developing new strategies to minimise the requirement for bought in concentrates and lower farm nutrient balances, and also by identifying labour efficient management practices for robotic milking farms.

In addition, the project will support technological advancement and automation in the dairy industry, increasing the digital skills base both on-farm and in the wider supporting industry.

Our partners and funders:

This four year programme is funded by the Department of Agriculture, Environment and Rural Affairs (DAERA) as part of the Evidence and Innovation programme, and farmer levy organisation, AgriSearch.

The project brings together scientists from AFBI and QUB, alongside CAFRE advisors and a team of 25 farmer co-researchers located across N.I., currently operating robotic milking systems.

The project is also supporting a PhD studentship which is seeking to investigate dairy cow behaviour to improve production and welfare in robotic milking systems.

Hills and uplands for beef and sheep (HUBS)

Research Lead: Dr Denise Lowe

The aim of HUBS is to apply an ecosystems framework approach to beef and sheep farming in the hills and uplands which would investigate the synergies and trade-offs that exist between production and other ecosystems services. The hills and uplands of Northern Ireland have potential to be an invaluable resource in our natural environment if properly managed; providing many important ecosystem services including climate regulation via carbon sequestration, flood mitigation, clean water and also educational and recreational opportunities.

However if these area are not properly managed they have potential to have a negative effect on the environment, such as a reduction in water quality and reduced biodiversity. Furthermore if peatlands are left to degrade they will release their stored carbon into the atmosphere and thus become a carbon source.

Innovative management strategies that deliver both economically and environmentally sustainable upland systems which are holistic and multi-functional in terms of agricultural production, the environment and the maintenance and enhancement of rural communities for farming families and the wider society are therefore urgently required.

In the current initial phase 1 of this project a literature review is being carried out on the effect beef and sheep production systems in the hills and uplands on production and environment, with synergies and trade-offs investigated. It is envisaged that phase 1 will form the scientific foundations for a transformative phase 2 project, which will use the key findings of phase 1 and rationalize them into key research areas to be taken forward.

Policy/ industry Impact

Low profitability in cattle and sheep farms in the hills and uplands is a major concern. This research is required to inform future agri-environment policy. While Brexit represents many challenges for the agricultural industry, it also presents an opportunity to re-think agri-environment policy for the hills and uplands of Northern Ireland. A primary UK government focus is on "public money for public good" and so initially this one year scoping study will use a transdisciplinary and multi-actor approach to investigate how beef and sheep production systems can be adapted to increase environmental benefits including increasing carbon sequestration and storage, improving water quality entering water courses, slowing water flow of the hills, and improving habitats to support biodiversity.

Our partners and funders

This project brings together a strong interdisciplinary collaboration between Livestock Production Science and Agri-Environment Branches within AFBI, along with a wide range of stakeholders in the industry steering group. It is co-funded by DAERA and AgriSearch.

Feed into Beef Nutrition (FIBNUT)

Research Leads: Francis Lively, Dr Denise Lowe, Dr Edward Garcia

Our partners and funders

Feed into Beef Nutrition (FIB NUT) is a collaborative research project funded by AHDB and the feed industry, working in partnership with CIEL, Agri-Food and Biosciences Institute (AFBI) and Scotland's Rural College (SRUC). The five-year programme aims to deliver improved beef cattle feeding guidelines for the UK.

Project aims

There is strong evidence that current guidance under- or over-estimates nutritional requirements for different classes of beef cattle in the UK. These nutrient requirements have not been revised since the publication of an AFRC book in 1993. Since that time the genetic base of the UK cattle population has changed considerably as have feeds commonly used by farmers, hence an update of these nutrition models is overdue.

The focus of updates include:

- **Predicting feed intake**
- **Growth and the effects on carcass composition**
- **Energy requirements**
- **Protein requirements**
- **Revised and broader information on feed values plus consideration of feed interactions**

Final results from this project will be published in a series of scientific journals to receive a robust peer review of the science behind the changes.

Our approach

This project aims to deliver new guidelines for predicting beef cattle performance and feed requirements by:

- **Engaging with industry to clearly define needs and priorities**
- **Developing new equations to provide improved predictions of feed intake for the main types of beef cattle**
- **Developing new models for predicting growth and composition of modern beef genotypes according to both category of animal and the feed they are offered and consume**
- **Revising models for rumen microbial protein synthesis and metabolisable protein requirements to better predict the effect of dietary protein on animal performance**
- **Revising feed values for major feed categories fed to beef cattle in the UK – particularly filling gaps in information about new feed types**
- **Modelling the effects of feed interactions on feed values. The current system does not consider such interactions**
- **Developing prediction models for methane emissions of beef cattle to help carbon footprinting of beef cattle production systems**

Towards the end of the project there will be a focused campaign of knowledge exchange to disseminate key outputs of the project and encourage the implementation of the new models.

Industry engagement is critically important to the success of this project. An Industry Advisory Group has been established to help fund and steer the development of the nutritional models and ensure they are fit for purpose for UK beef systems and those companies supporting farmers through the provision of feeds or advice on pasture management and feed conservation (e.g. silage making). This group are providing critical feedback to the science teams and will have access to the new models at an early stage to test and implement in their own systems.

Policy/ industry Impact

Accurate guidelines for rationing beef cattle are critical to ensure the nutritional requirements of beef cattle are met; and desired levels of performance are achieved in a cost effect and efficient manner.

This research will benefit those offering nutritional advice to beef farmers as well as the farmers themselves. It will also benefit the red meat industry as more accurate predictions of cattle flows to the meat plants can be made; and additional carcases should meet market specification in terms of age at slaughter, carcass weight and fat classification.

This research will indirectly benefit Policy with improved knowledge of cattle nutrition being closely aligned to beef cattle's contribution towards greenhouse gas emissions. The outcomes of this project will be available for future modelling to determine beef nutrition regimes or farm management practises which have the minimal environmental footprints.

The study is funded by AHDB.

Using automated thermography for early detection of welfare problems in dairy cattle

Research Leads: Dr Stephanie Buijs, Dr Lindsey Drummond

There is a strong demand for sustainably produced dairy products, and optimizing dairy cow welfare and reducing the use of antimicrobials are essential aspects of this. AFBI has recently started a project on the use of automated thermography which aims to develop technology that allows farmers to improve dairy cow welfare, reduce antimicrobial use and improve productivity.

By measuring heat radiated from the surface of an animal's body, thermography theoretically has the capacity to detect any welfare problem, in a very timely manner, associated with increased skin temperature. These can be physical problems resulting in local inflammation or fever (for instance mastitis, lameness or injury), but stress can also alter skin temperature through a process known as 'emotional fever'. AFBI will study which welfare issues can be detected reliably using routine monitoring with an automated thermography system, and if this can lead to earlier detection compared with traditional health monitoring.

Policy/industry impact

This project has the potential to benefit the NI dairy industry by increasing the sustainability of production through improving dairy cow welfare, reducing the use of antimicrobials and increasing animal productivity, thus strengthening the

industry's competitiveness. Disease, injury and stress can greatly reduce the welfare of dairy cows and can have important societal impacts (for instance a more negative public perception of dairy production) as well as a major economic impact (due to treatment costs and production losses). Early detection of welfare problems has an essential role in optimization of dairy cow welfare, because solving a problem first of all requires awareness of its existence. The earlier a problem can be detected, the earlier it can be solved or treated, and the smaller the impact the problem will be.

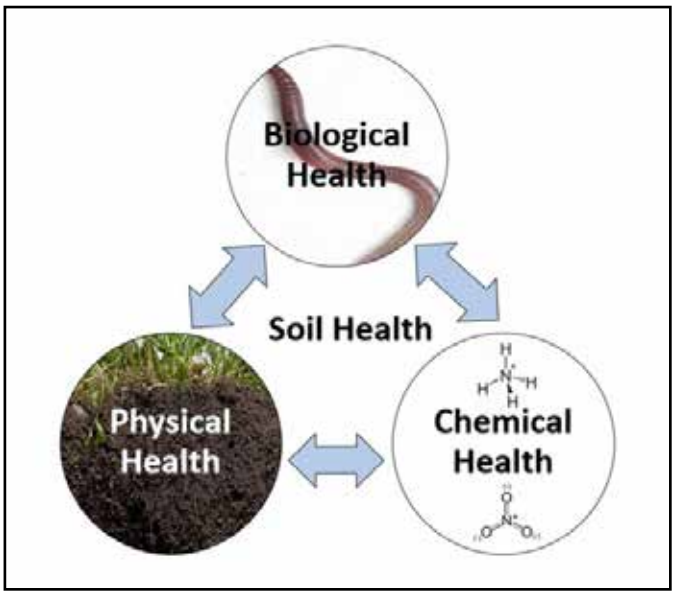
Our partners and funders

This project brings together a strong interdisciplinary collaboration between AFBI and Agricam AB, who specialize in health detection systems for the dairy sector.

This project is funded by DAERA under their E&I funding.

Soil Health

Research Leads: Dr Lisa Black, Dr Dario Fornara, Dr Rachael Ramsey, Dr Archie Murchie, Dr Suzanne Higgins



Soil Health' has many definitions but it is generally accepted that a healthy soil is one that has the ability to act as a living system to sustain, in the long term, its most important functions.

In NI, primary soil functions include biomass production, the regulation of nutrients and water in soils and the maintenance and enhancement of soil carbon (C) stocks.

There is a need to obtain baseline data on the health status of soils in NI and to use this information to empower farmers to make management decisions to improve soil health.

An important research challenge remains how to 'define' and 'measure' soil health. This project is assessing a range of biological, chemical and physical characteristics, in grassland and arable soil systems through trials and on-farm, to evaluate their potential as indicators of soil health for NI.

Policy/industry impact

The Soil Health project will facilitate insight into how changes in land-use and in agricultural practices affect soil health properties and soil Carbon levels with particular emphasis on the impact of organic manures. The ultimate aim is to enable informed decisions on soil management for improved resource use and production efficiency, whilst aiming to improve, or at least maintain organic Carbon stocks and therefore, soil health.

Identification of management appropriate ranges of, and targets for, key soil health indicators for NI will inform farmers on how best to assess their soils and make decisions that will improve soil health for grass and arable crop production.

The study is funded by DAERA under their Evidence and Innovation Programme.

Research highlights

Section 6

Research Highlights

Xianjiang Chen (PhD Student)

Chen, X., Finney, G., Zheng, H., Wang, H., Gordon, A. W., Ferris, C. P., Magowan, E., Yan, T. (2020)

Modern Holstein-origin dairy cows within grassland-based systems partition more feed nitrogen into milk and excrete less in manure. **Science of the Total Environment, 727: Article No: 138561.**

The genetic selection and dietary change during the last few decades might have resulted in a significant improvement on the milk production efficiency of modern dairy production. The objective was to determine whether modern Holstein-origin dairy cows, when managed within grassland based systems, partitioned more feed nitrogen (N) into milk and excreted less in manure, in comparison to an earlier population of Holstein-origin dairy cows.

Data used were collated from total diet digestibility studies undertaken at AFBI from 1990 to 2002 (old dataset, n = 538) and from 2005 to 2019 (new dataset, n = 476), respectively. An analysis of variance indicated that cows in the new dataset partitioned a significantly higher proportion of consumed N into milk and excreted a lower proportion in urine and total manure, compared to cows in the old dataset.

An alternative analysis used the combined data from both datasets to examine if there was a relationship between experimental year and N utilisation efficiency. Across the period from 1990 to 2019, urine N/N intake and manure N/N intake significantly decreased, while milk N/N intake increased. These results indicate that modern Holstein-origin dairy cows utilise consumed N more efficiently than earlier populations. Thus, N excretion is likely to be overestimated if models developed from the old data are used to predict N excretion for modern dairy herds. Therefore, the final part of analysis involved using the new dataset to develop prediction models for N excretion based on N intake and farm level data (milk yield, live weight and dietary N concentration).

These updated models can be used to estimate N excretion from modern Holstein-origin dairy cows within grassland-based dairy systems.

Jessica Pollock (PhD Student)

Pollock, J.G. Gordon, A.W., Huson, K.M., McConnell, D.A. (2020)

The Effect of Frequency of Fresh Pasture Allocation on Pasture Utilisation and the Performance of High Yielding Dairy Cows. **Animals, 10: (11) Article No: 2176.**

Pasture remains a major component in many dairy cow diets. However, to date research has not identified grazing practices that support both high levels of animal performance whilst maintaining high pasture utilisation rates, these are key factors to establish efficient and economically viable grazing systems.

The objective of this study was to investigate the impact of three different frequencies of pasture allocation (12, 24 and 36 hours (h)) on pasture utilisation and the performance of high-yielding dairy cows.

The results indicated reducing the frequency of fresh pasture allocation from a typical 12 h or 24 h allocation to 36 h pasture allocations improved the performance of primiparous animals grazing in mixed-parity herds. These findings highlight the effect of competition for resources within intensive pasture grazing systems where mixed-parity herds are common.

Primiparous animals are most likely to fall lower in the herd hierarchy, and therefore often don't have preferential access to prime grazing areas in highly-competitive grazing environments.

Overall, reducing the frequency of fresh pasture allocation from 12 h or 24 h to 36 h allocations created a balance between offering a higher pasture allowance to support animal performance whilst achieving low post-grazing residuals and high levels of grass utilisation.

The present study highlights a viable method to addressing within herd variation in animal nutritional requirements in grazing systems, to improve animal performance whilst maintaining high levels pasture utilisation.

Dr David Patterson

Patterson, J.D., Lafaillette, F., Woster, S., Roulund, N., Charrier, S. and Gilliland, T.J. (2020)

Impact of endophyte inoculation on the morphological identity of cultivars of *Lolium perenne* (L) and *Festuca arundinacea* (Schreb.). **Scientific Reports, 10 (1): Article No: 7729.**

Endophytes (*Epichloë* spp.) are non-sporulating asexually reproducing fungi of the *Clavicipitaceae* family and are indigenous in many soils and naturally occurring in many of the cool-season grass species of the *Pooideae* subfamily.

Some endophyte strains can confer greater environmental resilience and productivity to their host grass. The potential for creating differences in a grass cultivar's morphological identity by endophyte inoculation has implications for cultivar distinctiveness and for plant variety protection.

The objective of the study was to determine if the expression of the DUS characteristics of plants grown from endophyte infected seed lots was sufficiently modified to designate them as distinct from endophyte-free plants taken from the same seed lot of that cultivar or from its definitive seed stock.

The evidence from this study shows that inoculating a registered grass cultivar with an endophyte that is novel to the host does not ensure that the new association will be distinct from the original cultivar i.e. endophyte presence is not a reliable mechanism to change the DUS traits of a cultivar. However, this cannot be interpreted as a universal rule for all grass-endophyte associations but does confirm that distinguishing morphological changes are not an inevitable consequence of endophyte inoculation.

Dr Archie Murchie

Murchie, A.K., Thompson, G.M., Clawson, S., Brown, A., Gordon, A.W., Jess, S. (2020)

Field evaluation of deltamethrin and ivermectin applications to cattle on *culicoides* host-alighting, blood-feeding, and emergence. **Viruses, 11 (8): Article No: 731.**

Bluetongue and African horse sickness are two serious viral diseases vectored by biting midges. Biting midges (*Culicoides* spp.) are common in Northern Ireland and if these diseases became introduced they would cause major disruptions to livestock and equine markets.

This study investigated means of controlling biting midges by topical applications of deltamethrin and ivermectin to cattle. *Culicoides* spp. landing and blood-feeding was studied in this work using white plastic plates, covered in a non-drying glue and mounted on Friesian heifers' backs. As an indication of the biting pressure faced by cattle, the average number of midges caught per trap was 170 in 24 hours, which equates to upwards of 20,000 midges if extrapolated to the whole animal. There was no effect of the insecticides on total numbers of midges trapped or the proportion engorged.

Deltamethrin and ivermectin treatment did not prevent blood-feeding on these animals. Deltamethrin did result in significant *Culicoides* mortality as evidenced by the numbers of dead midges collected from heifers' upper flanks.

These results imply that there is no protective effect for individual animals from topical insecticide applications, as midges blood-fed despite receiving an ultimately lethal dose of insecticide. However, topical applications could reduce the risk of onward transmission of viruses.

These findings have implications for management and epidemiology of the diseases if intervention measures are adopted.

Dr Sara Vero

Vero, S.E., Sherry, E., Doody, D. (2020) Evidence and perception of phosphorus loss risk factors in farmyards. **Environmental Science and Policy, 114: pp. 542-548.**

Farmyards present potential point sources of phosphorus loss to watercourses, affecting their ecological quality and attainment of environmental goals.

The aim of this study was to evaluate the riskiness of runoff, management and infrastructure factors on phosphorus loss from farmyards to water, using expert opinion and to evaluate whether those estimates are supported by the literature.

A survey of research, advisory and policy stakeholders was conducted (147 respondents) in which individuals rated the importance of individual factors from 0 (having no impact) to 10 (having critical impact) on phosphorus loss from farmyards.

Factors relating to silage effluent and slurry storage were assigned the greatest risk (≥8.4). Runoff factors related to rainfall and connectivity were also ranked as high risk. Management factors were rated lower by all stakeholder groups but may offer low cost options to offset more intransigent risks.

Dr Naomi Rutherford

Rutherford, N.H., Gordon, A.W., Arnott, G., Lively, F.O. (2020) The Effect of Beef Production System on the Health, Performance, Carcass Characteristics, and Meat Quality of Holstein Bulls. **Animals, 10 (10): Article No: 1922.**

Holstein bull beef production is often an intensive indoor system, with a high level of concentrate feeding. However, the economic viability of such a system is often contested.

The aim of this study was to evaluate the effect of production system on the health, performance, carcass characteristics, and meat quality of Holstein bulls.

Production systems differed during the summer grower period with bulls receiving one of three concentrate levels (0kg, 2kg or *ad libitum*) at grass, in comparison to a housed *ad libitum* concentrate system. All bulls were finished indoors on *ad libitum* concentrates and silage at 15.5 months of age.

The results of this study demonstrate that *ad libitum* concentrates during the grower period resulted in superior live weight performance. However, the bulls offered 0 or 2kg concentrates at grass displayed elevated growth rates during the finishing period, and likely exhibited a degree of compensatory growth during this time.

However, differences in cold carcass weight still occurred, with that of lifetime *ad libitum* bulls being greatest. Nevertheless, the lower carcass weight of bulls on the 0 and 2kg grower concentrates can be somewhat offset by the lower total concentrate intake, which would assist in reducing production costs. Instrumental meat quality and animal health were unaffected in this study.

Dr Russell Adams

Adams, R., Quinn, P., Barber, N. and Burke, N. (2020) Identifying pathways for phosphorus transport using observed event forensics and the CRAFT (Catchment runoff attenuation flux tool). **Water (Switzerland), 12 (4): Article No: 1081.**

Identifying key flow pathways is critical for understanding the transport of phosphorus (P) from agricultural headwater catchments.

High frequency/resolution datasets from two such catchments in northwest England enabled individual events to be examined to identify the P dynamics (forensics).

However, the hourly event observations (comprising discharge (Q), total P (TP), total reactive P (TRP) and other water quality variables, such as electrical conductivity and water temperature) were limited when it comes to categorically identifying distinct flow pathways as they provided insufficient information in the absence of data on P concentrations in end members in the catchment.

Detailed analysis of multiple flow and water quality parameters was referred to here as the "event forensics". Modelling is essential when used in combination with the event forensics as this additional tool can identify distinct flow pathways in a robust form.

A case study applied the Catchment Runoff Attenuation Flux Tool (CRAFT) to two contrasting small headwater catchments in Northwest England, which formed part of the Demonstration Test Catchments (DTC) Programme. CRAFT captured the dominant flow and P fluxes as seen in the forensic analysis and created a set of outputs including smart export coefficients (based on flow pathways) that can be conveyed to policy makers to better underpin decision making. Identifying key flow pathways is critical for understanding the transport of phosphorus (P) from agricultural headwater catchments and this approach is being explored in NI catchments.

Dr Adewale Adenuga

Adenuga, A.H., Davis, J., Hutchinson, G., Patton, M., Donnellan, T. (2020) Analysis of the effect of alternative agri-environmental policy instruments on production performance and nitrogen surplus of representative dairy farms. **Agricultural Systems, 184: Article No: 102889.**

Compared to other agricultural sectors, dairy farming contributes significantly to the agricultural economy across the island of Ireland. However, the methods and levels of production within the sector has been identified as a major contributor to Nitrogen (N) surplus posing particular environmental problem not only for the sector but the region as a whole. Added to this, the abolition of the milk quota system in 2015 has seen production expand compounding further the environmental impacts. This has resulted in the need for policy measures to be implemented in order to improve the economic and environmental performance of dairy farms.

Employing a mathematical programming optimization modelling framework we simulated the economic and environmental impact of two alternative agri-environmental policy instruments on different dairy farm types on the island of Ireland.

Specifically, using scenario analyses applied to representative dairy farms, the study examined the effects of an N surplus tax and an agri-environmental nutrient application standard on both the production performance and N surplus.

Based on the two environmental policy scenarios simulated, it was shown that the choice of a tax on N surplus or the limiting of N from animal manure to 170 Kg N per hectare as a form of environmental policy instrument on the island of Ireland is dependent on the level of N surplus. The farm type clusters (grouped on the basis of milk yield, utilised agricultural area and herd size) exhibited different responses to

the policy changes in Ireland, both north and south. The impact of the policy options was more pronounced in larger farms with higher N surplus compared to the smaller farm. The application of N surplus tax resulted in a decrease in herd size and gross margin for the large farms. However, this also leads to a decrease in N surplus compared to the baseline scenario. The effect was relatively minor for smaller farms.

The study concluded that in situations where the nutrient surplus is already high, as with the larger farms clusters the use of manure application standards will be more effective in limiting nutrient surplus to soils compared to the use of nutrient surplus tax. This is because, the large farms being highly commercialised do not significantly reduce their N surplus under the nutrient surplus tax scenario as long as they continue to make profit.

This study has been published in the Agricultural Systems journal; it was funded through Teagasc's Walsh fellowship programme with technical supervisory input from AFBI.

Dr Catherine Gibson

Gibson, C.E., Williams, D., Dunlop, R., Beck, S. (2020) Using social media as a cost-effective resource in the photo-identification of a coastal bottlenose dolphin community. **Aquatic Conservation: Marine and Freshwater Ecosystems, 30: 1702-1710.**

Data gathered via social media has enabled the identification of 54 well-marked bottlenose dolphins around the coast of Northern Ireland and Donegal. This study alongside the first Northern Ireland Bottlenose dolphin photo-identification catalogue has provided evidence of year round occurrence of bottlenose dolphins with re-sightings between 2007 and 2016, suggestive of inter-annual site fidelity.

The research highlighted data collection via social media as a cost-effective and scientifically valuable method in the photo-identification of coastal cetaceans. The method is recommended for research on low density and wide-ranging coastal cetaceans.

Dr Stephaine Buijs

Buijs, S., Nicol, C. J., Booth, F., Richards, G., Tarlton, J. F. (2020) Light-based monitoring devices to assess range use by laying hens. **Animal 14 (4): 814-82**3.

Access to an outdoor range has many potential benefits for laying hens, but range use can be poor due to factors only partly understood.

Techniques to monitor individual range use within commercial flocks are crucial to increase our understanding of these factors. However, direct observation of individual range use is difficult and time-consuming, and automatic monitoring currently relies on equipment that is difficult to use in an on-farm setting without itself influencing range use.

This paper describes a trial carried out by the University of Bristol, which evaluated the performance of a novel small, light and readily portable light-based monitoring system. Hens from six commercial houses were equipped with light monitoring devices. Light levels were determined each minute: if the reading on the hen-mounted device exceeded indoor light levels, the hen was classified as outside. System accuracy was determined by validating its output against direct observations of hen location. Accuracy was high (92-96% depending on the amount of shelter on the outdoor range). Light-based monitoring was sufficiently accurate to indicate that a greater percentage of time was spent outside on ranges with more shelter (more: 67%, less: 56%).

Furthermore, large differences between individuals were found, emphasizing the importance of studying range use on an individual level.

Dr Eugene Carmichael

Carmichael, E., Ghassemieh, E., Lyons, G. (2020) Biorefining of lignocellulosic feedstock and waste materials using ionic liquid. **Materials Science and Engineering: B, 262: Article No: 114741.**

In this study we developed a chemical process for the separation and purification of cellulose from lignocellulosic materials including:- wheat straw, perennial ryegrass, willow, spent mushroom compost and anaerobic digestate solids. This included the synthesis of a novel ionic liquid combining hydrolysing and solvating properties – trihexyltetradecylphosphonium hydrogen sulphate (THTDP HSO4), which was compared to a traditional medium used in lignocellulose refining - dilute sulphuric acid.

In addition we examined the use of ultrasonication as a method of catalysing the process and compared this with a direct thermal method. Our results show that use of the ionic liquid medium resulted in a purer, more refined cellulose extract than that produced using dilute sulphuric acid. The cellulose extracted via THTDP HSO4 proved to be a more crystalline polymer which would be of benefit in the production of 'nano' cellulose.

In addition, enzymatic hydrolysis of the extracted cellulose showed that the use of THTDP HSO4 to refine the fibres resulted in the higher levels of conversion to glucose – a precursor of bioethanol.

Finally, while the thermal method used proved to be more successful in converting lignocellulose to glucose overall, the ultrasonic method required much less energy input which in turn proved to be more energy efficient. As such we have demonstrated an extraction process which has the potential to improve on current methods as part of an integrated biorefining process.

Prof Bob Hanna

Fairweather, I., Brennan, G. P., Hanna, R. E. B., Robinson, M. W., Skuce, P. J. (2020) Drug resistance in liver flukes. **International Journal for Parasitology-Drugs and Drug Resistance, 12: 39-59.**

Liver flukes include *Fasciola hepatica*, *Fasciola gigantica*, *Clonorchis sinensis*, *Opisthorchis* spp., *Fascioloides magna*, *Gigantocotyle explanatum* and *Dicrocoelium* spp. The two main species, *F. hepatica* and *F. gigantica*, are major parasites of livestock and infections result in huge economic losses. As with *C. sinensis*, *Opisthorchis* spp. and *Dicrocoelium* spp., they affect millions of people worldwide, causing severe health problems.

Collectively, the group is referred to as the Food-Borne Trematodes and their true significance is now being more widely recognised. However, reports of resistance to triclabendazole (TCBZ), the most widely used anti-*Fasciola* drug, and to other current drugs are increasing. This is a worrying scenario. In this review, progress in understanding the mechanism(s) of resistance to TCBZ is discussed, focusing on tubulin mutations, altered drug uptake and changes in drug metabolism.

There is much interest in the development of new drugs and drug combinations, the repurposing of non-flukicidal drugs, and the development of new drug formulations and delivery systems; all this work is reviewed.

Sound farm management practices also need to be put in place, with effective treatment programmes, so that drugs can be used wisely and their efficacy conserved as much as is possible. This depends on reliable advice being given by veterinarians and other advisors.

Accurate diagnosis and identification of drug resistant fluke populations is central to effective control: to determine the actual extent of the problem and to determine how well or otherwise a treatment has worked; for research on establishing the mechanism of resistance (and identifying molecular markers of resistance); for informing treatment options; and for testing the efficacy of new drug candidates.

Several diagnostic methods are available, but there are no recommended guidelines or standardised protocols in place and this is an issue that needs to be addressed.

Dr Dario Fornara

Fornara, D.A., Flynn, D. and Caruso, T. (2020) Effects of nutrient fertilization on root decomposition and carbon accumulation in intensively managed grassland soils. **Ecosphere, 11 (4): Article No: e03103.**

The decomposition of plant roots in soils can greatly influence the biogeochemical cycling of key elements such as carbon (C) and nitrogen (N).

Root mass decomposition processes have been mainly studied in natural ecosystems and less in intensively managed ecosystems, such as agricultural grasslands, which receive regular additions of N fertilizers.

Using a long-term grassland experiment established in 1970 at Hillsborough, this study addressed how repeated additions of organic (i.e. liquid manures) and inorganic (i.e. NPK) fertilizers over >45 years have influenced root mass decomposition and how. It was found that highest root mass decomposition was associated with highest additions of organic slurries, whereas lowest root mass decomposition occurred in inorganically N-fertilized and unfertilized soils.

Differences in root decomposition were explained by root chemistry (i.e. root carbon-to-nitrogen ratios) and by soil microbial composition (i.e. fungal-to-bacterial ratios).

These findings suggest that in the short-term (few months to one year) organic fertilization can enhance root detritus decomposition (thus promoting N release in soils for plant uptake) while contributing in the long-term (many years) to soil C accumulation.

This dual effect of organic fertilization could contribute making grassland intensification more sustainable by reducing the need of artificial NPK fertilizers.

Dr Georgine Milne

Milne, G., Allen, A., Graham, J., Kirke, R., McCormick, C., Presho, E., Skuce, R., Byrne, A.W., 2020. *Mycobacterium bovis* population structure in cattle and local badgers: Co-localisation and variation by farm type. **Pathogens 9, 592**.

Bovine tuberculosis (bTB), caused primarily by the M*ycobacterium bovis* bacterium, remains stubbornly persistent in Northern Ireland's national herd, despite intensive eradication efforts.

The European badger (M*eles meles*) is understood to present a reservoir of infection that maintains the epidemic. Surveillance efforts for bTB involve genetic typing of *M. bovis* extracted from test-positive cattle, and from badgers killed in road-traffic accidents (RTAs). We used these M. bovis isolates to describe and quantify the spatial clustering of genetic types in and between both hosts, with the ultimate aim of better understanding the processes driving the epidemic.

We find that in cattle, 50% of herds infected with a given genetic type lie within 35% of the total size of the cluster, highlighting the importance of "local" transmission routes such as spillback from badgers, nearby farms, and short range movements, which potentially diminishes the role of long-distance movements in the dissemination of infection.

We found that RTA badgers and cattle in a given geographical area tended to share the same *M. bovis* genetic types, consistent with a shared epidemic in both hosts and adding further weight to the importance of localised transmission.

After exploring whether our observations varied by beef or dairy production type, we found that RTA badgers were more likely to share genetic types with nearby dairy herds than beef herds.

We hypothesise that herd management practices are likely to be the driving force behind this observation, as beef rearing is associated with more animal movements compared to dairy production, wherein animals tend to reside in the same herd for many years.

This suggests that between-species transmission of *M. bovis* is not particularly efficient, given that herds with high turnover are less likely to share the same *M. bovis* genetic types as present in the local badger population.

Journal Articles

Section 7

Journal Articles

1st January 2020 to 31st December 2020

QUARTILE 1

Adams, R., Quinn, P., Barber, N. and Burke, N. (2020) Identifying pathways for phosphorus transport using observed event forensics and the CRAFT (Catchment runoff attenuation flux tool). **Water (Switzerland), 12 (4): Article No: 1081**.

Adenuga, A., Davis, J., Hutchinson, G., Patton, M., Donnellan, T. (2020). Modelling environmental technical efficiency and phosphorus pollution abatement cost in dairy farms. **Science of the Total Environment, 714: Article No: 136690.**

Adenuga, A.H., Davis, J., Hutchinson, G., Patton, M., Donnellan, T. (2020) Analysis of the effect of alternative agri-environmental policy instruments on production performance and nitrogen surplus of representative dairy farms**. Agricultural Systems, 184: Article No: 10288**9.

Adenuga, A.H., Jack, C., Olagunju, K.O., Ashfield, A. (2020) Economic Viability of Adoption of Automated Oestrus Detection Technologies on Dairy Farms: A Review., **Animals, 10: Article No: 1241**.

Allen, A., Guerrero, J., Byrne, A., Lavery, J., Presho, E., Courcier, E., O'Keefe, J., Fogarty, U., Delahay, R., Wilson, G., Newman, C., Buesching, C., Silk, M., O'Meara, D., Skuce, R., Biek, R. and McDonald, R.A. (2020) Genetic evidence further elucidates the history and extent of badger introductions from Great Britain into Ireland. **Royal Society Open Science, 7 (4): Article No: 200288.**

Almodóvar, A., Graciela, G.N., Ayllon, D., Trueman, C.N., Davidson, I., Kennedy, R., Elvira, B. (2020). Stable isotopes suggest the location of marine feeding grounds of South European Atlantic salmon in Greenland. **ICES Journal of Marine Science: 77 (2): 593-603.**

Araoz, R., Barnes, P., Sechet, V., Delepiere, M., Zinn-Justin, S., Molgo, J., Zakarian, A., Hess, P., Servent, D. (2020). Cyclic imine toxins survey in coastal european shellfish samples:Bioaccumulation and mode of action of 28-O-palmitoyl ester of pinnatoxin-G. First report of portimine-A bioaccumulation. **Harmful Algae, 98: 1-11**

Balta, I., Stef, L., Pet, I., Ward, P., Callaway, T., Ricke, S.C., Gundogdu, O., Corcionivoschi, N. (2020) Antiviral activity of a novel mixture of natural antimicrobials, in vitro, and in a chicken infection model in vivo. **Scientific Reports, 10: (1), Article No: 16631.**

Barley, J., Hanna, R.E.B., Robinson, M., Huson, K., Atcheson, E. (2020). Transcriptome and secretome analysis of intra-mammalian life-stages of the emerging helminth pathogen, Calicophoron daubneyi reveals adaptation to a unique host environment. **Molecular & Cellular Proteomics, Oct 20 2020:1-61**

Benaud, P., Anderson, K., Evans, M., Farrow, L., Glendell, M., James, M. R., Quine, T. A., Quinton, J. N., Rawlins, B., Jane Rickson, R., Brazier, R. E. (2020) National-scale geodata describe widespread accelerated soil erosion. **Geoderma, 371: Article No: 114378.**

Buijs, S., Nicol, C. J., Booth, F., Richards, G., Tarlton, J. F. (2020) Light-based monitoring devices to assess range use by laying hens. **Animal 14 (4): 814-823.**

Camp Montoro, J., Manzanilla, E., Solà-Oriol, D., Muns Vila, R., Gasa, J., Clear, O., Calderón Díaz, J. (2020). Predicting productive performance in grow-finisher pigs using birth and weaning body weight. **Animals, 10 (6): 1017**

Campbell, E.L., Byrne, A.W., Menzies, F.D., Milne, G., McBride, K.R., McCormick, C.M., Scantlebury, D.M., Reid, N. (2020) Quantifying intraherd cattle movement metrics: Implications for disease transmission risk. **Preventive Veterinary Medicine, Article No: 105203.**

Campbell, M., Ortuno, J., Stratakos, A., Corcionivoschi, N., Elliot, T., Koidis, A., Theodoridou, K. (2020). Impact of Thermal and High-Pressure Treatments on the Microbiological Quality and *In Vitro* Linton, W.M.R., Digestibility of Black Soldier Fly (Hermetia illucens) L**arvae. Animals, 10 (4): 682 Article No: 10040682**.

Carmichael, E., Ghassemieh, E.,Lyons, G. (2020) Biorefining of lignocellulosic feedstock and waste materials using ionic liquid. **Materials Science and Engineering: B, 262: Article No: 114741.**

Chen, X., Finney, G., Zheng, H., Wang, H., Gordon, A. W., Ferris, C. P., Magowan, E., Yan, T. (2020) Modern Holstein-origin dairy cows within grassland-based systems partition more feed nitrogen into milk and excrete less in manure. **Science of the Total Environment, 727: Article No: 138561.**

Chong, F.S., O'Sullivan, M.G., Kerry, J.P., Moloney, A.P., Methven, L., Gordon, A.W., Hagan, T.D.J., Farmer, L.J. (2020) Understanding consumer liking of beef using hierarchical cluster analysis and external preference mapping. **Journal of the Science of Food and Agriculture, 100: 245-257.**

Collins, P.C., Hunter, W.R., Carlsson, J., Carlsson, J. (2020) Fortuitous insights into the ecology of a recently charted deep-sea hydrothermal vent, using snails' feet. , **Deep-Sea Research Part I: Oceanographic Research Papers, Article No: 103358.**

Cottney, P., Black, L.C., White, E., Williams, P.N. (2020). The Correct Cover Crop Species Integrated with Slurry Can Increase Biomass, Quality and Nitrogen Cycling to Positively Affect Yields in a Subsequent Spring Barley Rotation. **Agronomy Journal, 10 (11): 1760**.

Courcier, E. A. , Pascual-Linaza, A. V. , Arnold, M. E. , McCormick, C. M. , Corbett, D. M. , O'Hagan, M. J. H. , Collins, S. F. , Trimble, N. A. , McGeown, C. F. , McHugh, G. E., McBride, K. R. , McNair, J. , Thompson, S., Patterson I. A. P., Menzies F. D. (2020) Evaluating the application of the dual path platform VetTB test for badgers (*Meles meles*) in the test and vaccinate or remove (TVR) wildlife research intervention project in Northern Ireland. **Research in Veterinary Science, 130: 170-178.**

Craig, A., Gordon, A.W., Stewart, S., Ferris, C.P. (2020) Supplementation strategies for lactating dairy cows offered very high quality grass silages: starch-based or fibre-based concentrates offered with or without straw. **Livestock Science, 234: Article No: 103973.**

Craig, A.L., Buijs, S., Morrison, S. (2020) Evaluation of veterinary antimicrobial benchmarking systems at farm- level in Europe: implications for the UK ruminant sector. **Veterinary Record, Article No: 105727.**

Craig, A.-L., Muns, R., Gordon, A., Magowan, E. (2020) Extended nursing and/or increased starter diet allowances for low weaning weight pigs. **Asian-Australasian Journal of Animal Sciences, 33 (8): 1301-1309**.

Criste, A., Copolovici, L., Copolovici, D., Kovacs, M., Madden, R.H., Corcionivoschi, N., Gundogdu, O., Berchez, M., Urcan, A.C. (2020) Determination of changes in the microbial and chemical composition of Țaga cheese during maturation. **PloS one, 15: (12) e0242824**.

Criste, A., Urcan, A.C., Bunea, A., Furtuna, F.R.P., Olah, N.K., Madden, R.H. and Corcionivoschi, N. (2020) Phytochemical Composition and Biological Activity of Berries and Leaves from Four Romanian Sea Buckthorn (*Hippophae Rhamnoides* L.) Varieties. **Molecules, 25 (5): Article No: 1170.**

Fairweather, I., Brennan, G. P., Hanna, R. E. B., Robinson, M. W., Skuce, P. J. (2020) Drug resistance in liver flukes. **International Journal for Parasitology-Drugs and Drug Resistance, 12: 39-59.**

Fitzgerald, R.M., Collins, P.J., McMenamey, M.J., Leonard, F.C., McGlynn, H., O'Shea, H. (2020) Porcine reproductive and respiratory syndrome virus: phylogenetic analysis of circulating strains in the Republic of Ireland from 2016 to 2017. **Archives of Virology, 165: 257-263.**

Ford, L., Stratakos, A.C., Theodoridou, K., Dick, J.T.A., Sheldrake, G.N., Linton, M., Corcionivoschi, N. and Walsh, P.J. (2020) Polyphenols from brown seaweeds as a potential antimicrobial agent in animal feeds. **ACS Omega, 5: 9093-9103**.

Fornara, D., Olave, R., Higgins, A. (2020) Evidence of low response of soil carbon stocks to grassland intensification. **Agriculture, Ecosystems and Environment, 287: Article no. 106705.**

Fornara, D.A., Flynn, D. and Caruso, T. (2020) Efffects of nutrient fertilization on root decomposition and carbon accumulation in intensively managed grassland soils. **Ecosphere, 11 (4): Article No: e03103**.

Fox, M., Service, M., Moore, H., Dean, M., Campbell, K., Barriers and facilitators to shellfish cultivation, Reviews in Aquaculture, 12 (1), pp. 406-437

Galparsoro, I., Murillas, A., Pinarbasi, K., Sequeira, A.M.M., Stelzenmüller, V., Borja, A., O´Hagan, A.M., Boyd, A., Bricker, S., Garmendia, J.M., Gimpel, A., Gangnery, A., Billing,S.L., Bergh, Ã˜., Strand, Ã˜., Hiu, L., Fragoso, B., Icely, J., Ren, J., Papageorgiou, N., Grant, J., Brigolin, D., Pastres,R., Tett, P. (2020) Global stakeholder vision for ecosystem-based marine aquaculture expansion from coastal to offshore areas. **Reviews in Aquaculture**,

Gangnery, A., Bacher, C., Boyd, A., Liu, H., You, J., Strand, Ø. (2020) Web-based public decision support tool for integrated planning and management in aquaculture. Ocean and Coastal Management, Article No. 105447.

Gibson, C.E., Williams, D., Dunlop, R., Beck, S. (2020) Using social media as a cost-effective resource in the photo-identification of a coastal bottlenose dolphin community. **Aquatic Conservation: Marine and Freshwater Ecosystems, 30: 1702-1710.**

Gravador, R., Brunton, N., Fahey, A., Gkarane, V., Claffey, N., Maloney, A., Diskin, M., Farmer, L.J., Allen, P., Monahan, F. (2020) Effects of dietary fat sources on the fatty acid composition and consumer acceptability of lamb". **Journal of the Science of Food and Agriculture: 100: 2176-2184.**

Grelet, C., Froidmont, E., Foldager, L., Salavati, M., Hostens, M, Ferris, C. P., Ingvartsen, K. L., Crowe, M. A., Sorensen, M. T., Fernandez Pierna, J. A., Vanlierde, A., Gengler, N., Dehareng, F., Gplus, E. C. (2020) Potential of milk mid-infrared spectra to predict nitrogen use efficiency of individual dairy cows in early lactation. **Journal of Dairy Science, 103 (5): 4435-4445.**

Grelet, C., Froidmont, E., Foldager, L., Salavati, M., Hostens, M., Ferris, C.P., Ingvartsen, K. L., Crowe, M. A., Sorensen, M.T., Pierna, J.A.F., Vanlierde, A., Gengler, N., Dehareng, F., Crowe, M., Fahey, A., Carter, F., Matthews, E., Santoro, A., Byrne, C., Rudd, P., O'Flaherty, R., Hallinan, S., Wathes, C., Salavati, M., Cheng, Z.R., Fouladi, A., Pollott, G., Werling, D., Bernardo, B.S., Ferris, C. Wylie, A., Bell, M., Vaneetvelde, M., Hermans, K., Hostens, M., Opsomer, G., Moerman, S., De Koster, J., Bogaert, V., Vandepitte, J., Vandevelde, L., Vanranst, B., Ingvartsen, K., Sorensen, M.T., Hoglund, J., Dahl, S., Ostergaard, S., Rothmann, J., Krogh, M., Meyer, E., Foldager, L., Gaillard, C., Ettema, J., Rousing, T., Larsen, T., de Oliveira, V.H.S., Marchitelli, C., Signorelli, F., Napolitano, F., Moioli, B., Crisa, A., Buttazzoni, L., McClure, J., Matthews, D., Kearney, F., Cromie, A.,

McClure, M., Zhang, S.J., Chen, X., Chen, H.C., Zhao, J.L., Yang, L.G., Hua, G.H., Tan, C., Wang, G.G., Bonneau, M., Sciarretta, M., Pearn, A., Evertson, A., Kosten, L., Fogh, A., Andersen, T., Lucy, M., Elsik, C., Conant, G., Taylor, J., Triant, D., Gengler, N., Georges, M., Colinet, F., Pamplona, M.R., Hammami, H., Bastin, C., Takeda, H., Laine, A., Van Laere, A.S., Mota, R., Darbagshahi, S.N., Dehareng, F., Grelet, C., Vanlierde, A., Froidmont, E., Becker, F., Schulze, M., Vera, S.P. and Gplus, E.C. (2020) Potential of milk mid-infrared spectra to predict nitrogen use efficiency of individual dairy cows in early lactation. **Journal of Dairy Science, 103 (5): 4435-4445.**

Guinguina, A., Yan, T., Bayat, A.R., Lund, P., Huhtanen, P (2020) The effects of energy metabolism variables on feed efficiency in respiration chamber studies with lactating dairy cows. **Journal of Dairy Science, 104 (9): pp. 7983-7997.**

Guinguina, A., Yan, T., Lund, P., Bayat, A.R., Hellwing, A.L.F., Huhtanen, P. (2020) Between-cow variation in the components of feed efficiency. **Journal of Dairy Science, 103 (9): pp. 7968-7982.**

Guo, P.H., Gao, P., Li, F.H., Chang, S.H., Wang, Z.F., Yan, T. and Hou, F.J. (2020) Prediction of Metabolizable Energy Concentrations of Herbage in the Qinghai-Tibetan Plateau Using Tibetan Sheep Digestibility Data. **Animals, 10 (3): Article No: 276.**

Guo, P., Gao, P., Li, F., Chang, S., Wang, Z., Yan, T., Hou, F. (2020) Prediction of metabolizable energy concentrations of herbage in the Qinghai-Tibetan plateau using Tibetan sheep digestibility data. **Animals, 10 (3): Article No: 376**.

Hall, R., Boisen Staal, L., Mcintosh, K.A., McGrath, J., Bailey, J.S., Black, L.C., Gro Nielsen, U., Reitzel, K., Williams, P. (2020) Phosphorus speciation and fertiliser performance characteristics: a comparison of waste recovered struvites from global sources. **Geoderma: 362: Article No: 114096**.

Hanna, R.E.B., Fairweather, I., Brennan, G., Robinson, M., Skuce, P. (2020). Drug resistance in liver flukes. International **Journal for Parasitology: Drugs and drug resistance, 12: 39-59.**

Hawe, S., Scollan, N., Gordon, A., Magowan, E. (2020). What is the current significance of low birthweight pigs on commercial farms in Northern Ireland in terms of impaired growth and mortality? **Translational Animal Science: 4 (3): 1-13.**

Hawe, S.J., Scollan, N., Gordon, A., Muns, R., Magowan, E. (2020) Impact of feeding low and average birthweight pigs on a weight basis post-weaning on growth performance and body composition. **Livestock Science, 241: Article No: 104233**.

Higgins, A.J., Cassidy, R., Bailey, J.S. (2020). The relative impacts of dairy and non-dairy ruminant sectors on the Olsen-P status of grassland soils and hence water quality. Soil Use and Management. **Soil Use and Management, Article No: 12618**.

Ijaz, U., Linton, W.M.R., Kelly, C.A., Sloan, W., Green, B., Lavery, U., Wren, B., Dorrell, N., Corcionivoschi, N., Gundogdu, O. (2020). Impact of industrial production system parameters on chicken microbiomes: mechanisms 1 to improve performance and reduce *Campylobacter*. **Microbiome: 8: 128.**

Jack, C., Ashfield, A., Adenuga, A.H., Mullan, C. (2020) Farm Diversification: Drivers, Barriers and Future Growth Potential. EuroChoices, Article No: 12295.

Jahangir, M.M.R., Fenton, O., Carolan, R., Harrington, R., Johnston, P., Zaman, M., Richards, K.G., Müller, C. (2020) Application of 15N tracing for estimating nitrogen cycle processes in soils of a constructed wetland. **Water Research, 183: Article No: 116062**.

Jia, Z.J., Zhou, X., Xia, W.W., Fornara, D., Wang, B.Z., Wasson, E.A., Christie, P., Polz, M.F., Myrold, D. (2020) Evidence for niche differentiation of nitrifying communities in grassland soils after 44 years of different field fertilization scenarios. **Pedosphere, 30 (1): 87-97.**

Klages, S., Heidecke, C., Osterburg, B., Bailey, J., Calciu, I., Casey, C., Dalgaard, T., Frick, H., Glavan, M., D'Haene, K., Hofman, G., Leitao, I.A., Surdyk, N., Verloop, K., Velthof, G (2020). Nitrogen surplus – a unified indicator for water pollution in for Europe? **Water (Switzerland), 12 (4): Article No: 1197.**

Krogh, M. A., Hostens, M., Salavati,M., Grelet, C., Sorensen, M. T., Wathes, D. C., Ferris, C. P., Marchitelli, C., Signorelli, F., Napolitano, F, Becker, F., Larsen, T., Matthews, E., Carter, F., Vanlierde, A., Opsomer, G., Gengler, N., Deharengv F., Crowe, M. A., Ingvartsen, K., Foldager, L. (2020) Between- and within-herd variation in blood and milk biomarkers in Holstein cows in early lactation. **Animal, 14 (5): 1067-1075.**

Lavery, A., Lawlor, P.G., Miller, H.M., Magowan, E. (2020) The effect of dietary oil type and energy intake in lactating sows on the fatty acid profile of colostrum and milk and piglet growth to weaning. **Animals, 9 (12): Article No: 1092.**

Liu, J., Elies-Oury, M.-P., Chriki, S., Legrand, I., Pogorzelski, C., Wierzbicki, J., Farmer, L., Troy, D., Polkinghorne, R. and Hocquete, J.-F. (2020) Contributions of tenderness, juiciness and flavor liking to overall liking of beef in Europe. **Meat Science, 168: Article No: 108190.**

Liu, J.J., Chriki, S., Ellies-Oury, M.-P., Legrand, I., Pogorzelski, G., Wierzbicki, J., Farmer, L., Troy, D., Polkinghorne, R., Hocquette, J.F. (2020) European conformation and fat scores of bovine carcasses are not good indicators of marbling. **Meat Science, 170: Article No: 108233.**

Liu, X., Liu, F., Yan, T., Chang, S., Wanapat, M., Hou, F. (2020) Cistanche deserticola addition improves growth, digestibility, and metabolism of sheep fed on fresh forage from alfalfa/tall fescue pasture. **Animals, 10 (4): Article No: 668.**

Livingstone, D., Smyth, B.M., Foley, A.M., Murray, S.T., Lyons, G., Johnston, C. (2020) Willow coppice in intensive agricultural applications to reduce strain on the food-energy-water nexus. **Biomass and Bioenergy, 144: Article No: 105903.**

Lowe, D. E., Gordon, A. W., Lively, F. O. (2020) Effect of overlaying rubber on fully slatted concrete floors on hoof health and lying postures in finishing dairy-origin bulls offered two contrasting diets. **Animal, 14 (5): 1043- 105**1.

Lyon, C., Cordell, D., Jacobs, B., Martin-Ortega, J., Marshall, R., Camargo-Valero, M., Sherry, E. (2020) Five pillars for stakeholder analyses in sustainability transformations: The global case of phosphorus. **Environmental Science and Policy, 107: 80-89.**

Malnarcic, C.M., Millar, C., Rao, J.R., Moore, J. (2020). Quality of antibiotics in destinations. **Travel Medicine and Infectious Disease: 1-3.**

McKenna, A., Ijaz, U.Z., Kelly, C., Linton, M., Sloan, W.T., Green, B.D., Lavery, U., Dorrell, N., Wren, B.W., Richmond, A., Corcionivoschi, N., Gundogdu, O. (2020) Impact of industrial production system parameters on chicken microbiomes: mechanisms to improve performance and reduce *Campylobacter*. **Microbiome, 8 (1): p. 128.**

Milne, G., Allen, A., Graham, J., Kirke, R., McCormick, C., Presho, E., Skuce, R., Byrne, A.W. (2020) Mycobacterium bovis population structure in cattle and local badgers: Co-localisation and variation by farm type. **Pathogens, 9 (7): Article No: 592.**

Montoro, J.C., Manzanilla, E.G., Solà-Oriol, D., Muns, R., Gasa, J., Clear, O., Díaz, J.A.C. (2020) Predicting productive performance in grow-finisher pigs using birth and weaning body weight. **Animals, 10 (6): Article No: 1017.**

Morton, P.A., Cassidy, R., Floyd, S., Doody, D.G., McRoberts, W.C., Jordan, P. (2020) Approaches to herbicide (MCPA) pollution mitigation in drinking water source catchments using enhanced space and time monitoring. **Science of the Total Environment, Article No: 142827.**

Murchie, A.K., Thompson, G.M., Clawson, S., Brown, A., Gordon, A.W., Jess, S. (2020) Field evaluation of deltamethrin and ivermectin applications to cattle on *culicoides* host-alighting, blood-feeding, and emergence. Viruses, 11 (8): Article No: 731.

Nicholson, F., Krogshave Laursen, R., Cassidy, R., Farrow, L., Tendler, L., Williams, J., Surdyk, N. and Velthof, G. (2020) How Can Decision Support Tools Help Reduce Nitrate and Pesticide Pollution from Agriculture? A Literature Review and Practical Insights from the EU FAIRWAY Project. **Water, 12 (3): Article No: 768**.

Ogunniyi, A.I., Mavrotas, G., Olagunju, K.O., Fadare, O., Rufai, A. (2020) Governance Quality, Remittances and their Implications for Food and Nutrition Security. **World Development, 127 (1): 104752**

Omotayo, A.O., Omotoso, A.B., Daud, A.S., Ogunniyi, A.I., Olagunju, K.O. (2020) What Drives Households' Payment for Waste Disposal and Recycling Behaviours? Empirical Evidence from South Africa's General Household Survey. **International Journal of Environmental Research and Public Health, 17: (19) Article No: 7188**.

Oster, M., Reyer, H., Keiler, J., Ball, E., Mulvenna, C., Murani, E., Siriluck, P., Wimmers, K. (2020) Comfrey (*Symphytum* spp.) as an alternative field crop contributing to closed agricultural cycles in chicken feeding. **Science of the Total Environment, 742: Article No: 140490.**

O'Sullivan, S.M., Ball, M.E.E., McDonald, E., Hull, G.L.J., Danaher, M., Cashman, K.D. (2020) Biofortification of Chicken Eggs with Vitamin K-Nutritional and Quality Improvements. **Foods, 9 (11): Article No: 1619.**

Patterson, J.D., Lafaillette, F., Woster, S., Roulund, N., Charrier, S. and Gilliland, T.J. (2020) Impact of endophyte inoculation on the morphological identity of cultivars of *Lolium perenne* (L) and *Festuca arundinacea* (Schreb.). **Scientific Reports, 10 (1): Article No: 7729.**

Pearman, T.R.R., Robert, K., Callaway, A., Hall, R., Lo Iacono, C. and Huvenne, V.A.I. (2020) Improving the predictive capability of benthic species distribution models by incorporating oceanographic data – Towards holistic ecological modelling of a submarine canyon. **Progress in Oceanography, 184: Article No: 102338.**

Pearodwong, P., Tretipskul, C., Panyathong, R., Sang-Gassanee, K., Collell, M., Muns, R., Tummaruk, P. (2020) Reproductive performance of weaned sows after single fixed-time artificial insemination under a tropical climate: Influences of season and insemination technique. **Theriogenology, 142: 54-61.**

Pollock, J.G., Gordon, A.W., Huson, K.M., McConnell, D.A. (2020) The Effect of Frequency of Fresh Pasture Allocation on Pasture Utilisation and the Performance of High Yielding Dairy Cows. **Animals, 10: (11) Article No: 217**6.

Qiao, Y., Zhang, S., Quan, C., Gao, N., Johnston, C., Wu, C. (2020) One-pot synthesis of digestate-derived biochar for carbon dioxide capture. **Fuel, 279: Article No: 118525.**

Rothwell, S.A., Doody, D.G., Johnston, C., Forber, K.J., Cencic, O., Rechberger, H., Withers, P.J.A. (2020) Phosphorus stocks and flows in an intensive livestock dominated food system. **Resources, Conservation and Recycling, 163: Article No: 105065**.

Roy, R., Wang, J., Mostofa, M.G., Fornara, D. (2020). Optimal water and fertilizer applications improve growth performance of *Tamarix chinensis* in a coal mine degraded area under arid conditions. **Physiologia Plantarum: Article No: 13147.**

Roy, R., Wang, J.X., Mostofa, M.G., Fornara, D., Sikdar, A., Sarker, T., Wang, X.Q., Jahan, M.S. (2020) Fine-tuning of soil water and nutrient fertilizer levels for the ecological restoration of coal-mined spoils using *Elaeagnus angustifolia*. **Journal of Environmental Management, 270: Article No: 11085**.

Rutherford, N.H., Gordon, A.W., Arnott, G., Lively, F.O. (2020) The Effect of Beef Production System on the Health, Performance, Carcass Characteristics, and Meat Quality of Holstein Bulls. **Animals, 10 (10): Article No: 1922**.

Vaux, A.G.C., Johnston, C., Dallimore, T., McGinley, L., Strode, C., Murchie, A.K., Iyanger, N., Pudney, R., Chow, Y., Brand, M., Rea, I., Medlock, J.M. (2020) Working towards a co-ordinated approach to invasive mosquito detection, response and control in the UK. **International Journal of Environmental Research and Public Health, 17 (14): Article No: 5166.**

Vero, S.E., Sherry, E., Doody, D. (2020) Evidence and perception of phosphorus loss risk factors in farmyards. **Environmental Science and Policy, 114: pp. 542-548.**

Wang, C., Hou, F., Wanapat, M., Yan, T., Kim, E.J., Scollan, N.D. (2020) Assessment of cutting time on nutrient values, in vitro fermentation and methane production among three ryegrass cultivars. **Asian-Australasian Journal of Animal Sciences, 33 (8): 1242-1251**.

White, H., León-Sánchez, L., Burton, V.J., Cameron, E.K., Caruso, T., Cunha, L., Dirilgen, T., Jurburg, S.D., Kelly, R., Kumaresan, D., Ochoa-Hueso, R., Ordonez, A., Phillips, H.R., Prieto, I., Schmidt, O., Caplat, P. (2020). Methods and approaches to advance soil macroecology. **Global Ecology & Biogeography, 29 (10): 1674-1690**.

Yang, C.T., Wang, C.M., Chen, T.B., Aubry, A., Gordon, A.W., Yan, T. (2020). Updating maintenance energy requirement for the current sheep flocks and the associated effect of nutritional and animal factors. **Animal, 14: 295-302.**

Zaczek-Moczydłowska, M. A., Young, G. K., Trudgett, J., Plahe, C., Fleming, C. C., Campbell, K., O'Hanlon, R. (2020) Phage cocktail containing *Podoviridae* and *Myoviridae* bacteriophages inhibits the growth of *Pectobacterium* spp. Under in vitro and in vivo conditions. **PLoS ONE, 15 (4): Article No: 0230842.**

Zioga, E., Kelly, R., White, B., Stout, J.C. (2020) Plant protection product residues in plant pollen and nectar: A review of current knowledge. **Environmental Research, 189, Article No: 109873**.

QUARTILE 2

Ashagidigbi, W.M., Babatunde, B.A., Ogunniyi, A.I., Olagunju, K.O., Omotayo, A.O. (2020) Estimation and Determinants of Multidimensional Energy Poverty among Households in Nigeria. **Sustainability, 12 (18): Article No: 733**2.

Barry, J., Kennedy, R., Rosell, R.S., Roche, W. (2020). Atlantic salmon smolts in the Irish sea: First evidence of a northerly migration trajectory. **Fisheries Management and Ecology, 27: 517-522.**

Craig, A., Gordon, A.W., Stewart, S., Ferris, C.P. (2020) Supplementation strategies for lactating dairy cows offered very high quality grass silages: Starch-based or fibre-based concentrates offered with or without straw. **Livestock Science, 234: Art No: 103973**.

Criste, A. , Urcan, A. C., Bunea, A., Furtuna, F. R. P., Olah, N. K., Madden R. H., Corcionivoschi, N. (2020) Phytochemical composition and biological activity of berries and leaves from four romanian sea buckthorn (*Hippophae Rhamnoides* L.) varieties. **Molecules, 25(5): Article No: 1170**.

Cunningham, E. M., Kiriakoulakis, K., Dick, J. T. A., Kregting, L., Schuchert P., Sigwart, J. D. (2020) Driven by speculation, not by impact - the effects of plastic on fish species. **Journal of Fish Biology, 1-4**.

de Groot, M., O'Hanlon, R., Bullas-Appleton, E., Csoka, G., Csiszar, A., Faccoli, M., Gervasini, E., Kirichenko, N., Korda, M., Marinsek, A., Robinson, N., Shuttleworth, C., Sweeney, J., Tricarico, E., Verbrugge, L., Williams, D., Zidar, S., Veenvliet, J.K. (2020) Challenges and solutions in early detection, rapid response and communication about potential invasive alien species in forests. **Management of Biological Invasions, 11: (4) pp. 637-660.**

Ellies-Oury, M.-P., Hocquette J.F., Chriki, S., Conanec, A., Farmer, L., Chavent, M. and Saracco, J.J. (2020) Various statistical approaches to assess and predict carcass and meat quality traits. **Foods, 9 (4): Article No: 525**.

Fan, Q.S., Wanapat, M., Yan, T., Hou, F.J. (2020) Altitude influences microbial diversity and herbage fermentation in the rumen of yaks. **BMC Microbiology, 20: (1) Article No. 370.**

Gkarane, V., Allen, P., Brunton, N.P., Gravador, R.S., Claffey, N.A., Harrison, S.M., Diskin, M.G., Fahey, A.G., Farmer, L.J., Moloney, A.P., Monahan, F.J. (2020) Volatile and sensory analysis to discriminate meat from lambs fed different concentrate-based diets. **Animal Production Science. 60 (13): 1654-1667.**

Glass, C.A., Glass, D.H. (2020) Opinion dynamics of social learning with a conflicting source. Physica A: **Statistical Mechanics and its Applications, 563: Article No: 125480**.

Gomes, D.J., Wierzbowska, I., Bevanger, K., O'Mahony, D.T., Rola, K. (2020) Diet of the European badgers (Meles meles) in urban and rural areas of Norway. **European Journal of Wildlife Research, 66 (1): Article No: 7.**

Gray, A., Adjlane, N., Arab, A., Ballis, A., Brusbardis, V., Charriere, J.-D., Chlebo, R., Coffey, M.F., Cornelissen, B., Amaro da Costa, C., Dahle, B., Danihlik, J., Drazic, M.M., Evans, G., Fedoriak, M., Forsythe, I., Gajda, A., de Graff, D.C., Grogorc, A. Ilieva, I., Johannesen, J., Kauko, L., Kristiansen, P., Martikkala, M., Martin-Hernandez, R., Medina-Flores, C.A., Mutinelli, F., Patalano, S., Raudmets, A., Martin, G.S., Soroker, V., Stevanovic, J., Uzunov, A., Vejsnaes, F., Williams, A., Zammit-Mangion, M., Brodschneider, R. (2020) Honey bee colony winter loss rates for 35 countries participating in the COLOSS survey for winter 2018–2019, and the effects of a new queen on the risk of colony winter loss. **Journal of Apicultural Research, 59 (5): 744-751.**

Jack, C.G., Adenuga, A., Ashfield, A., Wallace, M. (2020). Investigating the drivers of farmers' engagement in a participatory extension programme: the case of Northern Ireland business development groups. **Sustainability, 12: 1-17.**

Kennedy, R., Evans, D.W., Allen, M.M. (2020). Long term retention of dummy acoustic transmitters in adult brown trout. **Journal of Fish Biology, 97: (4) 1281-1284.**

Kennedy, R., Evans, D.W., Gallagher, K., Campbell, W. (2020). Identification of an unusual threat to a lake running Atlantic salmon stock. **Journal of Fish Biology, 97 (4): 1265-1267.**

Kennedy, R.J., Rosell, R. (2020) Does rod catch reflect the background size structure of the sea trout stock in a small coastal river? **Fisheries Management and Ecology, Article No: 12469.**

Lemon, K. (2020). Recombinant subtype A and B human respiratory syncytial virus clinical isolates co-infect the respiratory tract of cotton rats. **Journal of General Virology: 101 10: 1471.**

McClean, P., Hunter, W.R. (2020) 17α-ethynylestradiol (EE2) limits the impact of ibuprofen upon respiration by streambed biofilms in a sub-urban stream. **Environmental Science and Pollution Research, 27: 37149–37154.**

McGowan, J., O'Hanlon, R., Owens, R.A., Fitzpatrick, D.A. (2020) Comparative Genomic and Proteomic Analyses of Three Widespread *Phytophthora* Species: *Phytophthora chlamydospora*, *Phytophthora gonapodyides* and *Phytophthora pseudosyringae*. **Microorganisms, 8 (5): Article No: 653.**

McIlroy, R., Millar, C., Nelson, D.W.V.A., Rao, J.R., Murphy, A., Downey, D., Moore, J. (2020). *Pseudomonas aeruginosa – Candida* interplay: effect on in vitro antibiotic susceptibility of *Pseudomonas aeruginosa* when grown in the presence of *Candida* culture. **British Journal of Biomedical Science, 77 (4): 1-5.**

McMurray,, R.L., Ball, M.E.E., Tunney, M.M., Corcionivoschi, N., Situ, C. (2020) Antibacterial Activity of Four Plant Extracts Extracted from Traditional Chinese Medicinal Plants against *Listeria monocytogenes*, *Escherichia coli*, and *Salmonella enterica* subsp. *enterica* serovar Enteritidis. **Microorganisms, 8: Article No: 962.**

Milne, M., Allen, A., Graham, J., Kirke, R., McCormick, C., Presho, E., Skuce, R.A., Byrne, A. (2020). *Mycobacterium bovis* Population Structure in Cattle and Local Badgers: Co-Localisation and Variation by Farm Type. **Pathogens: 9 (7): 592.**

Milne, M., Allen, A., Graham, J., Lahuerta Marin, A., McCormick, C., Presho, E.L., Reid, N., Skuce, R.A., Byrne, A. (2020) Bovine tuberculosis breakdown duration in cattle herds: an investigation of herd, host, pathogen and wildlife risk factors. **Peer J: Article No: E8319**

Nicholson, F.A., Krogshave Laursen, R., Cassidy, R., Farrow, L., Tendler, L., Williams, J.R., Surdyk, N., Velthof, G., Wright, I. (2020) How can decision support tools help reduce nitrate and pesticide pollution from agriculture? **A literature review and practical insights from the EU FAIRWAY project. Water, Special Issue "Land Use and Water Quality" (12): 768**

Olagunju, K.O., Patton, M. and Feng, S. (2020) Estimating the impact of decoupled payments on farm production in Northern Ireland: An instrumental variable fixed effect approach. **Sustainability (Switzerland), 12 (8): Article No: 3222.**

Thompson, C.S., Traynor, I.M., Fodey, T.L., Barnes, P., Faulkner, D.V., Crooks, S.R.H. (2020) Screening method for the detection of residues of amphenicol antibiotics in bovine milk by optical biosensor. Food Additives and Contaminants. **Part A – Chemistry Analysis Control Exposure & Risk Assessment, 37 (11): 1854-1865.**

Thorman, R.E., Nicholson, F.A., Topp, C.F.E., Bell, M.J., Cardenas, L.M., Chadwick, D.R., Cloy, J.M., Misselbrook, T.H., Rees, R.M., Watson, C.J., Williams, J.R. (2020) Towards Country-Specific Nitrous Oxide Emission Factors for Manures Applied to Arable and Grassland Soils in the UK. **Frontiers in Sustainable Food Systems, 4: Article No: 62.**

Wang, C., Zhao, Y., Aubry, A., Arnott, G., Hou, F. and Yan, T. (2020) Erratum: Effects of concentrate input on nutrient utilization and methane emissions of two breeds of ewe lambs fed fresh ryegrass (Translational Animal Science DOI: 10.1093/tas/txy106). **Translational Animal Science, 3 (1): 238**.

Zaczek-Moczydlowska, M.A., Young, G.K., Trudgett, J., Fleming, C.C., Campbell, K., O'Hanlon, R. (2020) Genomic Characterization, Formulatuion and Efficacy in Planta of a *Sirphoviridae* and *Podoviridae* Protection Cocktail against the Bacterial Plant Pathogens. **Pectobacterium spp., 12 (2): Article No: 150**.

QUARTILE 3

Becker, C., Dick, J.T.A., Mánus Cunningham, E., Lundy, M., Bell, E., Eagling, L., Sigwart, J.D. (2020) Ovary resorption in the Norway lobster (*Nephrops norvegicus*) and its possible causes with special reference to sperm storage. Helgoland Marine Research, 74: Article No: 12.

Ferris, C.P., Jiao, H.P., Murray, S., Gordon, A., Laidlaw, S. (2020) Effect of dairy cow genotype and concentrate feed level on cow performance and enteric methane emissions during grazing. **Agricultural and Food Science, 29 (2): 130-138**.

Fox, M., Christley, R., Lupo, C., Moore, H.M., Service, M., Campbell, K. (2020). Preventing and mitigating farmed bivalve disease:a Northern Ireland case study. **Aquaculture International, 28: 2397-2417.**

Kobayashi, N., Hou, F., Tsunekawa, A., Chen, X., Yan, T., Ichinoche, T. (2020) Effects of feeding level of alfalfa hay on nitrogen utilization for 1-kg daily gain of crossbred Simmental male calves. **Grassland Science, 2020: 1-6.**

McHugh, O., Liu, J., Browne, F., Jordan, P., McConnell, D. (2020) Data-Driven Classifiers for Predicting Grass Growth in Northern Ireland: A Case Study. **Communications in Computer and Information Science, 1237: 301-312.**

O'Connor, S., Ehimen, E., Pillai, S.C., Lyons, G., Bartlett, J. (2020) Economic and Environmental Analysis of Small-Scale Anaerobic Digestion Plants on Irish Dairy Farms. **Energies, 13 (3): Article No: 637**.

Pegoretti, H., Muñoz, F., Teixeira, R., Sáez, K., Segura, C., Olave, R. (2020) Energy potential of paulownia and miscanthus clones for energy production in Chile. **Madera y Bosques, 26 (1): Article No: e2611916**.

Rao, J.R., Nelson, D.W.V.A., Martin, T.J.G., Fleming, C.C. (2020). Microbiological assessments in a cut flower crop polytunnel field trial adopting soil covering and microbiocides for *Fusarium* wilt suppression. **European Journal of Biology and Biotechnology, 1 (5): 1-10**.

Skuce, R.A., Breadon, E., Allen, A., Milne, M., McCormick, C., Hughes, C., Rutherford, D., Smith, G., Thompson, S., Graham, J., Harwood, R., Byrne, A. (2020) Longitudinal dynamics of herd-level *Mycobacterium bovis* MLVA type surveillance in cattle in Northern Ireland 2003-2016. **Infection, Genetics and Evolution, 79: Article No: 104131**.

QUARTILE 4

Mac An Tsaoir, S., Cross, G., Johnson, S., Humphries, C., Kearns, J. (2020) Millennium planting density trial of 'Bramley's Seedling' apple on M.9 and M.27 rootstocks from 2000 to 2016. **Acta Horticulturae, 1281: 131-135**.

Mac an tSaoir, S., Johnson, S., Humphries, C., Kearns J. (2020) Factors affecting 'Armagh Bramley' apple storage post DPA (diphenylamine) withdrawal. **Acta Horticulturae, 1275: 133-138.**

Soltani, N., Nazarian-Firouzabadi, F., Shafeinia, A., Sadr, A.S., Shirali, M. (2020). The Expression of Terpenoid Indole Alkaloid (TIAs) Pathway Genes in *Catharanthus roseus* in Response to Salicylic Acid treatment. **Molecular Biology Reports:**

NOT INDEXED

Ames, A., Angioloni, S., Ames, G. (2020). Drivers of school performance over time: Evidence from public schools in the United States. **Advances in Educational Research and Evaluation, 1(2): 79-87**.

Balenghien, T., Alexander, N., Arnþórsdóttir, A., Bisia, M., Blackwell, A., Bødker, R., Bourquia, M., Boutsini, S., Carpenter, S., Colenutt, C., Culverwell, L., Cvetkovikj, A., Dascalu, L., De Regge, N., Dhollander, S., Elbers, A., England, M., Filatov, S., Garros, C., Goffredo, M., Haddad, N., Høye, T., Hristescu, D., Khallaayoune, K., Kocišová, A., Larska, M., Lucientes, J., Mathieu, B., Miranda, M., Murchie, A.K., Ni?escu, C., Ozolina, Z., da Fonseca, I., Petric, D., Pudar, D., Ramilo, D., Richardson, J., Seglina, Z., Sghaier, S., Stefanovska, J., Stougiou, D., Sviland, S., Tchakarova, S., Van Bortel, W., Castello, M., Veronesi, E., Versteirt, V., Wint, W. (2020). VectorNet Data Series 3: *Culicoides* Abundance Distribution Models for Europe and Surrounding Regions. **Open Health Data, 7(1), p.2**.

Evans, D.W. (2020). Workshop on the temporal migration patterns of European eel (WKEELMIGRATION). **ICES Scientific Reports, 2020 (25): 1-78**

Gadaj, A., Ventura, E., Healy, J., Botre, F., Sterk, S.S., Mooney, M.H (2020) Enhanced UHPLC-MS/MS screening of selective androgen receptor modulators following urine hydrolysis. **MethodsX, 7: Article No 100926.**

Hawe, S., Scollan, N., Gordon, A.W., Magowan, E. (2020). Impact of sow lactation feed intake on the growth and suckling behavior of low and average birthweight pigs to 10 weeks of age. **Translational Animal Science: 655-665**.

Higgins, S., Nicholl, M.G., Vero, S., Bailey, J.S., Doody, D. (2020). Improving phosphorus use efficiency on extensive grassland farms without compromising productivity. **Grassland Science in Europe, 25: 436-438**.

Rao, J.R., Moore, J., Martin, T.J.G., Nelson, D.W.V.A., Fleming, C.C. (2020). Challenges and opportunities for crop and tree management in Northern Ireland. **Archives of Crop Science, 4 (1): 67-7**7

Rossi, G., Crispell, J., White, P., Lycett, S., Brough, A., Presho, E.L., Allen, A., Skuce, R.A., Harwood, R., Gordon, S., Palkopoulou, E., Ellis, R., Smith, G., Kao, R. (2020) Phylodynamic analysis of an emergent *Mycobacterium bovis* outbreak in an area with no previously known wildlife infections. **bioRxiv, Article No: 379297**.

Stevenson, P., Bidartondo, M., Cavagnaro, T.R., Cooper, A., Geslin, B., Koch, H., Lee, M.A., Moat, J., O'Hanlon, R., Sjoman, H., Sofo, A., Stara, K., Suz, L.M. (2020). The state of the world's urban ecosystems: what can we learn from trees, fungi and bees?. **Plants, People, Planet, 2: 482-498.**

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