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**Abbreviations\***

AAA Animal Health, Agritech, Aquaculture

ABM Agent Based Modelling

AFIC Arctic Food Innovation Clusters

AGEs Advanced Glycation End-product

AHDB Agriculture & Horticulture Development Board

AMR Antimicrobial Resistance

ANC Areas Facing Natural Constraints

ARIOB Agriculture Reform Implementation Oversight Board

BBSRC Biotechnology and Biological Sciences Research Council

BioSS Biomathematics & Statistics Scotland (SEFARI)

BVD Bovine viral diarrhoea

BVDV Bovine Viral Diarrhoea Virus

CBD Convention on Biological Diversity

CBEAR Center for Behavioural & Experimental Agri-Environment Research

CCC Climate Change Committee (UK)

CEO Chief Executive Officer

CKEI Centre for Knowledge Exchange and Impact (SEFARI Gateway)

CLLD Community Led Local Development

CNE Circular North East

CNPA Cairngorms National Park Authority

CoE Centre of Expertise

COP26 Convention of the Parties (UN-Climate Summit)

COVID-19 Coronavirus Disease-19

CPC Commonwealth Potato Collection

CREW Scotland’s Centre of Expertise for Waters

CSA Chief Scientific Advisor

CSC Centre for Sustainable Cropping

CT Computerised Tomography

CTP Collaborative Training Partnership

CTS Cattle Tracing System

CWR Crop Wild Relatives

CxC Centre of Expertise for Climate Change

DEC Directors’ Executive Committee

DEFRA Department for Environment, Food & Rural Affairs (UK Government)

DIT Department for International Trade (UK Government)

DNA Deoxyribonucleic acid

EC European Commission

EFSA European Food Safety Authority

ELPEG Ecosystems and Land Use Policy Engagement Group

ELSEG Land Use Stakeholder Engagement Group

EPA Environment Protection Agency (Irish)

EPIC Centre of Expertise for Animal Disease Outbreaks

ESCom Ecosystem Services Community Scotland

ESS Environmental Standards Scotland

EU European Union

FADN Farm Accountancy Data Network

FAO Food and Agriculture Organisation of the United Nations

FDFS Food & Drink Federation Scotland

FFCC Food Farming Countryside Commission

FSS Food Standards Scotland

FR Forest Research

GCRF Global Challenges Research Fund

GHGe Greenhouse Gas emissions

GIS Geographic Information System

GWCT [Game and Wildlife Conservation Trust](https://www.gwct.org.uk/)

HIE Highlands & Islands Enterprise

ICT Information and Communications Technology

IOBC-WPRS International Organisation for Biological Control – West Palaearctic Regional Section

IPM Integrated Pest Management

IUCN International Union for Conservation of Nature

IUFRO International Union of Forest Research Organisations

JHI (Hutton) The James Hutton Institute (SEFARI)

JHL James Hutton Ltd.

JTC Just Transition Commission

KE Knowledge Exchange

KPT Knowledge Transfer Partnership

KTN Knowledge Transfer Network

LAG Local Action Group

LEADER Liaison Entre Actions de Développement de l'Économie Rurale

LEAF Linking Environment and Farming

LLTNPA Loch Lomond & The Trossachs National Park Authority

LSSILG Life Sciences Scotland Industry Leadership Group

LTSER Long-Term Social-Ecological Research

MAP Multi-Actor Platform

MRC Medical Research Council

MRI Moredun Research Institute (SEFARI)

MSP Member of the Scottish Parliament

NCAI Natural Capital Asset Index

NDNS National Diet and Nutrition Survey

NE North East (Scotland)

NERC Natural Environment Research Council

NFM Natural Flood Management

NFUS National Farmers Union of Scotland

NHS National Health Service

NIAB National Institute of Agricultural Botany

NPF National Performance Framework

NTNU Norwegian University of Science and Technology

NWRM Natural Water Retention Measures

OEA Ovine Enzootic Abortion

ONE Opportunity North East

OPA Ovine Pulmonary Adenocarcinoma

PCN Potato cyst nematode

PCR Polymerase Chain Reaction

PfG Programme for Government (Scottish Government)

PHC Plant Health Centre

QBA Qualitative Behaviour Assessment

QMS Quality Meat Scotland

RBGE Royal Botanic Garden Edinburgh (SEFARI)

RDPE Rural Development Programme for England

REHIS Royal Environmental Health Institute of Scotland

RESAS Rural Environment Science & Analytical Services (Scottish Government)

RHASS Royal Highland Agriculture Society of Scotland

RHET Royal Highland Education Trust

RI Rowett Institute (SEFARI)

RIS Research Innovation Scotland

RISS Rural Innovation Support Service

RIVM National Institute for Public Health and the Environment (The Netherlands)

RLUP Regional Land Use Partnership

RPID Rural Payments and Inspections Division

RSGS Royal Geographical Society Scotland

RSPB Royal Society for the Protection of Birds

RSPCA Royal Society for the Prevention of Cruelty to Animals

SAG Specialist Advisory Group

SAOS Scottish Agriculture Organisation Society

SARS Severe Acute Respiratory Syndrome

SAS Soil Association Scotland

SDG Sustainable Development Goals

SDS Skills Development Scotland

SE Scottish Enterprise

SEFARI Scottish Environment, Food & Agriculture Research Institutes

SEPA Scottish Environment Protection Agency

SFD Scotland Food & Drink

SFNC Scotland Forum on Natural Capital

SG Scottish Government

SHA Scottish Hemp Association

SHERPA Sustainable Hub to Engage into Rural Policies with Actors

SLC Scottish Land Commission

SOSE South of Scotland Enterprise

SPA Sparsely Populated Areas

SRDP Scottish Rural Development Programme

SRP Strategic Research Programme

SRUC Scotland’s Rural College (SEFARI)

SSERC Scottish Schools Education Research Centre

SW Scottish Water

SWRI Scotch Whisky Research Institute

UHI University of Highlands & Islands

UKCP United Kingdom Climate Projections

UN United Nations

VHM Veterinary Health & Medicines Directorate

WHO World Health Organisation

WIC Water Industry Commissioner

WICS Water Industry Commission for Scotland

WTP Willingness to Pay

WWTW Wastewater treatment works

ZWS Zero Waste Scotland

**\*** The report necessitates extensive use of accepted acronyms and which, due to brevity may not be able to be defined within text.

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**Executive Summary**

This report summarises the extensive and multifaceted impacts arising from the Strategic Research Programme 2016-2022 (SRP 2016-22), supporting Scotland’s commitment to UN Sustainable Development Goals and including impacts showcased throughout COP26.

Impacts arise from long-term sustained strategic funding (e.g. on river catchments; biodiversity research; soils and peatlands; livestock and crop breeding; livestock vaccines, animal welfare; IPM; Greenhouse Gas emissions [GHGe]; food systems; communities research), and leveraged funding extends the SRP’s knowledge base (e.g. on green infrastructure) and global relevance (e.g. crop diversification in low and middle income countries). The SRP has played a crucial role in identifying and responding to emerging policy priorities (e.g. Just Transitions; environmental regulation), and fore-sighting (e.g. on future agriculture-policy decisions; food-health risks) for policy and industry. Long-term funding of the SRP also supports and drives regional investment that has national to global relevance (e.g. Dairy Nexus, [Advanced Plant Growth Centre](https://www.apgc.org.uk/), International Barley Hub).

The expertise and capability from SRP knowledge and SEFARI resources provided national capacity to respond to the COVID-19 Pandemic, including a unique ONE-Health approach through a [NHS testing hub.](https://sefari.scot/blog/2020/08/18/one-health-in-action-setting-up-a-new-testing-node-for-covid-19-with-the-nhs) SRP outcomes and access to expertise are supported by KE within individual projects and, at programme level, by the CKEI (SEFARI Gateway) and/or Centres of Expertise. This is underpinned by enduring relationships (e.g. NatureScot, SEPA, SFD, FSS, NFUS, HIE, SAOS, FR, DEFRA, RHET, CNPA) and new (e.g. EC, ESS, FFCC, LLTNPA, SOSE).

Highlights of the SRP with direct benefits to policy and practice include: a world first for monitoring and conserving genetic diversity; a suite of approaches for soil health; promotion of conservation in multi-use landscapes; informing woodland expansion and soil carbon sequestration; supporting peatland restoration; informing farming to achieve net zero; advice on farm payment support systems; IPM for reducing pesticide use; understanding data needs for Regional Land Use Partnerships; analyses and engagement for a National Island’s Plan; approaches to replacing EU LEADER funding; work on pre-natal food preference for health; and long-term SRP contributions supporting UK Folate fortification.

In support of Scotland’s economy and innovation, the potato genome project underpins development of new cultivars; work on pulses and hemp shows fundamental research delivering environmental and commercial co-benefits; and research findings on barley from SRP and leveraged partnerships are supporting the Scottish food and drink industry via new products offering nutritional values and sustaining cultural and natural heritage. For livestock, SRP advances include new methods for control of pulmonary adenocarcinoma in sheep; performance indicators of cattle informing reductions in GHGe; and Qualitative Behaviour Assessment continuing to deliver improved animal welfare.

Effectiveness in leveraging funds (e.g. EU, UKRI) contributed to the economic resilience of the institutes, and to Scottish research being positioned at the forefront of scientific advances. SEFARI’s engagement at international and local levels transfers SRP knowledge across scales and opens new co-benefits (e.g. biodiversity conservation and public health, tackling transgenerational disadvantage).

The SRP has been subject to an intense period of policy and societal needs and change, driven by a climate emergency, biodiversity crisis, COVID-19, EU Exit, and the war in Ukraine. The capability to be adaptable (e.g. via SEFARI Gateway projects), while maintaining strategic research operating over timescales beyond immediate shocks to deliver on long-term national or sectoral strategic aims, has been key to achieving the successes reported.

**External Context**

The external context for the 2016-22 SRP changed more than for any previous SRP funding round. At inception, the SRP’s research was enshrined within [Scotland’s National Outcomes and its incorporation of UN Sustainable Development Goals, reflecting Scotland’s commitment to the](https://nationalperformance.gov.scot/national-outcomes) global obligations under the Paris Agreement on Climate Change (2015). The specific policy context included a focus on Climate Change (Act 2009 & Annual Targets Order), strategies for Biodiversity ([2020 Challenge](https://www.gov.scot/publications/2020-challenge-scotlands-biodiversity-strategy-conservation-enhancement-biodiversity-scotland/)), Circular Economy ([Making Things Last](https://circulareconomy.europa.eu/platform/sites/default/files/making_things_last.pdf)), proposals for a [Good Food Nation](https://www.gov.scot/binaries/content/documents/govscot/publications/consultation-paper/2014/06/recipe-success-scotlands-national-food-drink-policy-becoming-good-food/documents/00453219-pdf/00453219-pdf/govscot%3Adocument/00453219.pdf) (from 2014), and a range of focused policy drivers for land, industry or sector type, e.g. Scottish Rural Development Programme, [Land Reform](https://www.legislation.gov.uk/asp/2016/18/contents/enacted) (2016) Act; on multi-functional land use ([Getting the Best from Our Land](https://www.gov.scot/publications/getting-best-land-land-use-strategy-scotland-2016-2021/)); [National Peatland Plan](https://www.nature.scot/doc/scotlands-national-peatland-plan-working-our-future); [Flood Risk Management Plan](https://www.legislation.gov.uk/asp/2009/6/contents); animal welfare in livestock industry strategy; Food and Drink Sector Strategy ([Ambition 2030](https://foodanddrink.scot/resources/publications/ambition-2030-industry-strategy-for-growth/)), Voluntary Initiative IPM plans; plus wellbeing objectives, e.g. SG-obesity route map; while communities saw a focus to (rural) place based polices (e.g. the [National Islands Plan](https://www.gov.scot/publications/national-plan-scotlands-islands/)). These were set within growing a productive, sustainable economy (including fair work) and an economic and capital investment framework including a spotlight on the importance of the EU.

As the SRP progressed, the [2019 Climate Change (Scotland) Act](https://www.legislation.gov.uk/asp/2019/15/enacted), setting a net zero target by 2045 and UK commitments to Net Zero by 2050, the ensuing Scotland [declaration of a climate emergency](https://www.gov.scot/publications/global-climate-emergency-scotlands-response-climate-change-secretary-roseanna-cunninghams-statement/#:~:text=We%20must%20take%20this%20journey,our%20planet%20for%20future%20generations.) and the vision for [biodiversity strategy beyond 2020](https://www.nature.scot/scotlands-biodiversity/scottish-biodiversity-strategy-and-cop15/scotlands-biodiversity-strategy-2022-2045#:~:text=Scotland%27s%20Biodiversity%20Strategy%20Consultation,and%20reverse%20it%20by%202045.) and the UK hosting [COP26](https://ukcop26.org/) in Glasgow (2021) created an increased focus in the stakeholder base towards net zero priorities and [Just Transition](https://www.gov.scot/groups/just-transition-commission/) (e.g. with Enterprise Agencies, Local Government, National Parks, sectoral or levy bodies). Such strategic momentum, however, has had major implications for the SRP and SEFARI. Facilitated by Gateway, they have had to adapt quickly to ensure relevance to the economic shocks caused by the EU exit and the multi-faceted pressures brought about by the COVID-19 pandemic (2020-2022). Energy and food insecurity, and inequalities have been further heightened by the war in Ukraine (2022).

The new SRP has been informed by the evolution of polices that founded the SRP 2016-2022, and challenges created by the pandemic and EU Exit, with a strong focus within [Green Recovery](https://www.gov.scot/news/scotlands-green-recovery/). The SRP (and SEFARI Gateway and other Centres of Expertise) have been crucial advocates for the science, best practices and innovation transfers that are needed to meet the multiple but interconnected policy challenges across climate, environment, land use, farming, food-chain, and rural community needs, both nationally and in place-based contexts.

In regard to the SRPs relationship to other key funders, [the formation of UKRI (2018)](https://www.ukri.org/about-us/epsrc/who-we-are/our-history/#:~:text=Established%20on%201%20April%202018%20by%20the%20Higher,into%20one%20unified%20body.%2020th%20anniversary%20of%20EPSRC) marked a shift to a greater overarching strategic coordination for UK research Councils. SEFARI SRP expertise and its extensive stakeholder networks, continued to be well-placed to leverage funding from UKRI Councils. However, there remains uncertainty in relation to the status of UK research organisations with the EU’s “Horizon” R&D scheme. Horizon 2020 (latterly [Horizon Europe](https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programm)) has represented a key source of external funding and adding value to SRP research, aided by a strong alignment between the SRP and the EU’s mission-led research strategy. At the time of writing both short- and long-term plans are being discussed to provide stability and continuity of funding, should the UK fail to associate with the EU Horizon Europe Research and Innovation Programme. The plans will be followed closely by SEFARI with the aim of ensuring that the significant benefits from international scientific collaboration are maintained.

**Internal Context**

The leadership of the Strategic Research Programme (2016-22) changed through the appointment of new CEOs at SRUC and James Hutton Institute, and new Directors of the Rowett Institute and BioSS. Cross MRP-SRP internal governance provided by the Directors Executive Committee (DEC), drawing upon DEC-SRP Advisors, CKEI, Theme Leads and Co-ordinators, bilateral working with SG, and through the SRP-SABOG, ensured changes in SRP leadership, other retirals and, for example, appointment of the Moredun Research Institute CEO as Scotland’s Chief Scientific Advisor (2021), were managed with limited impacts on the Programme.

Other significant changes internal to the research programme were new Leads of the Themes of Natural Assets (2020) and Productive and Sustainable Land Management & Rural Economies (2019),the role of the latter transferring from SRUC to Moredun Research Institute. An additional Theme Coordinator for the Natural Assets Theme was also appointed.

The period of the SRP 2016-22 coincided with significant investment and change in the infrastructure of the institutes. In 2016, the Rowett Institute completed its move to a new purpose-built building. Investments in new infrastructure at the James Hutton Institute Invergowrie campus, funded by [the Tay Cities Growth Deal (£62M)](https://protect-eu.mimecast.com/s/0ru4C98ROFmJVXOSErG2E?domain=eur03.safelinks.protection.outlook.com) ,commenced in 2020, enhance capabilities to deliver SRP outputs with only medium-term impacts on operations. This investment is concomitant with its [Open Science Campus developments](https://protect-eu.mimecast.com/s/QQFhC0gvOF2n05yu2Lz4h?domain=eur03.safelinks.protection.outlook.com) which will add value and stakeholder engagement for the SRP.

As part of the Borderlands Region Deal, SRUC is progressing an £8M [Dairy Nexus](https://protect-eu.mimecast.com/s/RcDmCj27LTjz1XOi186AR?domain=eur03.safelinks.protection.outlook.com) which builds long term strategic dairy research capability. SRUC also entered significant partnerships including with Opportunity North East through [Seedpod](https://protect-eu.mimecast.com/s/nVLLCg516Ilv5RBi3B7II?domain=eur03.safelinks.protection.outlook.com), a £21M investment (in the Aberdeen City Region Deal) in the food and drink sector’s innovation agenda. This agenda also links strongly with the Rowett Institute’s nutritional-food research capabilities.

Institutionally, in 2018, the James Hutton Institute and BioSS became eligible for submissions to UKRI, which has resulted in additional value-added research relevant to the SRP. BioSS also had a major increase in resources on the ecological impacts of offshore renewables. SRUC and Moredun Research Institute created a closer [strategic partnership](https://protect-eu.mimecast.com/s/ZskbC8qPOUjm80kingSaZ?domain=eur03.safelinks.protection.outlook.com) building on their complementary expertise and capacity in animal health, welfare, genetics, animal-nutrition and farming systems (2017).

Two other significant changes for BioSS in terms of research funded outside the SRP were [support for the COVID-19 wastewater monitoring programme](https://protect-eu.mimecast.com/s/huFVCk59DInD3jwF8jnk7?domain=eur03.safelinks.protection.outlook.com).

The onset of the COVID-19 pandemic required operational changes, with most staff working from home, whilst maintaining or reorienting the use of facilities. Delays on laboratory and trials research were agreed with RESAS and other funders. Very welcome support was received from the Scottish Government through its immediate extension of the SRP into 2021-22 ensured research continuity, integrity and adaptation through modified delivery.

Rescheduling of activities also enabled SEFARI staff and capabilities to act directly in support of the public [response to COVID-19](https://protect-eu.mimecast.com/s/TVUcClOjDHoWq8MtVcp2J?domain=eur03.safelinks.protection.outlook.com). The furlough scheme was used for some non-SRP funded (but interacting) staff but did not affect delivery of the SRP.

The SRP KE strategy evolved with the appointment (2016) of a full time Director for the CKEI, and a branding exercise in 2016-17 which led to [SEFARI](https://protect-eu.mimecast.com/s/E19tCmwlGF5VL3MU3ct7Z?domain=eur03.safelinks.protection.outlook.com) and the CKEI named as [SEFARI Gateway](https://protect-eu.mimecast.com/s/OySACnZn8hG4p2WSvQ8VM?domain=eur03.safelinks.protection.outlook.com). This was backed by a cross-institutional Collaboration Agreement defining SEFARI/Gateway collaboration, centering on SRP funding and inclusive of MRP activities under the “leading ideas for better lives” concept. In 2018, a new Director was appointed to Gateway. Its KE strategy was revised to meet the evolving priority needs of stakeholders, linked to the National Performance Framework and the contemporary Scottish Government Programme for Government.

In the SRP 2022-27, the CKEI format evolves into the Portfolio’s Centre of Expertise for Knowledge Exchange and Innovation, with its KE strategy complemented by horizon scanning, enhanced priority to KE-training/ crucibles and increased co-working with Scottish Government.

* 1. **Programme Level Outputs and Outcomes**
  2. **SUPPORTING POLICY AND PRACTICES**

**Woodland Strategy in Loch Lomond & The Trossachs National Park**

The Loch Lomond and The Trossachs National Park Authority (LLTNPA) Partnership Plan sets a target of 2,000 additional hectares of woodland by 2023, and their Trees and Woodland Strategy (2019) identifies over 23,000 hectares as ‘preferred’ areas for new woodland. However, in 2018-19, woodland creation was only 258ha, less than the required rate for achieving the 2023 target. To address this the LLTNPA launched a small-scale planting grant and co-designed a project (2019-21) with SEFARI Gateway to support woodland planting. [The project](https://sefari.scot/sites/default/files/documents/SEFARI%20Fellowship%20LLTNP%20Final%20Report.pdf), backed by a cross-SRP-LLTNPA advisory team, and SEFARI researchers, worked with public agencies, and the Park’s landowners and representatives of land-use and farming interests. [Recommendations](file:///C:\Users\rwt200\AppData\Local\Temp\MicrosoftEdgeDownloads\83a37a96-bcf5-4dd4-a8e1-a7d2bc2101de\Summary%20Briefing%20SEFARI%20LLTNP%20Fellowship.pdf) were to retain the National Park Tree Planting Grant Scheme, to develop a scheme for <5ha woodland creation, and to explore a locational premium for incentivising new planting within potential and preferred woodlands areas.

The project was supported by a programme of engagement with land managers to improve the sharing of best practice, coupled with brokering ongoing dialogue with forestry agents for understanding and addressing constraints. A webinar and series of site visits facilitated gathering local and regional information on ‘hot topics’ (e.g., carbon and agroforestry; woodland establishment schemes) including a ‘Woodland creation for farmers’ training day in partnership with Scottish Forestry, Woodland Trust Scotland and NFUS. LLTNPA noted “This was one of several identified areas for collaboration [with SEFARI], all of which leveraged the role of the National Park as a test bed for implementing and integrating national policy”. We look forward to continuing our collaboration with SEFARI. The work led to a further [SEFARI Fellowship and report to assist the Park Authorities’ approach to sustainable transport.](https://sefari.scot/document/exploring-participatory-approaches-to-policy-development-for-decarbonising-transport-to-and)

**Gamekeeper engagement in the CNPA: the safe use of medicated grit**

A SEFARI project (2016-17, with follow-on support to extend research benefits in 2017-19) with the [Cairngorms National Park Authority](https://cairngorms.co.uk/) ([CNPA](https://sefari.scot/node/5145)) brought together key stakeholders, including landowners and gamekeepers. This [report](https://sefari.scot/sites/default/files/documents/fellowship%20report%20final.pdf) led to a focus on responsible and sustainable use of medicated grit about which a Scotland wide series of [behaviour changing workshops](https://sefari.scot/blog/2019/11/01/knowledge-exchange-medicated-grit-and-scottish-grouse-moors) was developed and delivered. These workshops built on expertise from SRP animal-health research, through SEFARI partnership working with the [Game and Wildlife Conservation Trust](https://www.gwct.org.uk/) (GWCT), and were attended by over 130 gamekeepers. Outputs from the workshops was agreed positions that medicated grit should not be used as an insurance policy, but only when need is demonstrated by use of available diagnostics.

The use of diagnostics for medicating grit decisions is now regularly advised and can be carried out by a vet or by the GWCT. Feedback from the gamekeepers confirmed that the combination of expertise from scientists, vets and industry at the workshops was influential on their decisions on the use of medicated grit. The GWCT produced a free [guidance](https://www.gwct.org.uk/advisory/guides/medicated-grit-best-practice/) document using much of the information gathered at the workshops. Feedback from prescribing vets is of large increases in the proportions of land estates using diagnostics. The output from this work was provided to the [Werritty Committee](https://www.gov.scot/publications/grouse-moor-management-group-report-on-fourth-and-fifth-meetings/) on the use of medicated grit on Scottish grouse moors. This work demonstrated [the value of trusted, independent knowledge brokering between stakeholders](https://sefari.scot/node/5145).

**Spatial data needs for land-based policy and decision-making**

A SEFARI Gateway Fellowship with RESAS worked with the teams within Scottish Government (e.g. Natural Capital, Land Management, RPID, Regional Land Use Partnerships) and public agencies (SEPA, NatureScot, and Forestry and Land Scotland) to provide [a report](https://sefari.scot/document/gagkas-z-2021-scoping-for-developing-an-integrated-digital-data-approach-for-land-use) of both land and environmental monitoring and modelling programmes in England and Wales. Recommendations were made on the different components of a Scottish integrated approach to environmental and land use data, including in relation to its governance, utilisation of existing ICT infrastructure, methods, alignment and coordination with strategic research and the role of emerging digital and spatial technologies for new data collection and monitoring. An assessment was provided of data-related issues that pose potential risks to an integrated approach for the reporting of land use statistics, and recommendations for minimising these risks. Findings also identified the need for establishing clear leadership and coordination between partners, identifying knowledge gaps, mapping evidence and prioritising policy needs, and recognising any shortcomings in analytical resources, existing systems and related infrastructure.

In addition, consideration should be given to linking how planning decisions that affect land use change can be joined-up across sectors. The impact of such land use decisions on the wider environment and climate also needs to be taken into account.

An indicative timescale was also provided for the implementation and delivery of such a Scottish resource. Project findings are being assessed by Scottish Government.

**Defining environmental regulation data needs**

[Environmental Standards Scotland (ESS)](https://www.environmentalstandards.scot/) is a new independent public body, established by the UK Withdrawal from the European Union (Continuity) (Scotland) Act 2021. Its role is to monitor the effectiveness of environmental law in Scotland, the compliance of public authorities with it, and to prevent enforcement gaps arising from the UK leaving the European Union. A SEFARI Fellowship reviewed the potential challenges for ESS where systems understanding is required to ensure holistic (monitoring and regulatory) success, and where analyses and support needs to be sector specific and focussed. The SEFARI [report](https://sefari.scot/document/identifying-environmental-priorities-and-analytical-requisites-for-environmental-standards) provided approaches to establishing priorities, and mapped published priority lists onto current Scottish environmental strategy, identifying commonalities and gaps. The indicators used to evaluate the priorities were reviewed, as were the levels of compliance against legislation, and the maturity of the policies that support these evaluations. The analysis placed greater weighting on environmental priorities that have less-developed monitoring or evaluation processes, less-developed supporting policy, and where compliance is less consistent. On this basis, higher prioritisation was given to soils, biodiversity, and greenhouse gases and carbon. The Fellowship supported its recommendations by proposing a structure by which with ESS could conduct and govern analyses. It also made recommendations to minimise risks associated with errors, data breaches, inconsistent advice, poor compliance with information governance legislation, which would undermine the authority of the ESS. [ESS noted: “The SEFARI fellowship has helped us significantly in beginning to think through aspects of how ESS approaches the analytical part of its new role – in particular, what sort of approach we might take to identifying priority topics for consideration and what analytical skills and resources we will need in the team to be able to fulfil our role successful”]. ESS subsequently launched a public consultation on their [draft Strategic Plan](https://consult.gov.scot/environmental-standards-scotland/draft-strategic-plan/). The Plan considers the SEFARI report and is a statement of how ESS will work to investigate and secure improvements in environmental law compliance, effectiveness, and the way it is implemented and applied in Scotland.

**Supporting the Just Transition Commission**

[The Just Transition Commission](https://www.gov.scot/groups/just-transition-commission/) (JTC) supports a net zero and climate resilient economy in a way that delivers fairness and tackles inequality and injustice. To support the delivery of this ambition, the Scottish Government is leading the production of key just transition plans, co-designed and co-delivered by communities, businesses, unions and workers, and across society. SEFARI researchers worked with the JTC and explored examples of (and learnings from) Just Transitions in other nations/regions by looking at their scope, methodology, approaches to participation and engagement, timelines, perceived risks/benefits, and resultant policy outcomes. The project [reported to the JTC](https://www.gov.scot/publications/transitions-comparative-perspective/pages/2/) on possible interventions for managing or minimising the disruption to workers and communities caused by economic structural change, similar to that implied by the move to a carbon-neutral economy. The findings were delivered to the [Just Transition Commission, which met between 2019 and 2021](https://www.webarchive.org.uk/wayback/archive/20210111123819/https:/www.gov.scot/groups/just-transition-commission/) and subsequently directly informed their [report](https://www.gov.scot/publications/transition-commission-national-mission-fairer-greener-scotland/) (March 2021). The report led to a podcast [interview](https://anchor.fm/yfoes/episodes/Energy-decentralisation-for-a-just-transition---Annabel--The-James-Hutton-Institute-eejcfg) on just transitions with Young Friends of the Earth Scotland in 2020, and a [presentation](https://climateweeknortheast.org/job/friends-of-the-earth-scotland-old-torry-community-centre-torry-abbey-place-aberdeen-ab11-9qh-20-just-transition-for-the-north-east-what-can-500-million-do) on just transitions in March 2022. SEFARI Gateway also contributed to the Commissions land user - agri sector engagement as part of the Just Transition [debate](https://www.webarchive.org.uk/wayback/archive/20210111130831/https:/www.gov.scot/publications/just-transition-commission-community-engagement/) on Agriculture and Land Use Change and implications for transitions. The Commission is currently using findings from this first phase of the work, including that of the SEFARI report. The current work of the JTC is delivery focused and is supporting and scrutinising the production and delivery of Scottish Government-led transition plans.

**Potential roles of spatial data for the Regional Land Use Partnerships**

[The Programme for Government (2021/22)](https://www.gov.scot/publications/fairer-greener-scotland-programme-government-2021-22/) and [3rd Land Use Strategy](https://www.gov.scot/publications/scotlands-third-land-use-strategy-2021-2026-getting-best-land/#:~:text=Published%2024%20March%202021&text=Scotland's%20Third%20Land%20Use%20Strategy,we%20get%20from%20our%20land.) commit the Scottish Government to creating [Regional Land Use Partnerships (RLUPs)](https://blogs.gov.scot/rural-environment/2021/02/05/working-together-to-maximise-the-potential-of-our-land/) in their strategy for tackling climate change. A [SEFARI Specialist](https://sefari.scot/document/roles-of-spatial-data-by-regional-land-use-partnerships-report-draft) Advisory Group with the Scottish Land Commission (SLC), Scottish Government and public agencies reviewed how spatial data can support RLUPs to achieve their aims. Reporting covered the sources, availability, content, quality and governance of data, technological platforms, human skills, and institutional arrangements. It was accompanied by 17 example uses (e.g., measuring and monitoring natural and socio-economic resources by different geographies; presenting public strategies; community visioning; modelling future land uses). Outputs contributed to SLC advice to the Scottish Government on establishing the RLUPs. Participation by organisations in pilot RLUPs triggered follow-up queries, such as:

1. South of Scotland Enterprise (SOSE) and Scottish Government sought information on mapping and assessing natural capital, subsequently an Annex in the [Final Reporting](https://sefari.scot/document/roles-of-spatial-data-by-regional-land-use-partnerships-report-draft) [“Many thanks for this – huge resource and successfully received”, J Ashley, SOSE].
2. Scottish Government and Aberdeenshire Council enquired about methods (e.g. community visioning using the [Virtual Landscape Theatre](https://www.hutton.ac.uk/learning/exhibits/vlt)), to which reporting and additional information were sent. [“Thanks so much for sending this SEFARI paper, though it comes at a very timely point for us.” K McWhinnie, Scottish Government].

**SEFARI contribution to COVID-19 pandemic response and recovery**

SEFARI researchers, utilising the expertise and capabilities underpinned by Strategic Research and Unpinning National Capacity resources, responded at [scale and pace to support responses to the COVID-19 pandemic and its ongoing recovery](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fsefari.scot%2Fcovid-19-response&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C476472ac3f6d46c297d208da7f5852a9%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637962314571652781%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=0qeyQ7cglvoIVXrA1DdBA73YuPIlcqiyhUmRwjq6Ae8%3D&reserved=0). The COVID-19 response included a unique demonstration of the value of a one-health capability through use of SEFARI expertise and core-facilities to provide [support to the NHS in Scotland in their COVID-19 testing programme for SARS-CoV-2](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fsefari.scot%2Fblog%2F2020%2F08%2F18%2Fone-health-in-action-setting-up-a-new-testing-node-for-covid-19-with-the-nhs&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C476472ac3f6d46c297d208da7f5852a9%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637962314571652781%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=7oOVbegG%2BfK%2F2F0cIaEibBB5tBgvrObABBTp5RntBXw%3D&reserved=0), and to pilot a study looking at pooling test samples to increase efficiency of testing regimes. The latter was based on experience gathered from strategic research conducted for the Scottish Bovine Viral Diarrhoea Virus (BVDV) eradication campaign.

The COVID-19 response also included the provision of other SEFARI laboratory equipment to regional NHS laboratories; [research on sustainable personal protective equipment from agri-waste](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fsefari.scot%2Fnews%2Fenvironmentally-friendly-ppe-in-scots-researchers%25E2%2580%2599-sights&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C476472ac3f6d46c297d208da7f5852a9%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637962314571652781%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=MzijJLT6o9XPkr4mPTQ7Jq0ABEd5k31ySyPp7f%2FL4zg%3D&reserved=0); [assessing food habit changes during lockdown](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fsefari.scot%2Fblog%2F2020%2F07%2F14%2Fresearching-the-impact-of-the-covid-19-pandemic-on-our-food-habits&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C476472ac3f6d46c297d208da7f5852a9%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637962314571652781%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=oezjbLSoTA9EACZ9d1DDeEiPy17HnO%2FRiFoZCLiBMvU%3D&reserved=0); examining the influence of the pandemic on agricultural production and trade; undertaking COVID-19 food security assessments e.g. SEFARI researchers, with collaborators at Cranfield University and Chatham House, [provided crucial fore-sighting for UK food and nutrition security](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fonlinelibrary.wiley.com%2Fdoi%2Ffull%2F10.1111%2Fnbu.12485&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C476472ac3f6d46c297d208da7f5852a9%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637962314571652781%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=NinG4KZ7KQ9Lwnq2DKVp7YA14eogZxzF6NKlQsJuQNw%3D&reserved=0); expertise through membership of the SG COVID-19 Stakeholder Group for Rural Economy and Communities; co-leading (via SEFARI Gateway) an expert group on [rural economic post-COVID recovery through the lens of food and drink sector](file:///C:\Users\rwt200\AppData\Local\Temp\MicrosoftEdgeDownloads\9e371cc7-d0ff-4569-ba7c-5ca72b8fe718\COVID-19%20FOOD%20AND%20DRINK%20SECTOR%20THINK%20TANK%20FOR%20SCOTLAND%25E2%2580%2599S%20RURAL%20ECONOMY%20&%20EXPERT%20ADVISORS%20(1).pdf); [support for the COVID-19 wastewater monitoring programme](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.news-medical.net%2Fnews%2F20220614%2FScotlands-monitoring-program-for-SARS-CoV-2-in-wastewater.aspx&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C476472ac3f6d46c297d208da7f5852a9%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637962314571809048%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=sQH5fmaQhWrCffpQa75A1saI%2BCPXLwAvile2PkgaeV0%3D&reserved=0) (for which CREW was at the forefront in coordinating wastewater-based epidemiological research and establishing partnerships behind the National surveillance programme); voluntary support to local health and wellbeing organisations and, through SEFARI Gateway, supporting [remote education](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fsefari.scot%2Fblog%2F2020%2F04%2F17%2Faccessible-education-resources-%25E2%2580%2593-coming-soon&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C476472ac3f6d46c297d208da7f5852a9%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637962314571809048%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=U6eXZDyyLRXvd4g%2F2pCEVllkstEReoZBIScyt5KBQCU%3D&reserved=0) for families and schools witha range of [online educational materials](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fsefari.scot%2Fdocument%2Fonline-education-resources-table&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C476472ac3f6d46c297d208da7f5852a9%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637962314571809048%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=2bfhvnkDeywqQ5ejIpEHYksTqFrVH5xfZ6nmsVJx%2BhM%3D&reserved=0).

**Climate change emission contributions ‘smart inventory’ for agriculture**

Whilst previous versions of the National Inventory for Agriculture used simpler, fixed emission factors, the ‘Smart Inventory’ for Agriculture calculates emissions more dynamically using a set of models to improve accounting for heterogeneity across different farming systems. As part of SEFARI work to support the development of the Scottish Government’s future agricultural policy (including support for the [Farmer Led Climate Change Groups)](https://www.gov.scot/policies/agriculture-and-the-environment/farmer-led-climate-change-groups/#:~:text=Farmer%20led%20groups%20were%20established,upland%20farming%2Fcrofting)%20sectors.) researchers were asked to estimate the contribution that different sectors of Scottish agriculture make to greenhouse gas emissions in the agricultural ‘Smart Inventory’. The degree of aggregation in published emission figures masks some of the detail required to identify sectoral emission envelopes for policy purposes. The task to provide further evaluation of the sectoral emissions was completed through recourse to additional information and some assumptions. A number of reports were completed for the [sheep](https://www.gov.scot/publications/estimated-sheep-emissions-mitigation-smart-inventory/pages/2/), [arable](https://www.gov.scot/publications/estimated-arable-emissions-mitigation-smart-inventory/), [suckler beef](https://www.gov.scot/binaries/content/documents/govscot/publications/factsheet/2021/01/suckler-beef-climate-scheme-research-papers/documents/suckler-beef-climate-scheme---estimated-effects-of-sbcs-within-the-national-ghg-smart-inventory/suckler-beef-climate-scheme---estimated-effects-of-sbcs-within-the-national-ghg-smart-inventory/govscot%3Adocument/estimated-suckler-beef-climate-scheme-effects-within-national-ghg-smart-inventory.pdf), and [dairy](https://www.gov.scot/publications/estimated-dairy-emissions-mitigation-smart-inventory/) sectors offering an estimated breakdown of the types of emissions, estimated emission factors and mitigation potential. A summary report on [Greenhouse gas emissions - agricultural: disaggregating headline figures](https://www.gov.scot/publications/disaggregating-headline-smart-inventory-figures/) provided new insights on emissions (including from dairy beef) and mitigation potential to Scottish Government analysts and policy leads. SEFARI researchers concluded that further exploration of the Smart Inventory for agriculture methods and data would be advisable to support future policy interpretation of reported headline figures.

**Islands Revival: power of the local voice**

[The Islands Revival](file:///C:\Users\rwt200\AppData\Local\Temp\MicrosoftEdgeDownloads\5a1332a9-debc-4a68-aec8-ccd3a25e452c\The%20Islands%20Revival%20(Gateway-Responsive%20Opportunity%20Fund)%20project%202019-2020%20and%20its%20legacy%20(Gateway%20Flexible%20fund)%20project%20) Gateway project (2019-20) and its legacy work “Research on the Edge” (2020 onwards) is a partnership between Scotland’s Island communities, community-land organisations, including Community Land Scotland, CoDeL, and researchers linking with local and national Government (Scottish Government National Island's Plan Delivery Group). Highlighting the necessity for [research](https://sefari.scot/research/objectives/demographic-change-in-remote-areas) developed with those who live and work locally, the Islands Revival [revealed population and economic trends not readily identified in national data sets](https://sefari.scot/research/is-the-demographic-tide-turning-for-some-island-communities). The project led to the [Island’s Revival Declaration](https://www.bbc.co.uk/news/uk-scotland-highlands-islands-49741336). [The Declaration](https://islandsrevival.org/the-islands-revival-declaration/) affirmed that there is credible evidence of growth in the Scottish islands but, importantly, population growth in itself is not necessarily a goal of island communities. Often, the aspiration is to achieve sustainability, vitality, and viability, for which maintaining an economically active population is a part. Positive signs of renewal are driven by investments in connectivity (digital and physical), housing, services, and the availability of attractive jobs, and due to less tangible factors, such as community leadership, self-confidence, and the interest and energy brought by young people. In developing policy, Island’s Revival emphasised the need to engage local communities meaningfully, being aware and adapting if there is diminished capacity for such engagement and to consider the unique challenges and characteristics of places.

The project has led to two PhD students examining island migration and influencing the “living labs” in islands (as well as mainland rural areas) initiative within the SRP 2022-27. In related work, SEFARI researchers prepared the [summary](https://www.gov.scot/publications/national-islands-plan-survey-final-report/documents/) and an [online results explorer](http://www.hutton.ac.uk/islands-survey) of the [National Islands Plan](https://www.gov.scot/binaries/content/documents/govscot/publications/research-and-analysis/2021/07/national-islands-plan-survey-final-report/documents/national-islands-plan-survey-final-report/national-islands-plan-survey-final-report/govscot%3Adocument/national-islands-plan-survey-final-report.pdf?forceDownload=true). Islands groups developed by researchers during the survey were also engaged by the Scottish Government (e.g., in the consultation on an Islands Bond) and are being used by the National Registry of Scotland’s small area population estimates.

**Sustainable diets, climate change and human health**

Current lifestyles and eating patterns are a major factor in health issues within the Scottish population. In addition, the way food is produced and consumed is taking a toll on the environment. The Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) were approached by several countries to develop guidance on what constitutes sustainable healthy diets. A SEFARI researcher was invited to join the committee leading the FAO-WHO consultation. The researcher’s expertise in nutrition and the environmental impacts of the food system was used to underpin the concept of sustainable diets. The report, [FAO-WHO Guiding Principles for Sustainable Healthy Diets](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.fao.org%2F3%2Fca6640en%2FCA6640EN.pdf&data=05%7C01%7Ck.crosley%40abdn.ac.uk%7C8609d3af81614b1d578008da658aa843%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637933943444716686%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=lDPyERf0WYpBQQeaMMdbMas4H%2FOv17Kbrm9%2BrFxmD8U%3D&reserved=0), is being used nationally and internationally to develop public policies. In 2021, the Academy of Medical Sciences and The Royal Society also set up a steering committee to gather evidence on the threat of climate change to human health. The SEFARI researcher led that committee, the report from which [summarised](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Froyalsociety.org%2Ftopics-policy%2Fprojects%2Fclimate-change-mitigation-human-health%2F&data=05%7C01%7Ck.crosley%40abdn.ac.uk%7C8609d3af81614b1d578008da658aa843%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637933943444716686%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=58T65UtGk6z6Ew2wNSVBMDxanKO0%2BOhLSQxT96qpQsU%3D&reserved=0) the evidence of how climate change mitigation actions could promote human health in the near term, through ‘co-benefits’. The same researcher was invited to be a member of a review panel advising Food Standards Scotland (FSS) on developing their new ‘Dietary Guidance for Scotland’ and website [Eat Well, Your Way](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.eatwellyourway.scot%2F&data=05%7C01%7Ck.crosley%40abdn.ac.uk%7C8609d3af81614b1d578008da658aa843%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637933943444716686%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=ATQ%2B7PNdP4pxwoLinKxIuMopTYOCWwZ8XnRzlGlMwGY%3D&reserved=0) launched in February 2022. This built on advice provided to FSS over the course of the SRP for, and underpinning, its research into dietary behaviour.

**1.2. SUPPORTING INNOVATION AND THE ECONOMY**

**Water resources and benefits to the Scottish economy**

A SEFARI Gateway project with the [Water Industry Commission for Scotland (WICS](https://wics.scot/)) and Scotland’s Hydronation Initiative, and in collaboration with [Scotland's Centre of Expertise for Waters (CREW)](https://www.crew.ac.uk/), provided insight to frameworks for use in valuing different benefits of water to Scotland. The project was a contribution to the commitment of ensuring that Scotland’s water resources are developed to bring the maximum benefit to the Scottish economy, whilst working towards net zero carbon by 2040.

The work reviewed literature of accounting frameworks for internalising non-cash, non-monetised elements, such as carbon, in the operations of companies from across the world, including a wider look at how natural capital is reported. The output was to inform a reporting framework being explored by Scottish Water.  The project focused on the creation of social value from the operations of the UK water companies, reviewed current practices of Scottish Water, and identified practices of other companies, sectors and countries which could be suitable for adoption. Findings showed that water companies have considerable potential to create added value for their customers, supply chains and the communities in which they operate. The different capital frameworks and methodologies offer scope for monetising and accounting for different value types (e.g., environmental, social, human, intellectual). Such frameworks have the potential for future valuing of the wider benefits of water resources in Scotland and in accounting of the true value created by the Scottish Water. The findings are also of potential use for the strategic agenda of the Water Industry Commission for Scotland and the on-going social capital programme of Scottish Water.

**Defining the innovation landscape for Scotland’s AAA sector**

Scotland’s Agritech, Animal Health & Aquaculture (AAA) sector represents a significant opportunity for enhancing trade and attracting inward investment from the UK and internationally. However, the sector lacks a clear platform understanding of its capacity and capabilities. In collaboration with Highlands and Islands Enterprise, Scottish Enterprise and the Life Sciences in Scotland Industry Leadership Group for AAA, a SEFARI project created an [inventory](https://lcshome.directories.scot/) of AAA capabilities and resources in Scotland across academic institutes, companies, innovation centres, networks and consortiums, charities, government and development agencies, business gateways and venture studios.

The future AAA landscape was also explored, with multiple new centres, hubs, and trial facilities in development, including at SEFARI sites, showing the significant expansion and investment in this area. The [report](https://sefari.scot/document/animal-health-agri-tech-and-aquaculture-improving-awareness-and-links-for-innovation) references the excellence of trial facilities, including at SEFARI [research farms](https://sefari.scot/blog/2021/03/27/five-sefari-research-farms-take-a-tour-from-your-sofa), which exist across Scotland. The report noted a need to define the gross value added (GVA) for the sector and a desire within the sector to address regulatory constraints to innovation. The project output [provides a platform from which further exploration of the sectors can build on](https://www.lifesciencesscotland.com/news/new-report-highlights-scotlands-aaa-strength). [The Director, (Scotland) of We Are Pioneer Group and Co-Chair of AAA ILG said: “This is a comprehensive report that definitively identifies Scotland’s world leading core capabilities and international assets within AAA”.] The importance of the report was acknowledged via its seminal role in the [A3 2020 International Conference](https://sefari.scot/events/a3-scotland-conference-apr-2022) and HIE enhanced focus on the AAA sector.

**Supporting clarity for a route to farming GHG reductions**

A SEFARI project sought to clarify the impact of Scottish agriculture on the climate and wider environment, and covered, through a series of [booklets](https://sefari.scot/document/navigating-greenhouse-gases), [fact sheets](https://www.nfus.org.uk/policy/environment-and-land-use/sefari-fellowship.aspx), [infographics](file:///C:\Users\rwt200\AppData\Local\Temp\MicrosoftEdgeDownloads\509c1267-ec2e-4707-9d6c-62d7cd428223\NFUS%20booklet%20Mar22.pdf) and discursive online blogs on areas of high-need as identified by the NFUS Board. The topics covered were: [reducing methane from livestock](https://www.nfus.org.uk/userfiles/images/Policy/ELU/0720%20N2O%20Factsheet.pdf), reducing [nitrous oxide](https://www.nfus.org.uk/userfiles/images/Policy/ELU/0720%20N2O%20Factsheet.pdf) emissions, [improving soil carbon sequestration](https://www.nfus.org.uk/userfiles/images/Policy/ELU/0620%20Grassland%20Factsheet.pdf), understanding [forestry impacts](https://www.nfus.org.uk/userfiles/images/Coronavirus/0620%20Forestry%20Factsheet.pdf) on soil carbon and best practice [climate sensitive arable systems](https://www.nfus.org.uk/userfiles/images/Policy/ELU/0720%20Arable%20Factsheet.pdf) and [upland farming](https://www.nfus.org.uk/userfiles/images/Policy/ELU/0620%20Uplands%20Factsheet.pdf) systems. The SEFARI scientist(s) liaised closely with Scottish Government Agriculture Policy Teams and directly with farmers, the work influencing Farmer led Groups on net zero targets for the sector. Social media interest was [intense](https://www.pressreleasepoint.com/dr-gemma-miller-sefari-fellowships-blog), with animated debate, particularly on the issue of soil carbon sequestration [NFUS President, in responding to the work noted: “Although, as yet the science is not 100% definitive, [snip] using the most up-to-date data available at the moment has allowed us to set a baseline to work from [snip] in taking the industry forward”].

**Reducing GHGs from livestock by improving animal health**

A number of important reports including [UKCCC](https://www.theccc.org.uk/), [Farming 1.5C](https://www.farming1point5.org/), [CIEL](https://www.cielivestock.co.uk/expertise/net-zero-carbon-uk-livestock/report-april-2022/), SG [Farmer-led Groups](https://www.cielivestock.co.uk/expertise/net-zero-carbon-uk-livestock/report-april-2022/) have identified sub-optimal animal health as a key constraint on efficient livestock production and a significant contributor to the carbon footprint of animal agriculture. A SEFARI Gateway-funded Specialist Advisory Group was established to discuss and agree priority health conditions (diseases and syndromes) and practical intervention strategies that would have a demonstrable impact on GHG emissions across the beef, dairy, and sheep sectors in Scotland. The group comprised key industry stakeholders, advisors, farmers, vets, government policy teams and SEFARI researchers (n=100), with activity based around two workshops and intervening correspondence.

One of the main outputs of the group was the ‘[Acting on methane’](https://ruminanthw.org.uk/actingonmethane/) Report, commissioned by the UK-wide Ruminant Health and Welfare Group, which aims to provide farmers with animal health options that they can tackle now to help reduce their farm’s carbon footprint. Several group members are actively engaged in consultation with the SG Agriculture Reform Implementation Oversight Board (ARIOB) Animal Health & Welfare Sub-Group around including priority animal health measures in future Government-supported agricultural payment schemes.

**Dairy Nexus at heart of regional development**

The Borderlands partnership announced investment of up to £8M into a new Centre of Dairy Innovation at a SEFARI campus. This will draw on the SEFARI organisation’s pedigree in teaching, research and consultancy, including the long term underpinning of SRP diary research and its data and expertise (e.g. the long-term [Langhill dairy experiment](https://www.sruc.ac.uk/research/research-facilities/dairy-research-facility/dairy-projects/langhill-breeding-study/)), to support dairy industry skills and careers, encourage KE and create innovative research across the Borderlands region. The work will accelerate research and technology to be applied within dairies and the supply chain. [The Nexus](https://www.sruc.ac.uk/all-news/dairy-nexus-moves-one-step-closer/), which is part of the £452M Borderlands Inclusive Growth Deal, will support innovation to de-carbonise the dairy sector and move it towards a circular bio economy and support significant and inclusive regional growth to underpin rural community resilience.

**Supporting SEPA Crop Production Sector Plan development**

A workshop – Think Tank, co-led by the [Scottish Environment Protection Agency](https://www.sepa.org.uk/) (SEPA) and SEFARI Gateway (March 2019), assisted development of the Crop Production Sector [Plan](https://sectors.sepa.org.uk/media/1146/crop-production-sector-plan_final_single_page_-308284_sct0219532820-003.pdf#:~:text=6%20Crop%20production%20sector%20plan%201.%20Introduction%20SEPA%E2%80%99s,health%20and%20wellbeing%20benefits%20and%20sustainable%20economic%20growth.) (CPSP). Six key sub-topics were considered: nutrients, water, soil, biodiversity, pesticides, and climate change. The [reporting](https://sefari.scot/document/sepa-crop-sector-plan-think-tank) recognised that stakeholders were acutely aware of the role of soil in delivering multiple benefits to the environmental landscape, but there was a perception of no clear definition of soil health. There was also a lack of a clear understanding of the financial value of soil itself, which would be essential for encouraging changes in land management practices. Proposals included the development of case studies of farmer approaches to managing the landscape and the associated costs. Such case studies would help with understanding: i) why particular practices are adopted; and ii) barriers to uptake. Full cost benefit analysis of differing approaches was also identified as being important. While the SEPA Sector plan moved into hiatus, findings have been taken forward in [Know your Rules](https://www.farmingandwaterscotland.org/know-the-rules/) and [Valuing Your Soils](https://www.farmingandwaterscotland.org/soil-nutrients/valuing-your-soils/), helping producers comply with regulations and to improve efficiency and protect the environment.

**Defining Agri-co product potential from North-ast Scotland**

To support the development of the bio-circular economy, a SEFARI Gateway project was carried out in collaboration with Zero Waste Scotland (ZWS) and Circular Northeast. The aims was to analyse bioarisings (agri-waste, co-product) tonnage and location (at local authority level) and, based on the macro- and micro-composition, identify opportunities for capturing untapped economic value from these feedstocks at the level of North-east Scotland. Based on 2014 data, the [report](https://sefari.scot/document/circular-bioeconomy-opportunities-valorising-agricultural-wastes-and-co-products) (2020-21) identified that Scotland has significant levels of bioarisings from agricultural sources that currently have nil or low value uses. The cumulative total of agricultural-related bioarisings is 16.7Mt which can provide significant opportunities as feedstocks, ingredients and products in global markets looking to deliver both economic returns and achieve Net Zero emissions. Most opportunities identified are replacing fossil fuel-based products. [“The SEFARI project team provided excellent guidance and support throughout the process to all parties involved and were understanding of and adaptable to the changing demands on time and resource throughout the delivery of the fellowship to enable its successful completion and the delivery of a final report and recommendations that provides invaluable insight that will help shape Scotland’s future bioeconomy”, Zero Waste Scotland].

**Working with stakeholders to increase legume production in Scotland**

Grain legume crops such as peas and beans provide environmental benefits and contribute towards a healthy diet but are not widely grown or consumed in Scotland. SEFARI researchers worked with stakeholders in legume supply chains to find innovative ways of increasing legume production. Collaborative on-farm research with farmers and crofters tested legume-cereal intercrops, facilitated by a Soil Association Scotland ‘[field lab’](https://www.soilassociation.org/our-work-in-scotland/scotland-farming-programmes/field-labs/plant-teams/) run jointly between two SEFARI Institutes (2018-2020). The intercrop trials continued amongst a network of farmers across Scotland through the [SEAMS project](https://www.hutton.ac.uk/research/projects/seams-sustainability-education-and-agriculture-using-mixtures) (2020-2023, funded by the Esmée Fairburn Foundation), with multiple value chains identified for the crop products.

To address low dietary uptake of legumes, SEFARI researchers joined with Soil Association Scotland to establish a [Rural Innovation Support Service (RISS) group](https://innovativefarmers.org/welcometoriss/), comprising stakeholders and researchers across legume supply and value chains, on the [potential of pulse supply chains in Scotland](https://innovativefarmers.org/news/2021/march/01/fingers-on-the-pulse-growing-healthy-sustainable-crops-for-scotland/) (2020-2021). The group provided expert input regarding the contribution of legumes to climate mitigation in the Farmer-led [Arable Climate Change Group](https://www.sasa.gov.uk/accg) consultation. Research articles were published on [the significance of the multi-functional provisions of grain legume supported cropped systems](https://doi.org/10.3389/fsufs.2021.692137); the [quantification of the fixed nitrogen contribution to food/feed and soil by faba bean grown in Scotland](https://doi.org/10.1007/s11104-021-05246-8); and [supply chain perspectives on breeding for cereal-legume intercrops](https://doi.org/10.3389/fpls.2022.844635).

**Valorising home-grown protein production using disruptive short-value chains**

In collaboration with Arbikie Distillery and Abertay University, SEFARI researchers, led high impact research and development to realise the world’s first climate positive gin, and only climate positive [vodka](https://www.abertay.ac.uk/news/2020/second-climate-positive-spirit-launched-with-pea-based-vodka/). This success emerged from RESAS-SRP funded research, supported by PhD student, Master Distiller, and Manager of Arbikie Distillery, and the EU funded project TRUE (www.true-project.eu). Collaboration with Bangor University and Trinity College Dublin led to the publication of key data for Life Cycle [Analysis](https://planetscotland.teclan.org/index.php/2020/02/19/watch-arbikie-nadar-team-explain-worlds-first-carbon-neutral-gin/) to support the launch of Arbikie’s ‘Nádar’ products, to international acclaim and numerous awards, most recently for ‘outstanding business engagement’. Due to this approach pulses now occupy 20% of the Arbikie Farm area, and demand for peas from other local growers is anticipated.

The same research team worked with Barney’s Beer Ltd. (Edinburgh), to realise a series of faba bean-based beers which, following positive results of taste tests, culminated in CoolBeans® Faba Bean IPA, a gluten free and vegan-friendly beer which was sold by Lidl. While the faba-bean IPA remains to be up- and out-scaled, the optimised methodology is published. High-protein potale co-products are utilised to feed cattle in a circular economic approach and the potential of pulse-proteins isolate for aquaculture feed and human food was scoped with HorizonProteins Ltd. In partnership with another SEFARI Institute, brewed-bean co-product has also been valorised for broiler feed. Explanatory videos by Taskscape Associates Ltd., RD Content Ltd., and Abertay University highlight the role of pulses in addressing existential challenges.

**Improvements to sustainability and resilience of barley**

SEFARI research continued to benefit commercial barley varietal production by establishing baseline information including the barley Pan-Genome (genome-scale comparison of multiple barley varieties) and development of the 50K genotyping array enabling improved variety genetic fingerprinting. This genotyping platform has been taken up by breeding companies and academia allowing rapid, robust genetic assessments of material, facilitating comparisons and uptake of research. Several of leveraged projects were undertaken including ‘IMPROMALT’ (led by a SEFARI Institute and including all UK commercial breeding programmes, AHDB, MAGB and [SWRI](https://www.swri.co.uk/partners---projects.html)), which is focussed on improving winter barley malting quality to ease harvest pressure and supply sustainability. Interaction with industry has crystallised with the formation of the International Barley Hub that has energised the crosstalk between industrial and academic partners. This is exemplified by the Barley Away Day meeting (8th and 9th Februrary 2020) where future research needs were delineated through discussion, focussing on the need for net zero carbon barley production with reduced inputs in the future, and the sustainability of the supply chain given climate change scenarios. Mapped outputs of spatial modelling of climate change impacts on barley using multiple climate projections (56,256 unique soil-climate combinations) identified hotspots of vulnerability and indicated risks of an overall decline in national yield, primarily due to potential water stress. Results were used by SWRI to raise awareness of potential risks with whisky supply chain stakeholders.

**Food integrity monitoring-appraisal of technological approaches for Scotland Food and Drink (SFD).**

As supply chains increase in complexity it becomes more difficult to assure the provenance, authenticity, and traceability of food products. High profile cases such as the 2013 horsemeat scandal highlight the needs for adequate food safety, quality management and traceability to protect revenue, prevention of damage to brand reputation, and protection of public health and livestock welfare (e.g., food product fraud costs the UK c.£1.17Bn a year). [The project](https://sefari.scot/research/how-can-technology-help-ensure-authenticity-provenance-and-traceability-in-scottish-food) involved a survey of different technologies and, using beef or salmon products as the “case study”, an assessment of cost-benefits with regards to their application in establishing authenticity, provenance, and traceability. The advantages and limitations of each of the shortlisted technologies were identified, and communicated to relevant stakeholders in the food and drink industry. A directory was created of each of the institutions and businesses with relevant expertise in each of the technologies.

Work is being undertaken with SFD on a demonstrator proof-of-concept project that integrates multiple technologies to assure authenticity and traceability across an agri-food supply chain. The aim is to enable agri-food businesses to assess how these tools can be implemented in the Scottish context and will highlight the benefits, challenges, and limitations of these technologies. Although in hiatus due to the pandemic, it is expected that this information will help businesses decide on whether they will want to develop an authenticity, provenance, and traceability scheme.

**Food Swaps for healthier, more sustainable and affordable food choices**

A SEFARI funded collaboration resulted in an innovative tool that offers individual [food swaps](https://sefari.scot/blog/2020/02/04/innovative-new-tool-food-swapping-for-healthier-and-more-sustainable-diets) for healthier, more sustainable and affordable ‘shopping baskets’. The ‘FoodSwap’ tool is underpinned by a newly developed in-house National Diet and Nutrition Survey **(**NDNS) Nutrient Databank which provides information on nutrient composition, greenhouse gas emissions and average costs of c.6,000 foods and drinks regularly consumed in the UK. The next step will be to develop an interface offering a more personalised experience in which the input of information on an individual’s age, gender and known diseases or nutrient deficiencies will inform more effective food swaps. The FoodSwap tool was runner-up at the KTP Food Industry Innovation event (March 2021), presented at the Foods of the Future Colloquium (November 2021), and formed the basis of an EASTBIO PhD studentship which aims to model healthy and sustainable seafood choices. Modelling of data in the NDNS Nutrient Databank has identified new ‘food swap’-based strategies for dietary choices with the highest nutritional quality and lowest environmental impact and cost. The results were communicated to Food Standards Scotland (FSS) and included in academic papers, of which two are now published (‘[Nutritional quality, environmental impact and cost of ultra-processed foods: a UK food-based analysis](https://www.mdpi.com/1660-4601/19/6/3191)’, and ‘[Food-level analysis to identify Genomiadietary choices with the highest nutritional quality and lowest greenhouse gas emissions and price](https://www.frontiersin.org/articles/10.3389/fnut.2022.851826/full)’).

Pump-priming funding from the Aberdeen Grants Academy facilitated the use of the NDNS Nutrient Databank in the development of personalised dietary recommendations for individuals with Type 2 diabetes, in collaboration with a multi-disciplinary team of academics, and diabetologists at NHS Grampian, using artificial intelligence and natural language generation. The intended impact is to develop an e-health app to motivate dietary behaviour change, and to improve the way individual glucose control is managed from a home setting of a Type 2 diabetic. This is particularly timely as NHS strategies increasingly focus on managing health and wellness of patients in the community, assessing how the use of digital tools can reduce spending on, and improve the management of, chronic health conditions.

* 1. **COLLABORATIVE AND MULTIDISCIPLINARY RESEARCH**

**Land use for carbon sequestration**

Interest in carbon markets is increasing rapidly, leading to new market opportunities and interest in acquiring land to invest in natural capital. In response to this, a SEFARI led Specialist Advisory Group (SAG) conducted an evidence review and convened more than 60 experts from policy, investment, third sector, research, land management and rural communities. Based on this review, sixteen options for policy and practice across the UK were identified across five themes identified: land market transparency, regulation, and best practice in land acquisitions; participatory and collaborative approaches to natural capital investment; supporting access to land for nature-based land uses; values-led, high-integrity ecosystem markets; and, rural land use frameworks, redistributing support and incentivising landowners. The Scottish Government noted that prior to this [report](https://sefari.scot/document/large-scale-land-acquisition-for-carbon-opportunities-and-risks-briefing) “discussion of the impact of carbon markets on land markets was … dominated by individual feedback and anecdote rather than quantitative data and trends”.

The [report](https://sefari.scot/document/large-scale-land-acquisition-for-carbon-opportunities-and-risks-report) and [briefing](https://sefari.scot/document/large-scale-land-acquisition-for-carbon-opportunities-and-risks-briefing) echoed a number of recommendations from the Scottish Land Commission, with the “academic rigour and timing of the report” helping to underline the robustness and urgency of these recommendations, which are now part of the proposed Land Reform Bill. [The SG Head of Natural Capital Policy and Valuation stated, “The report and its recommendations have been helpful in informing the SG programme to develop a high-integrity, values-led market for responsible investment in natural capital, including discussions underway on the SG Interim Principles for Responsible Investment in Natural Capital.”]

**UN Climate Change Conference of the Parties (COP26)**

COP26, taking place in the midst of the COVID-19 pandemic, provided a crucial renewed global focus to the intense damage being caused by, and future threats of, the climate and nature crises. There is an urgent need to accelerate climate action at pace and scale. [SEFARI research and knowledge exchange responded with engagement across national and international stakeholder](https://sefari.scot/events/COP26-nov-2021)s before, during and after COP26 to inform research and forge partnerships for delivering climate action. SEFARI organised or contributed to:

1. the Scottish Government’s COP26 programme, running an online debate and follow-up withrepresentatives of [rural and island communities](https://www.youtube.com/watch?v=-yE2TQM705M), rural mental health and wellbeing and business discussing the needs of rural communities for a Just Transition to net zero;
2. the True Animal Protein Price Coalition as part of the EU COP26 Programme, on the dichotomy of local versus global effectiveness of [carbon pricing](https://www.youtube.com/watch?v=Y_irK6gpmtc) in agriculture’s route to net zero;
3. showcasing [SEFARI innovation in environmental, agriculture, land use and food research as part of a UK Department for International Trade presentation on innovation for global climate action](https://www.youtube.com/watch?v=YdHQ4V3qQ5c) at the UK COP26 Presidency Pavilion;
4. [engaging with indigenous communities on climate action](https://www.rbge.org.uk/whats-on/inverleith-house/climate-house-presents/the-encampment-of-eternal-hope/);
5. demonstrating [sustainable innovation](https://twitter.com/scotfoodjames/status/1458487215374446597) for Scotland’s Food and Drink Sector during COP26;
6. the [EU Horizon 2020 SHERPA](https://rural-interfaces.eu/) online Panel Q&A at the COP26 Green Zone on the role of agriculture, rural communities and social innovation for a [Just Transition to climate neutrality](https://rural-interfaces.eu/2021/12/20/sherpa-cop26/);
7. supporting international engagement on peatlandsresearch in the Peatlands Pavilion; and the creation of new online platforms to engage the public with [SEFARI’s climate research](https://sefari.scot/blog/2021/11/12/a-virtual-tour-around-scotland%E2%80%99s-innovative-climate-research).

A series of online [workshops was run with the Centres of Expertise to define strategies and best practice in addressing the climate emergency in Scotland](https://www.youtube.com/watch?v=WcTqsEDjI-k), highlighting [the threat of vector borne diseases](https://www.youtube.com/watch?v=VXDFPgLeQes) for animal, plant and human health in the face of climate change, and to engage [early career researchers and students](https://www.youtube.com/watch?v=lO2IVaJGAxs) on best practice in climate-policy. The presence of the youth voice was a crucial component of SEFARI work for COP26 as evidenced by both [T.B. Macaulay lecture](https://www.tbmacaulaylecture.co.uk/recording) and SEFARI Gateway providing an active platform for youth to speak on climate science (e.g. [on gender in the climate debate](https://sefari.scot/blog/2022/01/14/here-queer-and-looking-to-volunteer)).

**Innovative platforms for engagement on climate change**

Designed by an interdisciplinary cross-SRP team, a [Google Earth](https://bit.ly/OnSEFARITour) virtual [tour](https://earth.google.com/web/@57.61193016,-3.83423195,-0.65340868a,845229.10089019d,30y,0h,0t,0r/data=MikKJwolCiExOWIybGptV3VMNjBqNnJvMlc5Y0dXRTJ2VEVaTTM1X0cgAQ) of climate change related research from across SEFARI was created. It features:

1. the [temperate rainforests](https://www.rbge.org.uk/media-centre/press-releases/current/climate-change-and-the-plight-of-scotland-s-rainforests/) on the Scottish west coast, where these rare ecosystems support unique species, including studies of epiphytic lichens which create microclimates suitable to aid their survival and ensure the rainforests continue to support such distinct life forms;
2. urban [rain gardens](https://www.rbge.org.uk/collections/living-collection/sustainability-at-the-gardens/the-rain-garden/), built to regulate water flow during extreme flooding events;
3. the impact of peatland restoration on greenhouse gas (GHG) emissions at [the Forsinard Flows](https://earth.google.com/web/@58.34985513,-3.905708,172.08343575a,2430.93170355d,35y,5.97417316h,76.10082091t,0r/data=MicKJQojCiExOWIybGptV3VMNjBqNnJvMlc5Y0dXRTJ2VEVaTTM1X0c6AwoBMA?authuser=0), Caithness;
4. how plants such as hemp will sequester carbon helping to [combat climate change](https://sefari.scot/blog/2019/10/14/hemp%E2%80%99s-role-in-diet-biodiversification-and-reducing-greenhouse-gas-emissions);
5. the [Green Cow Facility](https://www.sruc.ac.uk/research/research-facilities/beef-sheep-research-facility/beef-sheep-research-projects/greencow/) in which GHG emissions from livestock are measured in support of reduced emissions;
6. the effect of climate change on the spread of parasites, including helminths (worm-like parasites) and how research is helping to protect farm animals;
7. multi-functional seascapes at Aberdeen Bay, explaining how renewable energy production becomes one element amongst many uses of land and sea.

The work, accessed from the SEFARI [website](https://sefari.scot/blog/2021/11/12/a-virtual-tour-around-scotland%E2%80%99s-innovative-climate-research), was supported by RHET, STEM and SAGT, and used as part of the UN Climate Change Conference [COP26](https://ukcop26.org/) activities. It shone a spotlight on initiatives being taken in Scotland to address climate change, accessible by audiences within and out with COP26. The suite of resources (including videos, images and reports) informed debate amongst a panel of [experts](https://sefari.scot/events/COP26-nov-2021) at COP26, formed content of the joint SEFARI/EU Horizon 2020 SHERPA exhibit in the COP26 Green Zone, was showcased to audiences at the Royal Highland Show 2022, and is regularly used in teaching on MSc Wildlife and Conservation Management, and HNC in Wildlife and Conservation Management courses.

**SEFARI educational resources**

During COVID-19, SEFARI researchers developed a wide range of materials for use as [educational resources](https://sefari.scot/document/online-education-resources-table), and provide access to experts across a range of environmental topics of interest, via [case studies](https://sefari.scot/research/case-studies), [blogs](https://sefari.scot/blog) and a [directory of expertise](https://sefari.scot/directory-of-expertise). The education group at SEFARI Gateway produced an online [table](https://sefari.scot/document/online-education-resources-table) of free-to-access, online educational resources for teachers (and home-schooling parents in the COVID-19 lockdowns). Contents covered topics such as Food and Health; Climate and Biodiversity; Land and Communities; Agriculture and Forestry & Careers. An [education booklet](https://sefari.scot/sites/default/files/documents/Leading%20Ideas%20EDUCATION%202020.pdf) was published with examples of the online resources, and a selection of in-person activities and training programmes. The resources were developed for all levels in education, from primary school (e.g. building a [bug hotel](https://sefari.scot/blog/2020/06/22/educational-activity-become-a-bug-hotel-builder)), farmers and growers (e.g. [Soils of the Crofts](https://sefari.scot/blog/2020/05/11/soils-and-crofting-resources-diversity-is-key-to-life)), secondary school (e.g. a series of posters for Higher geography pupils, water [words](https://sefari.scot/blog/2022/03/11/water-words)) and tertiary education and the general public (e.g. [Soils and Sustainability](https://www.rsgs.org/soil-science-society-sustainability)). Many of the resources were developed in partnership with key stakeholders. For example, a poster on water and agriculture was created with SAOS, CREW and pupils at Dollar Academy.

A hands-on science workshop was run which introduced children to Microbiology, a timely topic with the COVID-19 pandemic. The SEFARI scientist remarked: [“I was truly humbled by taking part in this collaboration. These children have had the hardest of lives imaginable and for one reason or other have missed so much schooling. Most were curious and keen to take part while others were curious but adamant that it looked too scary and left –but they came back now and again, I think to ‘take a wee look’ – then the most amazing thing happened - one girl that was adamant she wasn’t going to take part came back in and put on a lab coat and gloves and sat down with the rest and took part in the whole practical”.] An event was also run for secondary school teachers Continuing Professional Development at [Scottish Schools Education Research Centre](https://www.bing.com/ck/a?!&&p=85e685bb7d2fb2a8JmltdHM9MTY1OTk4ODI1MiZpZ3VpZD1mZDNlYmU5Ni01OWJiLTRhNjctYTIzNy1iMGUxYTZhM2NmNTgmaW5zaWQ9NTQ0MQ&ptn=3&hsh=3&fclid=68a5441d-1753-11ed-bb05-c57b20b048d5&u=a1aHR0cHM6Ly93d3cuc3NlcmMub3JnLnVrL2NvbnRhY3Qv&ntb=1) (SSERC), September 2021, covering educational resources for Food security and Sustainable agriculture. Educational resources were used with public audiences at the Scottish Game Fair (2017, 2018) and the Game and Wildlife Conservation Fair (September 2021) at which the Moredun Mobile laboratory was set up to carry out educational work on ticks and tick-borne diseases, including the Ticking Time Bomb educational project (September 2021). This event focused on updating Scottish landowners and managers on development of a new generation vaccine against Louping Ill Virus in sheep.

**Healthy milk from healthy cows** [Includes pre-2016 funding]

SEFARI researchers from three Institutes worked together to better understand how dairy cow breeding and management strategies can be optimised to improve both the health of the cow and the nutritional quality of the milk for the consumer. This work exploited expertise in immunity, animal breeding and nutrition, and built on a previous BBSRC-funded project awarded to two of the SEFARI partners on dairy cow immunity. Analysis of c.1,000 paired blood and milk samples from UK dairy cows fed on different diets found that levels of micronutrients (minerals and vitamins) in the blood and milk of dairy cows are influenced by both the cow’s diet and her genetics. While diet is known to influence micronutrient levels, this was the first convincing evidence that dairy cow genetics also play a role. Furthermore, cow blood and milk nutrients known to be beneficial to health were positively correlated at the genetic level, meaning that improving levels of one of these nutrients through selective breeding would lead to improvements in other beneficial nutrients. These findings are important as they demonstrate the potential to optimise dairy cow breeding strategies to improve both the health of the cow and the nutritional value of the milk for the human consumer. Such interdisciplinary research was only possible due to the combined expertise available within the participating organisations and the long-term funding of successive RESAS Strategic Research Programmes.

**Transdisciplinary knowledge integration with agent-based modelling**

Agent-Based Modelling (ABM) is computer simulation that explicitly represents individuals and their interaction with each other and/or their environment. It is an [inherently interdisciplinary exercise](https://doi.org/10.1007/s10707-018-00340-z) involving, at a minimum, computer scientists and social scientists (e.g. sociologists, psychologists and especially environmental and social psychologists), and also potentially geographers, economists, statisticians and ecologists. When applied in policy contexts, ABM is transdisciplinary.

Over the course of the SRP, SEFARI scientists have developed [expertise in empirical ABM](https://doi.org/10.1371/journal.pone.0208451), in which models are built integrating diverse data sources, especially from Geographic Information Systems (GIS) and survey data. The expertise developed in Scottish Government funded work has been instrumental in attracting funds from other sources, most notably the European Commission’s Horizon 2020 Programme (e.g. on [energy](https://doi.org/10.1016/j.erss.2021.101966)), and the Research Council of Norway (e.g. on the circular bioeconomy and cultured protein). Internationally, SEFARI researchers have fostered collaborations, especially with [NTNU](https://www.ntnu.edu/employees/christian.klockner) and [Ruralis](https://ruralis.no/en/employees/rob-burton-en/) (Norway), and the Universities of [Groningen](https://www.rug.nl/ucg/about-us/education-teaching-staff/dr.-wander-jager) (Netherlands) and [A Coruña](https://pdi.udc.es/es/File/Pdi/AF2AF) (Spain).

**A sustainable future for Scottish barley**

SEFARI researchers collaborated with stakeholders in the barley industry to highlight opportunities to increase the sustainability of barley production and use based on SRP findings. An event funded by [SEFARI](https://sefari.scot/sefari-gateway) and [SSCR](https://www.sscr.org.uk/) was held in February 2020, inviting stakeholders in the barley industry to learn about and discuss barley research. The aim was to understand the main issues that industry stakeholders face, particularly in terms of priorities for future sustainability of the industry, and to explore how barley research can address these needs.

A [podcast](https://sefari.scot/node/7602) produced for the virtual Hutton Symposium (November 2020) summarised [the main findings of the event](https://sefari.scot/document/sustainable-barley-production-for-future-health-of-people-community-and-environment-summary), covering agronomic, environmental and economic challenges associated with current and future barley breeding, cropping and processing, and examined potential solutions to those challenges. Discussions involving SEFARI researchers, and the Chivas Group resulted in a refinement of the [Centre for Sustainable Cropping](https://csc.hutton.ac.uk/) prototype toolkit developed for farmers. This will form the basis for workshops with Chivas’ Sustainable Barley Growers group for practical integration of agroecological approaches into farm businesses. Projects have been proposed as PhD studentships in the [BARiTONE CTP programme](https://www.barleyhub.org/baritone/) to address knowledge gaps prioritised by stakeholders.

**Improving agroecosystem and crop efficiency for water and nutrient use**

SEFARI researchers were members of a consortium awarded funds from EU Horizon 2020 for the SolACE project (2018-22). [SolACE](https://www.solace-eu.net/) has the aim of helping European agriculture face major challenges, notably increased rainfall variability and reduced use of nitrogen and phosphorus fertilisers for both economic and ecological purposes. SolACE has designed solutions (strategies and tools) that combine novel crop genotypes and agroecosystem management innovations and modelling to improve water and nutrient use efficiency. The project is multidisciplinary with SEFARI researchers contributing to modelling, plant physiology and genomics and potato genetics and has taken account of a range of agricultural contexts across pedo-climatic regions and farming systems of Europe. The project is coordinated by INRAE (France), with [*25 partners*](https://www.solace-eu.net/partners.html) in 14 countries. Part of the SolACE consortium, including SEFARI researchers, formed a new consortium to bid for funds in Horizon Europe which was successful with follow-on funds being awarded for the ‘Roots 2 Resilience’ project which will start in September 2022 and run for 5 years.

**New information on prevalence of tick-borne pathogen**

A multi partner project assessed the risk to animals and the public of tick-borne disease in the Scottish countryside**.** Ticks and tick-borne disease incidence have been increasing in many parts of Europe, including Scotland, over recent decades. Initially started as a cross-SEFARI collaboration, this developed further links and emerged as an international collaboration. Links between the SRP and the EPIC CoE enabled new international collaborations between SEFARI researchers, University of Glasgow, ETH Zurich and RIVM (Netherlands). This interdisciplinary team combines expertise in animal ecology, vector biology, pathogen diagnostics, genetics, and statistics to elucidate new prevalence estimates for a wide range of tick-borne pathogens in Scotland. Of particular note was the first detection of *Spiroplasma ixodetis* in Britain, published in the journal [Parasites & Vectors](https://parasitesandvectors.biomedcentral.com/articles/10.1186/s13071-021-04946-5).

**Impact of the COVID-19 crisis on food and nutrition security**

SEFARI scientists were invited to contribute to a review on the [effect of the COVID-19 crisis on food and nutrition security](https://onlinelibrary.wiley.com/doi/10.1111/nbu.12485), supported by ESRC funding, using the ‘FeedUs’ model of global trade. Findings suggested that COVID-19 was part of a worsening ‘perfect storm’ for UK food and nutrition security. Globally, the impacts of economic pressures arising from COVID-19 have been relatively mild, but in the UK, they have highlighted burgeoning inequalities in access to nutritious food. This review was accompanied by analysis published as [blogs](https://sefari.scot/research/objectives/food-trade-and-consumption) on the London School of Economics Business Review website addressing a number of food policy issues including the effect of COVID-19 on the UK’s food supply chains, and the UK’s fresh produce supply under COVID-19 and a no-deal Brexit. The latter attracted significant attention in print ([Scotsman,](https://www.scotsman.com/news/politics/fears-no-deal-brexit-could-hurt-food-supplies-more-covid-19-crisis-2892070) [Daily Mail](https://www.dailymail.co.uk/wires/pa/article-8447119/Food-supplies-hit-no-deal-Brexit-Covid-19-experts-claim.html)) and in online media ([Yahoo news](https://uk.news.yahoo.com/food-supplies-could-hit-more-115850716.html?guce_referrer=aHR0cDovL21lZGlhcGxhdGZvcm1wbHVzLnByZWNpc2UuY28udWsvcmV2aWV3LmFzcHg&guce_referrer_sig=AQAAAFTm0z3vENe3orZyjy0dg1GCFWLbDwDD3rR1XP8y3LuoP6W68yVNuq1ekdfogkY_d4lMzgPrBobcLRRXzU9O3W7JM4juk8HbCcAkil6bwGh5Z6X8jBA6Lc3CUUm6TgLoqUwxxDZ-367KSzh4atF5Va488RWXsScrrsDs-1ld0AM1&guccounter=2), [AOL](https://www.aol.co.uk/news/2020/06/22/food-supplies-could-be-hit-more-by-no-deal-brexit-than-covid-19/?guce_referrer=aHR0cDovL21lZGlhcGxhdGZvcm1wbHVzLnByZWNpc2UuY28udWsvcmV2aWV3LmFzcHg&guce_referrer_sig=AQAAANIdKnCvlgJ00jM6RcZvAS6x7_NxfH2zhtpvOQS3HgPHqYrYaajYozum4wAiVsmqscWkZoHL2RU8xAiDLZvD9FviK2iZ2AZpTvR2kPR7KjscMng367hZC1b2WYEGgkiVZVzM3pevL0HSyQ-Y9d9C6R1rvTBGhEGPSP77GnbFpYtc)).

**Long-term impacts of flooding**

Many areas of Scotland suffered extreme flooding during the winter of 2015/16 leading to severe impacts on the people living in affected areas. SEFARI researchers from CREW and the Strategic Research Programme investigated the effects of weather events of this nature on individuals and communities using a longitudinal qualitative design. The [final report](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.crew.ac.uk%2Fsites%2Fwww.crew.ac.uk%2Ffiles%2Fsites%2Fdefault%2Ffiles%2Fpublication%2FCRW2016_02_Summary_Report_1.pdf&data=05%7C01%7Ck.crosley%40abdn.ac.uk%7C5ee44c4a8a6c4b2c485d08da6636c502%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637934682656683814%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=pwfbnPupgrrFyrIK4L2wDMVkrW4g159nVnIRNoibUxE%3D&reserved=0), published in 2020, included guidance on how households can prepare for future flood events, and suggestions on how statutory agencies and other organisations can help increase the resilience of communities and individuals. The research was presented at two SNIFFER conferences, a Scottish Government conference on resilience, and received media coverage (e.g. [The Guardian](https://www.theguardian.com/environment/2020/feb/11/scottish-study-reveals-significant-long-term-impact-of-flooding)). Amongst its impacts, the work featured in [Scottish Government policy documents](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.gov.scot%2Fpublications%2Fguidance-support-sepa-responsible-authorities%2F&data=05%7C01%7Ck.crosley%40abdn.ac.uk%7C5ee44c4a8a6c4b2c485d08da6636c502%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637934682656683814%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=uboplk88E%2BxGfLtl5y5GoOb1Jmy3NOKJhRMsRDnzt6o%3D&reserved=0) and led to an additional £90k of support for the Scottish Flood Forum from the Scottish Government to improve and lengthen the duration of support to flooded communities.

**Transdisciplinary collaboration through Horizon 2020 projects**

Responding to EU Horizon 2020 calls can lead to new transdisciplinary teams forming which add value to the SRP through leveraging funding for SEFARI, research papers, and sharing skills and knowledge. The [Horizon 2020 Aquaspace](http://www.aquaspace-h2020.eu/) project (Ecosystem Approach to making Space for Aquaculture; 2015-18) addressed challenges of marine spatial planning in relation to environmental effects of aquaculture (Total value €3M Euros; €906K for Scottish partners in research, government, and industry; €120K to SEFARI). Coordinated by Scottish Association for Marine Science, partners were from government Directorates (e.g. Marine Scotland), arms-length government bodies (e.g. ABFI, Northern Ireland; National Oceanic and Atmospheric Administration, USA), international agencies (e.g. FAO), industry and research in Australia, Canada, China and across Europe, including SEFARI.

SEFARI deployed [virtual reality tools](https://www.hutton.ac.uk/learning/exhibits/vlt) from the SRP and expertise on spatial modelling of environmental impacts across the land/sea interface, and with partners (Marine Scotland, SAMS) developed materials for MSc courses in [visualisation and spatial modelling](https://mobile.twitter.com/Hutton_VR/status/1011350077712076802?cxt=HHwWhMC82bHihIkcAAAA), and interactive tools in theatre and headset modes for exploring multi-functional seascapes, including [within fish cages](https://mobile.twitter.com/Hutton_VR/status/1011350077712076802/photo/2). The transdisciplinary approach was reflected in scientific papers in which SEFARI, Marine Scotland and industry are co-authors (e.g. [The Science of the Total Environment](file:///C:\Users\ld40087\AppData\Local\Microsoft\Windows\INetCache\Content.Outlook\DUA49Q1L\10.1016\j.scitotenv.2018.01.133)), and SEFARI and Marine Scotland leading project engagement with EC delegates at [Scotland Europa offices](https://mobile.twitter.com/AquaSpaceH2020/status/960871862543806465/photo/1), Brussels, and invited by the EU to present [an exhibit](https://mobile.twitter.com/AquaSpaceH2020/status/1007566066539778048/photo/1) and demonstration at its [High Level Food 2030 Conference](https://research-and-innovation.ec.europa.eu/events/upcoming-events/2nd-high-level-food-2030-conference-2018-06-14_en), Bulgaria (2018). Follow-on engagement includes exploring bids for Horizon Europe funding.

**1.4. SCIENTIFIC EXCELLENCE**

**Conserving Genetic Biodiversity: a world first for Scotland**

A SEFARI Gateway and NatureScot funded Think Tank filled a significant gap in addressing the International Convention on Biodiversity Aichi13 target, establishing a world-first method to help understand and conserve genetic diversity, drawing on cross thematic and cross-SEFARI biodiversity and ecological expertise. Membership of the Think Tank comprised NatureScot, the University of Edinburgh, and 17 collaborators from across SEFARI, UK Universities and institutions. Outputs from the [Think Tank](https://sefari.scot/research/developing-agenetic-scorecard-a-world-first-for-scotland) provided crucial insight to conservation in some of Scotland’s most iconic wild species and contributed to the establishment of the first UK Genetic Conservation Unit at Beinn Eighe, in [Wester Ross](https://www.bbc.co.uk/news/uk-scotland-47633399). The project produced proposals that have contributed to biodiversity strategy development nationally and internationally through interaction with Scottish Working Group on [Aichi Target 13](https://www.pure.ed.ac.uk/ws/portalfiles/portal/164603150/Scotland_s_Biodiversity_Progress_to_2020_Aichi_Targets_Aichi_Biodiversity_Target13_supplementary_report.pdf) and the IUCN Conservation Genetics Specialist group to the Convention on Biological Diversity (CBD), and receiving support from UK Cabinet Office with respect to international adoption. Extension of the project is being tested in collaborative work between University of Edinburgh and German academics, and the Western Ross genetic conservation site links into a dynamic network of [conservation units](http://www.euforgen.org/forest-genetic-resources/conservation/) across Europe. The project’s ground-breaking method, recognised by the UK Government for its international importance, received the prestigious RSPB Nature of Scotland Innovation Award, 2020.

**A Nature based Solutions (NbS) framework**

Nature-based Solutions (NbS) has been defined many times, which can be summarised as “solutions to societal challenges that are inspired and supported by nature” (such as the restoration of peat bogs). However, not all NbS are equal: the term can be applied to different interventions in very different settings, tackling varied problems. There was a need to evaluate and understand NbS, to help understand the potential of alternative approaches, and how best to allocate resources amongst a choice of different NbS. A SEFARI project, co-developed with NatureScot, identified a [framework](https://sefari.scot/document/evaluating-nature-based-solutions-a-synthesis) suitable for use in Scotland’s terrestrial landscapes from the range of (different) frameworks already developed. Each framework had its own strengths and weaknesses. The recommendations focussed on using the IUCN Global Standard. This is a comprehensive method supported by a significant international institution and is likely to be employed widely. However, it was noted that other frameworks performed better in some areas, so the project proposed that guidance be developed for the use of the IUCN standard which enables users to reinforce its approach with the strengths of other frameworks. The project produced a [simple infographic](https://sefari.scot/research/nature-based-solutions-%e2%80%93-how-should-we-plan-and-evaluate-them) for land users on applying such a process which is being taken forward by NatureScot.

**Socioeconomic and biodiversity impacts of driven grouse moors**

[Scotland's Land Use Strategy](https://www.gov.scot/publications/getting-best-land-land-use-strategy-scotland-2016-2021/) promotes an integrated approach to land management, with woodland regeneration, biodiversity conservation, carbon sequestration and recreation encouraged in moorland areas alongside traditional sporting activities. However, this can increase pressure on land managers to deliver multiple benefits from moorlands, including public benefits. Questions have been raised about the positive and negative impacts of grouse shooting on biodiversity and other public benefits. While grouse moor managers and collaborators are taking active steps to reverse the decline of wading birds in Scotland, concerns focus on the unregulated killing of mountain hares on grouse moors, muirburn and the persecution of raptors. Raptor persecution has generated emotive reactions from the public, conservation organisations and campaigners, and increased pressure on politicians to address the issue.

SEFARI researchers built on the existing [research](https://sefari.scot/research/socioeconomic-and-biodiversity-impacts-of-driven-grouse-moors-in-scotland) knowledge base regarding grouse moors, aiming to better understand employment rights, attitudes, motivations and behaviours of gamekeepers. The research focused on providing new evidence on the key objectives relating to grouse moor management of:

1. the extent and impact of economic connections between grouse shooting estates and surrounding businesses and communities;
2. the socio-economic impacts of alternative land uses for moorland and how they compare against land used for grouse shooting;
3. the employment rights and benefits available to the gamekeepers involved in grouse shooting, working conditions, attitudes, behaviours and aspirations for the future.

The results from a survey of gamekeepers provides unique insights into wage rates, tied housing and terms of employment, as well as sentiments and experiences from being a gamekeeper in Scotland. It has led to the creation of a profile of the sector (e.g., what they would like to change about their job) which is often related to public and political perceptions of land and game management. Updates were made to the estimated extent of muirburn in Scotland and its change over time, and of grouse butt density (butts per m2) through a nuanced demarcation of the area of moorland associated with grouse shooting. Outputs from the mapping exercise (e.g., strip burning intensity) were overlaid with species data, enabling researchers to assess the effect of grouse moor management intensity on the distribution of selected upland species where the association between species distribution and grouse moor management is less well understood or unknown.

The research demonstrated a new approach to assessing impacts (both positive and negative) of driven grouse moor management at different intensities on biodiversity. A report on [Driven grouse moors - socioeconomic and biodiversity impacts](https://www.gov.scot/ISBN/978-1-80004-212-4) provided key information derived from thematic reports. The work was very influential in determining the outcome of the [Werritty review](https://www.gov.scot/publications/grouse-moor-management-group-report-scottish-government/) and the findings have influenced the[Scottish Government's response to grouse moor management](https://www.gov.scot/news/werritty-report-response/). NatureScot are currently using this information to help design means of licensing grouse moors.

**Sequencing of BVDV strains in support of Scottish BVD eradication**

Bovine viral diarrhoea (BVD) is an endemic disease of cattle that impacts fertility, production, and animal [welfare](https://sefari.scot/document/bvdv-eradication-in-scotland). The BVD virus (BVDV) is highly variable, with two biotypes and multiple sub-types. Approximately eight subtypes of BVDV1 have been identified in the UK, while BVDV2, which can cause more acute disease, is found in the USA and Europe. Work in the SRP has used diagnostic samples (serum, ear-tags, milk) to generate sequence data from specific regions (UTR, Npro) of BVDV and identifying the BVDV subtype by sequence comparison. Methods developed in the Strategic Research Programmes prior to 2016 were used within the EPIC CoE to identify virus subtypes in BVD-positive serum samples. Over 4,500 BVDV UTR sequences are currently in public databases, supporting BVDV strain identification and [infection tracing](https://bvajournals.onlinelibrary.wiley.com/doi/full/10.1136/vr.104072).

More recent work focused on sequencing other virus regions (e.g., Npro), analysing difficult sample types (ear-tags, milk), and developing methods to sequence complete BVDV genomes. Sequencing of UTR and Npro was possible from all sample types and sufficient for phylogenetic analysis and tracking infections, while whole genome sequences were obtained using PCR approaches adapted for each virus strain. Sequences of seven complete and 12 partial BVDV genomes included the most frequent Scottish strains BVDV1a, 1b and 1i, plus three archived strains after culture. Data were published showing that [virus culture introduced changes](https://www.microbiologyresearch.org/content/journal/mgen/10.1099/mgen.0.000343) in the virus sequence, illustrating that non-cultured diagnostic samples should be used whenever possible.

**Advancing knowledge on gut microbiome links to health**

Core expertise in anaerobic microbiology has driven many key advances over the funding period, outputs from which feature in prestigious journals such as [*Nature Biotechnology*](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.nature.com%2Farticles%2Fnbt.3935&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532096885%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=djWpMh31NggLZrkCMnPeINgoTgGtS4kh8xvUWOndihU%3D&reserved=0)*,* [*Nature Medicine*](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.nature.com%2Farticles%2Fs41591-020-1095-x&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532096885%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=UoPxUrSKlIKQ82fvSZHQShhIm%2FyXq2oiPPHbXY5LS5c%3D&reserved=0)*,* [*Nature Communications*](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.nature.com%2Farticles%2Fs41467-018-03317-6&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532096885%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=Wblf2hLEPh2rq%2F0m%2Fgrc67yeePhG1MDWkVrfZltLiPI%3D&reserved=0)*,* [*FEMS Microbiology Reviews*](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Facademic.oup.com%2Ffemsre%2Farticle%2F45%2F3%2Ffuaa060%2F6000215&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532096885%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=YqgzizIscjRK5K8l20oP7cdO8Q%2FXMYm7wWOps%2FN9Q90%3D&reserved=0) and [*Genome Biology*](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fgenomebiology.biomedcentral.com%2Farticles%2F10.1186%2Fs13059-020-02042-y&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532096885%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=Ho8CTbQeeswrePg4xt3zMCXmtOD4Bv%2FUenAPgEBLzeI%3D&reserved=0)*,* with four SEFARI researchers repeatedly included in the [Clarivate Highly Cited Researcher List since 2018](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Frecognition.webofscience.com%2Fawards%2Fhighly-cited%2F2021%2F&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532096885%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=jAgz5%2FMTmfss3k5ope6ddYUEIHZftc1Ctx5ghjEuQiY%3D&reserved=0). The research in the SRP included work in which novel gut bacteria were isolated from human stool and from ruminants generating a collection of over 1,500 gut bacterial strains. This invaluable and rare scientific resource will be made publicly available to other scientists via FigShare. An [extended mathematical model](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fgithub.com%2FHelenKettle%2FmicroPopGut%2Fblob%2Fmain%2FmicroPopGut_1.0.tar.gz&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532096885%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=QMRvxFzG5a04xsPqoY0GI2MWnkt1COeLN2qVSR1WKWc%3D&reserved=0) of microbiota metabolism has been made available to the research community. The work has greatly increased understanding of the impact of dietary interventions on the gut microbiome by identifying gut bacteria that grow on different fibres, including resistant [starch](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fsfamjournals.onlinelibrary.wiley.com%2Fdoi%2F10.1111%2F1462-2920.14000&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532096885%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=Esz%2FwHH9JLvrxYEY248E9J5L7eJqAP3e9iXRFnQHALM%3D&reserved=0), [pectin and inulin](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Facademic.oup.com%2Ffemsec%2Farticle%2F95%2F1%2Ffiy201%2F5124376&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532096885%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=19MQAdmsX3wYZCJmQL1th2BPX2MzaRTG7210Ee4d1z4%3D&reserved=0), [oligosaccharides](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fgenomebiology.biomedcentral.com%2Farticles%2F10.1186%2Fs13059-020-02042-y&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532096885%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=Ho8CTbQeeswrePg4xt3zMCXmtOD4Bv%2FUenAPgEBLzeI%3D&reserved=0), [beta-glucan](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fsfamjournals.onlinelibrary.wiley.com%2Fdoi%2F10.1111%2F1462-2920.14977&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532096885%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=B0xp1adpeV1O5zdMo42XR%2F9Ksecg5SNI3freEof3zxI%3D&reserved=0) and [mannans](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fjournals.asm.org%2Fdoi%2F10.1128%2FmBio.03628-20&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532253134%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=dLdzUe2ARE%2B2mkpyFy8Ta8%2BNrf3%2FudeH5qfKLX9buTw%3D&reserved=0). It has shown the impacts of dietary interventions in [elderly cohorts](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fdoi.org%2F10.1186%2Fs12866-020-01968-4&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532253134%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=4BNfIeGEzD%2FA%2BweTUoIpOR5vgIrA89D%2B%2F5vTeAJc020%3D&reserved=0) and in [children with inflammatory bowel disease](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fdoi.org%2F10.1038%2Fs41598-020-75306-z&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532253134%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=QkCFZihtcm2Nb4fUrE3CyqjKZoim82QjhwMJ8ixjl5Y%3D&reserved=0), revealing the importance of baseline gut microbiome composition in determining how an individual will respond to a given dietary intervention, which is likely to be a key aspect of the emerging field of personalised nutrition.

Further studies characterised gut bacteria with important functions, including [lactate-utilising](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fjournals.asm.org%2Fdoi%2F10.1128%2FmSystems.00645-20&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532253134%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=CPpIWUu6b2L5RweGsCIp4j%2FTPQdzEHtZvktyTL1U5%2Fg%3D&reserved=0) [bacteria](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.microbiologyresearch.org%2Fcontent%2Fjournal%2Fmgen%2F10.1099%2Fmgen.0.000739&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532253134%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=Jn3O649kosg7MxmnhhiI7S2tz25vdVM5gWvG5%2FZ8nVE%3D&reserved=0) as promising next-generation probiotics, and [gut bacteria with inhibitory activity against a range of pathogens](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.biorxiv.org%2Fcontent%2F10.1101%2F2021.12.21.473717v1&data=05%7C01%7Cc.bestwick%40abdn.ac.uk%7C25c0d8136ddd4c2301ff08da696ac54d%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637938204532253134%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=0gQGO3sFuLfXEzGJn76HEHzaMw%2FFhfo1q%2Feh%2B8M44IY%3D&reserved=0). These novel microbiome-focussed approaches to disease mitigation will form the basis of continuing work in the SRP 2022-27, in which the aim is to identify similar beneficial bacteria from the intestines of ruminants and poultry. SEFARI researchers have been recognised for their contribution to this field by having three gut bacteria named after them: *Faecalibacterium duncaniae, Duncaniella (sp) and Petralouisia* (sp).

**Consumer views on food attributes and labels**

Considerable research work has been conducted to investigate consumers' attitudes, preferences, and willingness to pay (WTP) for animal welfare-friendly food products using both hypothetical and non-hypothetical surveys. Most studies agree there is a potential market for animal welfare-friendly food products among consumers who are concerned about farm animal welfare and are willing to pay higher prices to compensate farmers who opt to use more animal welfare-friendly farming practices. However, these encouraging signals on consumers' high interest in animal welfare may not fully translate into actual purchases of animal-friendly products, partly due to the trade-offs consumers make when choosing between food products with different desirable attributes (e.g., animal welfare-friendly meat versus local or organic meat). While extensive research has been devoted to assessing consumers' preferences and WTP for animal welfare-friendly meat, little research has assessed how consumers weigh-up and trade-off high animal welfare against other desirable food attributes of meat such as organic, local, low-fat, carbon footprint, and fair-trade. Work in this topic has been reported in outputs such as the book chapter on ‘Consumer Demand for Animal Welfare Products’ published in ‘[The Economics of Farm Animal Welfare: Theory, Evidence and Policy](https://doi.org/10.1079/9781786392312.0000)’, and ‘[How consumers in the UK and Spain value the coexistence of the claims low fat, local, organic, and low greenhouse gas emissions’ capacity](https://www.mdpi.com/2072-6643/12/1/120/htm) (in [*Nutrients*](https://www.mdpi.com/2072-6643/12/1/120/htm)).

**Agent-based modelling of international trade in nutrients**

Agent-Based Modelling is a computer simulation of individual actors and their interactions with each other and the environment. In collaboration with a Belmont Forum project on ‘Delivering Food Security from Limited Land’, within the SRP an ABM model was designed and implemented in which each agent represents a country. The model, known as ‘FeedUs’, uses United Nations (UN) [Food and Agriculture Organization](https://www.fao.org/home/en/) (FAO) data called ‘[Food Balance Sheets](https://www.fao.org/faostat/en/#data/FBSH)’ (FBS) to simulate international trade in all 91 commodities in the FBS. This constitutes a considerable advance on the state-of-the-art, which tends to concentrate on a small sample of commodities and/or fewer countries, typically for the sake of analytical tractability. Simulating all the commodities, together with data on how they are typically used in each country, enabled an assessment of the trade in terms of nutrients, both macronutrients (fat, protein, and carbohydrate) and micronutrients (vitamins and minerals). Then, under- and over-nutrition has been studied under various scenarios, including change in trade, climate change, sustainable intensification, waste reduction and dietary change.

The [model software](https://www.comses.net/codebases/8a004bf7-5468-402e-8796-e5f4f0aa6ecd/releases/1.2.0/) is publicly available, and an article published in [Royal Society Open Science](https://royalsocietypublishing.org/doi/10.1098/rsos.201587) showing that removing obstacles to trade increases food and nutrient security. SEFARI researchers also collaborated on an article in [Global Environmental Change](https://doi.org/10.1016/j.gloenvcha.2020.102085) on general considerations for modelling food security. FeedUs was adapted for use in an Economic and Social Research Council [Rapid Response](https://www.ukri.org/wp-content/uploads/2022/06/ESRC-21062022-Social_science_COVID_activity_20220609.pdf) grant to simulate [scenarios](https://doi.org/10.1111/nbu.12485) for the [impact of COVID-19 on global food trade](https://doi.org/10.5281/zenodo.6338066).

**Agro-ecology fellowship with Food Farming and Countryside Commission**

A project, jointly funded by SEFARI Gateway and the [Food Farming and Countryside Commission](https://ffcc.co.uk/home) (FFCC), and working with the [Soil Association Scotland](https://www.soilassociation.org/our-work-in-scotland/) (SAS) and the [Scottish Agricultural Organisation Society](https://saos.coop/) Ltd (SAOS), examined the current use of agroecological farming practices and motivations amongst land managers in Scotland for using [agroecological approaches](https://sefari.scot/document/the-adoption-of-agroecological-principles-in-scottish-farming-and-their-contribution). It found that 60% of Scottish farmers already use an agroecological approach, new farming entrants are more likely to adopt agroecological farming. and new knowledge acquisition differs between genders. A full report on these [findings](https://ffcc.co.uk/scotland) was disseminated to stakeholders in policy and agriculture, and to the public through exhibits and presentations at events jointly run with project partners in the MSP lobby at Holyrood (30th May to 1st June 2022), a policy event at the Scottish Parliament (1st June 2022), and at the Royal Highland Show (RHS; 24th June 2022). An electronic poster was also displayed at the RHS 2022 and is available together with an interactive online digital [resource](https://agroecology.sefari.scot/) summarising the main findings. [“Partnering with the James Hutton Institute, the SAOS, and the SAS on a SEFARI Fellowship programme has been a real privilege for us at the FFCC. Through this partnership, we have been able to contribute to the design of, and are now benefiting from, a national research study that strengthens the evidence base for agroecology in Scotland”, FFCC].

**1.5. SCIENTIFIC RESILIENCE**

**Funding for applied catchment management concepts**

Two awards, benefitting from cross-Portfolio knowledge, were secured from the Irish EPA Research funding. The first, Smarter Buffer Zones (2018-22; total value £166K), in collaboration between a SEFARI institute and Teagasc (Ireland), examines the scientific underpinning knowledge, designs and correct placement of a riparian (river corridor) management known as ‘[buffer zones'](https://www.teagasc.ie/environment/water-quality/research/smarterbufferz/). Whilst considerable research has been undertaken on nutrient, and some wider ecosystem services, outcomes from such management, the range of designs being considered, and the tools to optimise their placement in strategic catchment locations is not sufficiently developed. Mechanistic research supported by the SRP provides a basis to move away from linear grass strips towards a greater range of designs. This applied research enables the exploration of practicalities and spatial data tools within Ireland working with Teagasc and Irish Agencies and extension services. Reciprocally, landscape typing concepts and a database of 16 measures produced for the Irish EPA have informed a Scottish CREW project on [buffers](https://www.crew.ac.uk/publication/better-buffer-design-placement-and-management).

The second award, a Strategic LOok at natural WAter reTention mEasuReS ([SLOWATERS](https://nwrmireland.wordpress.com/slowaters/)) (2019-23; value €50K) is assessing the benefits of Natural Water Retention Measures (NWRM) for agricultural catchments in Ireland. It is a four-year collaborative project funded by the Irish EPA and the Irish Office of Public Works (OPW), with partners from SEFARI, Trinity College Dublin, University College Cork, and Newcastle University. Project outputs will include recommendations for the management of specific catchment types relevant to the Irish environment by quantifying the magnitude of NWRM required to reduce flood peaks. The project draws on knowledge from the SRP on designing and understanding Natural Flood Management measures (another term for NWRM). For example, the project utilises the Flooding Measures Automatic Placement Tool (F-MAPT) which was developed in the SRP and is accessing knowledge from the [Natural Flood Management network Scotland](https://www.nfm.scot/), with considerable crossover of the measures and interventions being studied and their benefits for Natural Flood Management.

**Tackling antimicrobial resistance (AMR) in the environment**

Antimicrobial resistance (AMR) is a [major public health priority](https://www.gov.scot/publications/antimicrobial-resistance-information/). As it sits within the One Health context, SEFARI researchers have been ideally placed to address the issues at the interface between agriculture/livestock farming and public health, leveraging further funding from national programmes. Quantification of spatial AMR patterns across urban and rural landscapes on a national-scale was investigated (2016-18, [NERC](http://gotw.nerc.ac.uk/list_full.asp?pcode=ne/n020626/1&cookieConsent=A) total value £104K, SEFARI value £55K) and additional funding obtained to determine the emergence of hot-spots of enzymes called Extended-Spectrum Beta-Lactamases (ESBL) and carbapenemase genes in Scottish soils using historical samples (NERC, £25K). Sensors for AMR and pollutants were developed ‘Antimicrobial resistance and pollutants: interactive studies and novel sensor technologies’ (2018-21, NERC, total value £450K, SEFARI value £150K) which leveraged further funding to investigate distinct pathways for AMR proliferation (British Council, total value £10K, SEFARI value £5K) facilitating [knowledge exchange](https://www.glamsham.com/world/technology/novel-paper-based-sensor-to-detect-antimicrobial-pollutants/amp) with Indian partners. AMR was characterised in the River Dee (COVID-19: Has mass societal behaviour change left any underlying effects for the River Dee?, [Macaulay Development T](https://www.macaulaydevelopmenttrust.org/funding)rust, SEFARI value £25K, 2021) and ‘[the effect of drinking water treatment on antimicrobial resistance](https://www.ed.ac.uk/edinburgh-infectious-diseases/news/news/edinburgh-researchers-funding-success-with-sulsa)**’** was investigated (SULSA, total value £8K, SEFARI value £2K). The creation of a [register](https://www.crew.ac.uk/sites/www.crew.ac.uk/files/publication/CD2020_05_SOHAR-FINAL.pdf) of research literature, projects and collaborations in Scotland (SOHAR, [CREW](https://www.crew.ac.uk/publication/scottish-one-health-amr-register-sohar), £30K) mapped AMR work and additional funding (SEFARI Gateway, £17K, 5 months) scoped how the register could be converted to an online resource. The expertise gained allowed provision of policy recommendations ‘[Antimicrobial Resistance in Scotland’s Waters - Status and Solutions](https://www.crew.ac.uk/publication/antimicrobial-resistance-scotland%E2%80%99s-waters-status-and-solutions)**’** (CREW, total value £14K, SEFARI value £7.5K, 2022).

**Comparing mountain value chains and aquatic Nature based Solutions**

EU Horizon 2020 funding worth £5.2M (2020-24; SEFARI value £350K) ([MOVING](https://www.moving-h2020.eu/)) and £17.8M (2021-25; SEFARI value £681k) ([MERLIN](https://project-merlin.eu/)) has been leveraged by SEFARI SRP underpinning, enabling ongoing comparative research. H2020 [MOVING](https://www.moving-h2020.eu/) (MOuntain Valorisation through INterconnectedness and Green growth) involves 23 cases and 30 partners. It assesses how economic, social, and environmental value is added to mountain assets as products are produced, processed, distributed, and finally consumed. A community of practice linking all actors involved in this chain is helping deliver the analysis to see how best these value chains can contribute to sustainable mountain development, given that mountains are often fragile but precious ecosystems and the source of freshwater, clean air and wild places on which society depends for health and wellbeing.

**Natural alternatives to using antibiotics to treat diseases in animals**

The EU H2020 NeoGiANT project (2021-25; total value £8M; SEFARI value £1.125M) offers new solutions based on the known potential of natural antimicrobial and antioxidant activities of grape marc extracts. This is due to their arsenal of phytochemicals, in particular phenolic compounds, that produce enhanced feed, treatment products and natural sperm preservatives for livestock and aquaculture. The new antimicrobial products to be developed will focus on the control and prevention of the most relevant diseases in animal production feedstock and aquaculture. Using these alternative products will help to direct the use of antibiotics solely for treating acute infections, thus reducing their current prophylactic use. NeoGiANT products are based on 3 pillars:

i) the use of local biomass sources;

ii) cost-effective, efficient, sustainable production;

iii) functional ingredients obtained in sustainable circular economy production systems.

Focusing on cattle, NeoGiANT will produce enhanced intramammary injectables to treat mastitis. The functional antimicrobial ingredient will be from natural origin, without the need for synthetic chemical compounds. As a result, farmers may be able to exploit their use as a sustainable alternative to traditional antibiotics, thus increasing their “green” credentials. [NeoGiANT](https://www.neogiant.eu/) comprises 8 industrial partners, 10 research Institutions and universities and 2 non-profit organisations across 8 European Countries.

**Characterising *Toxoplasma gondii* virulence: role of host and pathogen**

*Toxoplasma gondii* is a parasite of both veterinary and public health importance, being a major cause of abortion in sheep as well as an important foodborne pathogen. The high pathogenicity of some strains of the parasite has sparked research interest on the virulence of *T. gondii* in a bid to further our understanding of the host-parasite relationship as well as predict disease outcome. SEFARI researchers , together with the University of São Paulo and Newcastle University, were awarded £0.57M from the BBSRC-FAPESP Joint Funding of Research (2020-22). The main aims of the project are to assess the role of meat borne transmission of *T. gondii* in São Paulo; to investigate the effect of host background (mouse, human, sheep) in determining virulence of *T. gondii*; and to develop a host-specific *in vitro* system to characterise virulence and offer a platform to aid vaccine design and drug development.

Results and information arising from the project, along with current methods to help prevent and control *T. gondii* infection causing abortion in sheep, have been discussed at roadshow events with farmers and vets, with a particular emphasis on discussing the impact of variation in virulence of different strains of the parasite. A short animated film, “[Tackling Toxoplasmosis](https://moredun.org.uk/resources/videos/tackling_toxoplasmosis)”, has been produced, available in English and Portuguese, which can be used in Europe and Brazil to raise awareness of *T. gondii*.

**Vertical farming and controlled environment agriculture**

Building on SRP research into vertical farming, four major applications for competitive research funding were successful:

1. Exploration of the development of Controlled Environment Agriculture (CEA), its optimisation for a range of fresh produce, and the transfer of this technology to international partners (e.g., Singapore) for adoption and adaptation to local produce. The project ‘Hybrid Advanced Research Vertical-Farming Environment Systems and Technology (HARVEST)’ was funded by Innovate UK/Eureka, runs from 2021-23, involving a SEFARI partner with Liberty Produce, Republic Polytechnic (Singapore) and LivFresh Ltd (Singapore); total value €606K.
2. The development of real-time sensors for monitoring, guiding, and optimising fresh produce production in vertical farming, through sensor-derived algorithms that will facilitate continuous produce optimisation, increased productivity, and reducing the carbon footprint. The project, ‘System Sensing in Vertical Farming and Controlled Environment Agriculture (Sys-Sens)’, funded by InnovateUK, runs from 2021-23, involving a SEFARI partner with Gardin Ltd. and Intelligent Growth Solutions Ltd; total value £0.49M.
3. Applying cold plasma technologies for seed cleaning as part of vertical farming to eliminate disease and reduce fresh produce waste and exploring diverse germplasm for optimised CEA production to both expand the range of fresh produce and to enhance nutritive value and organoleptic characteristics. The project, ‘CEA Heirloom Optimisation & Pathogen Control for Seeds (CHOPS)’, funded by InnovateUKinvolves a SEFARI partner Vertical Future Ltd. and the National Inst of Agricultural Botany, Zayndu Ltd.; total value £0.82M
4. Developing the concept of nanobubbles as part of a CEA system and identifying positive impacts from growing in varied CEA systems and demonstrating that the application of nanobubble nutrient treatment technology gave uplifts in terms of productivity, biomass, and nutritional enhancement. The project, ‘Hydrobubbles to Boost Plant Growth Through Captured Carbon Utilisation’ runs from 2020-22, funded by InnovateUK, involves a SEFRAI partner and Liberty Produce Ltd.; total value . £0.25M.

**Microbiome expertise as a platform for additional funding**

The international standing of SEFARI researchers in gut microbiome research has led to the leveraging of over £2M of funding, including as part of large, prestigious, multi-national consortia. For example, studies of microbiota species with antimicrobial activity against human pathogens led to participation in the €3.5M Innovative Training Network “[FunHoMic](https://www.funhomic.eu/en)” funded by the [European Commission](https://cordis.europa.eu/project/id/812969) from 2019 to 2023. This project aims to better characterise interconnections between the gut microbiota, host biology, and the fungal pathogen *Candida albicans*. SEFARI researchers are leading the Microbiome Workstream component of the international [Action Against Stunting Hub](https://actionagainststunting.org/), an £18.3M project (2019-24) funded by the [UKRI Global Challenges Research Fund](https://gtr.ukri.org/projects?ref=MR%2FS01313X%2F1), which aims to reduce the global burden of childhood stunting in low to middle income countries. Funding has also been leveraged from:

1. Innovate UK (£194K) for a [Knowledge Transfer Partnership](https://www.ktpscotland.org.uk/ViewArticle/tabid/4421/articleType/ArticleView/articleId/13826/ENTEROBIOTIX-LTD.aspx) with the company EnteroBiotix Ltd, based in Aberdeen and Glasgow, which aims to develop novel microbiome-based therapeutics (2020-23);
2. the MRC for an investigation into links between dietary emulsifiers and the gut microbiota ([MECNUT](https://gtr.ukri.org/projects?ref=MR%2FP023606%2F1) 2017-20);
3. the Wellcome Trust for pilot work applying food science to inform diet choices and improve health ([Transforming Nutrition Science for Better Health](https://wellcome.org/sites/default/files/transforming-nutrition-science-report.pdf), 2019-20);
4. Tenovus Scotland for a PhD studentship investigating mechanisms underpinning the links between diet, the intestinal microbiota and health (2016-20, £83K).

Work in the SRP has also led to investment in clinical science with recent funding received from the charity Friends of Anchor to investigate the links between dietary fibres, the gut microbiota and patient response to pelvic radiotherapy (£189k).

**Developing nature engagement capabilities and transformative research**

Nature-based interventions to support people’s use of the outdoors for health and wellbeing benefit are becoming more numerous. In the SRP, tools were developed to evaluate how such interventions promote different types of health and wellbeing and build capabilities for engaging with nature. Group outdoor health walks were evaluated and findings published (e.g. [Growing resilience through interaction with nature: can group walks in nature buffer the effects of stressful life events in mental health](https://pubmed.ncbi.nlm.nih.gov/30893850/); [Social isolation in older adults: a qualitative study on the social dimensions of group outdoor health walks](https://www.mdpi.com/1660-4601/19/9/5353)).

Adding value to the programme of work, in collaboration with the project ‘Creating Natural Connections’, in Cumbernauld, a nature engagement capabilities tool was piloted for evaluating the benefits of conservation volunteering. The work on understanding people’s engagement with nature and impact on human health provided a strong grounding to leverage funding from the NERC Valuing Nature Programme to examine the role of environmental sciences in understanding the impact of the environment on mental health. Recommendations from this project emphasised the need for transformative collaborations between the natural, health and social science disciplines.

**Sustainable hub to engage into rural policies with actors (SHERPA)**

[SEFARI researchers](https://www.apgc.org.uk/) levered funding (EU Horizon 2020, 2019-23, €375K) in a [Sustainable Hub to Engage into Rural Policies with Actors](https://rural-interfaces.eu/) ([SHERPA](https://rural-interfaces.eu/)), which is co-constructing recommendations for [policy](https://rural-interfaces.eu/wp-content/uploads/2022/04/SHERPA_D7.3_Recommendations-future-rural-policies_set1.pdf) and [research](https://rural-interfaces.eu/wp-content/uploads/2022/04/SHERPA_D7.2_Recommendations-rural-reseach-agenda_set1.pdf) relating to rural areas with representatives of science, policy and civil society. SHERPA comprises 40 transdisciplinary Multi-Actor Platforms (MAPs) at EU, regional and national levels. SEFARI contributions to the EU level MAP creates networks with EU Directorates and agencies, Committee of the Regions, European Rural Parliament, and Local Action Groups across Europe, and equivalent networks by facilitating UK MAPs ([Rural Scotland](https://rural-interfaces.eu/maps/united-kingdom-scotland/); [River Dee Catchment](https://rural-interfaces.eu/maps/united-kingdom-dee-catchment/)). In response to the UK MAPs [Position Paper on Climate Change and Environmental Sustainability](https://rural-interfaces.eu/wp-content/uploads/2022/03/Climate_MAP_PP-UK-Scotland.pdf), a member of a UK MAP reported “This is very helpful for our thinking on where CNPA can contribute most effectively to tackling the climate emergency.” [CNPA = Cairngorms National Park Authority]. In 2020/21 [SHERPA MAPs](https://rural-interfaces.eu/2021/12/20/sherpa-cop26/) focused on the EU Long Term Vision for Rural Areas of Europe, drawing on insights to challenges and enablers of rural development in Scotland obtained from the SRP, recommendations for which are cited extensively by [DG Agri](https://ec.europa.eu/info/sites/default/files/strategy/strategy_documents/documents/ltvra-c2021-345-documents-part3_en.pdf). SEFARI Gateway and SHERPA jointly organised and hosted an [online panel session](https://rural-interfaces.eu/news-or-events/sherpa-cop26-how-rural-areas-can-contribute-to-a-just-transition-towards-climate-neutrality/) and interactive exhibit from [COP26 Green Zone](https://rural-interfaces.eu/2021/12/20/sherpa-cop26/) (November 2021), with international, EU and UK contributions. Participation in SHERPA led to a further Horizon Europe award on rural proofing policies for the EU Rural Observatory (Horizon Europe GRANULAR; 2022-26; SEFARI value £420K).

**2.0. THEME LEVEL OUTPUTS AND OUTCOMES**

**2.1. NATURAL ASSETS THEME**

**2.1.1 SUPPORTING POLICY AND PRACTICES**

**Monitoring soil health**

Monitoring soil health is important for understanding the impacts of climate change and changes in land management on ecosystem services and functions performed by soils, such as growing crops and timber, filtering and buffering rainfall, reducing flooding. Part of [the Scottish soil monitoring action plan](https://soils.environment.gov.scot/soils-in-scotland/soil-monitoring/) involved working with SEPA to develop and integrate the monitoring of soil erosion. This methodology was subsequently adapted and implemented in Ireland as part of the [SMARTER BUFFER-Z](http://www.smarterbufferz.ie/) project, funded by the Irish EPA. It also informed the development of the Scottish [National Peatland Plan](https://www.nature.scot/scotlands-national-peatland-plan-working-our-future). Subsequent work led to the identification of 13 key indicators of soil health that could be used to further understand and monitor changes in soil functions and processes under a range of land uses and soil types. Increasing the understanding of soils and soil risks by policy makers, agencies, land managers and more widely is an important way of protecting soils in Scotland. To promote this understanding, Scotland’s soils data and maps have been made available through [Scotland’s Soils website](https://soils.environment.gov.scot/soils-in-scotland/soil-monitoring/). Since 2017, the annual number of page views of which has grown by 75%, and the number of users by almost 60%. The most downloaded data set is the National Soil Map of Scotland. SEFARI staff have contributed to work on soil health at European and global scales through membership of several committees, including the European Technology Platform, [Plants for the Future,](https://www.plantetp.eu/) UN-FAO [International Soil Biodiversity Network](https://www.fao.org/global-soil-partnership/areas-of-work/soil-biodiversity/en/) and UN-FAO [Global Soil Laboratory Network](https://www.fao.org/global-soil-partnership/glosolan/en/).

**Investigating Scotland-wide evidence for trends in high river levels**

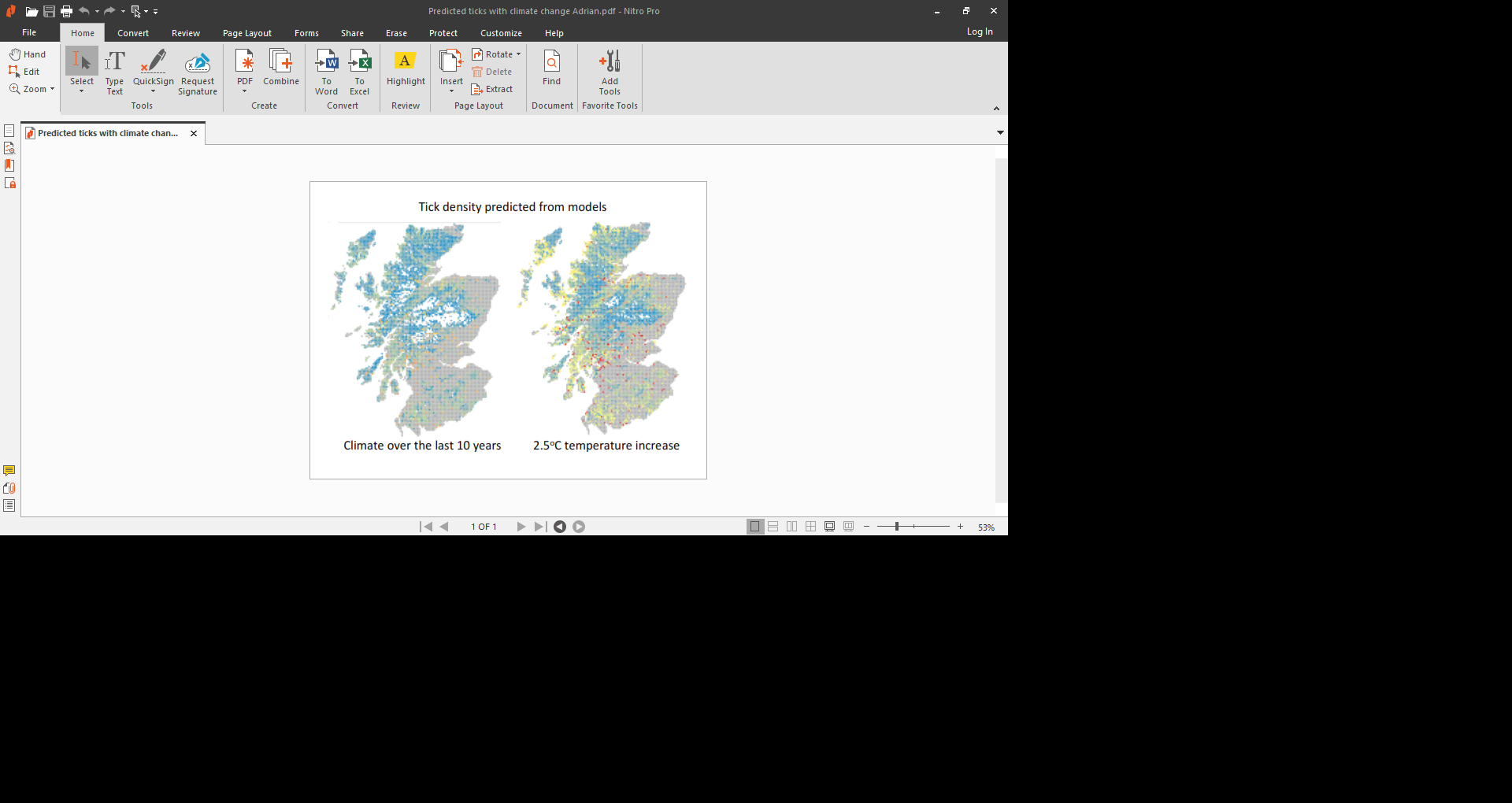
SRP research looked for trends in high river levels, which provide a rough proxy for trends in flood risk at catchments throughout Scotland. The work was developed in conjunction with SEPA and motivated by the belief that climate change is leading to an increasing frequency and size of extreme events, including flood events. Initial analyses focused on looking for trends at each gauging station in turn, whilst subsequent analyses focused on whether there are trends in the extent to which high river levels occur simultaneously at multiple stations. The results suggested evidence for trends in high river levels at a small number of specific gauging stations. However, feedback from SEPA suggested these were likely to be influenced by local factors, and no broader evidence was found for consistent trends in the magnitude of high river levels, or in the tendency for high levels to occur simultaneously at multiple stations. Simulations were used to investigate the number of years of data needed to detect the size of trends that might be expected to occur because of climate change, finding they were typically much higher than the number of years of data currently available. The findings that currently there is insufficient data available to be able to detect trends in high river levels are important in ensuring the scientific validity of conclusions drawn from observations available over the short term.

***Cryptosporidium* sources in a drinking water catchment in Orkney**

*Cryptosporidium* is an important zoonotic parasite and a major concern to the drinking water industries worldwide. Determining sources of *Cryptosporidium* is crucial to understanding its transmission and the development of mitigation strategies to prevent contamination of drinking water and infections. In the SRP, techniques were developed to improve detection, quantification, and speciation of *Cryptosporidium* in different sample types, including faeces from livestock and wildlife, and environmental contexts. Application of these methods in a catchment study in Orkney led to identification of high levels of *Cryptosporidium parvum* in cattle and geese grazing in the vicinity of the main drinking water reservoirs. *Cryptosporidium* was also detected in water samples taken from these reservoirs, highlighting the potential role of livestock and wildlife in contributing to faecal pollution and parasite transmission.

Results from the study were disseminated at an on-farm workshop held in 2019 with over 70 stakeholders, including Scotland’s Chief Veterinary Officer, livestock farmers, and representatives from the Orkney Goose Management Group, NFUS, Scottish Water, RSPB and NatureScot. A further Knowledge Exchange event took place in August 2021 at Kirkwall Auction Mart with an accompanying handout communicating the main research findings. These events, together with regular webinars, provided opportunities to discuss implications of research findings with relevant stakeholders. They have helped inform policy and industry colleagues about the risk to water quality from large numbers of Greylag geese and have been an important driver in helping to establish measures to control the goose population.

**Ticks and Lyme disease shift range in response to climate change**

To predict range shifts and resilience of ticks and Lyme disease to climate change existing data were analysed and models and risk maps developed for Scotland and Europe ([*Journal of the Royal Society Interface*](https://royalsocietypublishing.org/doi/full/10.1098/rsif.2016.0140)*;* [*Environmental Health Perspectives*](https://ehp.niehs.nih.gov/doi/full/10.1289/EHP4615)). A major syntheses was conducted on the response and resilience of ticks and disease to climate change, including indirect impacts such as green recovery schemes, both globally ([*Annual Review of Entomology*](https://www.annualreviews.org/doi/10.1146/annurev-ento-052720-094533)) and Scotland-specific (CAB International [*Climate, Ticks and Disease*](https://eprints.gla.ac.uk/250452/)), and an assessment of interdisciplinary climate change experiments ([*Nature Climate Change*](https://www.nature.com/articles/s41558-019-0609-3)). This work supported policy and practice through a programme of Knowledge Exchange through: i) membership of the Scottish Health Protection Network Lyme borreliosis group, advising policy on awareness and mitigation to Scottish Government, NHS and the general public;

*Model predictions for range shifts in Ixodes ricinus ticks over Scotland in response to climate warming. Warmer colours indicate higher densities of ticks (Blue: low; yellow: high; red: very high).*

ii) advising the then Minister for Mental Health on Lyme disease for Members Business in Scottish Parliament (June 2017); iii) a presentation to the Scottish Government Animal Health & Welfare Division (November 2017, contact Nia Ball) and stakeholders at ELSEG meetings (November 2017); iv) advising the Scottish Parliament Independent Deer Working Group and Scottish Government Grouse Moorland Management Group; and v) presentation at the NHS Lyme disease conference (August 2017). Direct impact on practice (tick and disease control) resulted from advising North Queensferry and Arran community councils, Wilderculture and Scottish Countryside Rangers Association. Further public communications were through BBC TV and radio appearances, Pint of Science, articles in 3 national newspapers and international *Knowable Magazine*.

**Liver fluke risk and conservation grazing**

Over the period of the SRP, the potential risk of liver fluke disease to livestock grazing the saltmarsh (merse) at Caerlaverock Estate has been evaluated as part of conservation grazing schemes designed to improve the habitat for wetland birds and protected natterjack toad populations. Evidence was found of grazing livestock carrying liver fluke (and rumen fluke) infection onto the merse, but no evidence of the fluke life cycle being completed in the saltmarsh habitat. This is likely to be because the fluke larval stages do not survive in the high salinity environment, and because its favoured mud snail intermediate host is typically not present. However, it is important to assess the ongoing risk to grazing livestock, which is best done by testing faeces from grazing ‘sentinel’ animals and identifying suitable mud snail habitat, snail species identity and fluke infection status.

The work carried out at Caerlaverock has featured in a new Moredun technical [news sheet](https://sefari.scot/research/liver-fluke-risk-and-agri-environment-schemes-a-tale-of-toads-snails-and-wetland-birds) on 'Fluke risk and conservation grazing', a case study on the SEFARI website, and as a feature in a ‘Conservation Grazing on the Caerlaverock Estate’ booklet being produced with NatureScot and the Wildfowl and Wetlands Trust. (Policy Contact: Suzanne McIntyre, NatureScot, Caerlaverock NNR Reserve Manager).

**Conserving the alpine blue-sow-thistle in Scotland** (Includes pre-2016 funding)

Many plant populations are left as small, scattered, and isolated populations. This makes them vulnerable to genetic problems such as inbreeding depression and reduced genetic diversity. Mixing genes from different populations (genetic rescue) can increase plant fitness and help to overcome fitness declines in small populations. It is often accompanied by conservation translocations, particularly when previous habitats are no longer suitable. In the SRP, genetic rescue was attempted for the alpine blue-sow-thistle (*Cicerbita alpina*) in Scotland where it is very rare and remains at only four, small, montane sites. Findings showed that remaining genetic diversity is low and levels of inbreeding are high in wild populations. Cross-pollinated individuals tended to develop into larger plants and had better survival rates.

Over five years of the SRP, more than 1,200 plants have been planted out at 12 new sites in Scotland. At lower-altitude sites (300-400 m a.s.l.), plants needed to be caged to prevent grazing damage. These results suggest that cross-pollinations and conservation translocations can support plant conservation if combined with habitat conservation. Moreover, good knowledge is required on the study species, time, and space to grow large numbers of genetically healthy plants. Ideally, species should be protected before their populations become too small and vulnerable. Scottish Parliament champion of the species, Graeme Dey MSP, visited conservation collections at RBGE and took part in planting at Glen Doll. Communication with public audiences included appearances on the BBC’s Grand Tours of Scottish Rivers, press releases, blog posts, and a public display planting at Braemar including interpretation. (Policy contacts: MSP Graeme Dey, Iain MacDonald, NatureScot).

**Stakeholder dialogue promoting conservation in multi-use landscapes**

Engagement with stakeholders and policy advisors aided the development of tools to facilitate dialogue and co-construction of sustainable land use solutions, and to support evidence-based policy. Three examples of the outputs of such engagement resulted are:

1. 'CaperMap', was developed in collaboration with NatureScot, the Cairngorm National Park Authority (CNPA), RSPB, and the Cairngorm Capercaillie Project. 'CaperMap' is a participatory digital communication and engagement tool to support the Capercaillie Framework. It enables users to interactively and visually explore complex spatial information and compare outcomes of different opinions and land-use scenarios. The CNPA uses CaperMap in its capercaillie conservation and community work to support decision and policy making. (Policy contact: Sue Haysom, NatureScot).
2. 'WaderMap', was developed with Working for Waders to engage and inform stakeholders and promote collaborative wader conservation. It is a web-based app enabling stakeholders to map wader conservation projects and display these in user-selected contexts such as renewable energy developments, land management types, and the population status of waders. WaderMap was developed with additional financial support from Working for Waders. (Policy contact: Jessica Findlay, NatureScot).
3. A [Bioregional Mapper](https://vimeo.com/643920114) was developed to support participation in discussions over land use, with additional support from SEFARI Gateway. It was presented in the COP26 Green Zone and in two workshops with additional stakeholders including NatureScot.
4. Woodland expansion in Cairngorms National Park (CNP). Extensive woodland expansion is advocated to mitigate climate change and enhance biodiversity. However, how large-scale woodland expansion can sit alongside existing land use without negatively affecting existing biodiversity is unclear. The CNP woodland expansion targets were assessed with respect to how they might affect land use and the distribution of mountain hares within the park to help inform decision making (Policy contact: Rob Raynor, NatureScot).

**Developing new biodiversity indicators**

SEFARI researchers worked with NatureScot to develop new, and add context to existing, biodiversity indicators. Data on bryophytes from the National Biodiversity Network were linked with indicators of environmental preferences. These indicators show that bryophytes with preferences for warmer climates are expanding, and that has been a recent expansion of bryophytes preferring less nitrogen rich environments. The data indicate that bryophyte occupancy is affected by climate heating but there is evidence of recovery from the effects of nitrogen pollution. These indicators were published as Ecosystem Health Indicators 14a and 14b on SEWeb (<https://www.environment.gov.scot/our-environment/state-of-the-environment/ecosystem-health-indicators/resilience-indicators/>), a presentation given to the Science Support Group of the Scottish Biodiversity Strategy and a paper published in [Ecological Indicators](https://www.sciencedirect.com/science/article/pii/S1470160X19303310).

The trends for bryophytes and lichens, documented in the most recent State of Nature report, were studied for how species of different environmental preferences have fared. Climate change, pollution and increased shade have affected shifted species occupancy patterns. Contrasting trends between bryophytes and lichens imply increased bryophyte competitive advantage over lichens. The prevailing negative trends for lichens are concerning for Scottish biodiversity as Scotland has a globally important lichen flora. This work has been published in [Ecological Indicators](https://t.co/2lA5LRgzr7). (Policy contact: David O’Brien, NatureScot).

**Woodland expansion and soil carbon** [Includes pre-2016 funding]

Increased woodland cover is currently proposed as mitigation for climate change. The assumption is that as trees lock up carbon dioxide in their biomass more carbon will be stored. However, this ignores any impact of tree establishment on the soils which can contain significant amounts of carbon. Utilising a long-term experiment, funded by Scottish Government since 2006, where Downy birch and Scots pine were planted on heather moorland, comparisons were made between soil carbon stocks under trees 12 and 39 years old. Soil carbon stocks declined under both birch and pine. At best these declines were only off set by above ground gains in carbon storage, resulting in no net ecosystem level increase in carbon storage. The work has been presented in [Scientific papers](https://onlinelibrary.wiley.com/doi/full/10.1111/gcb.15229), magazine articles and blogs for the [Heather Trust](https://www.heathertrust.co.uk/blog), The Woodland Trust, at stakeholder meetings such as [ELSEG](https://www.hutton.ac.uk/research/srp2016-21/elpeg-ecosystems-and-land-use-policy-engagement-group), at the [Defra Trees and Woodlands Science Advisory Group](https://www.gov.uk/government/groups/trees-and-woodlands-scientific-advisory-group) and at [NatureScot Science Advisory Committee](https://www.nature.scot/about-naturescot/board-directors-and-committees/scientific-advisory-committee). (Policy contact: Duncan Stone, NatureScot).

**Soil carbon assessments over time**

Change in the carbon stocks of soils can be driven by change in both inputs to soil such as plant litter and outputs such as soil decomposition processes. Work in the SRP utilised shifts in carbon isotopes naturally occurring down soil profiles to determine a proxy for soil carbon decomposition. Determination of the proxy for soil carbon decomposition at sites differing in land use across Scotland showed that decomposition was greater under woodland compared with moorland, suggesting that planting trees on moorland may increase soil carbon decomposition. This finding was subsequently confirmed through determining the proxy for soil carbon decomposition on sites which were previously moorland following afforestation.

To enable an assessment of the trade-offs involved in woodland expansion with carbon and other benefits/dis-benefits it may bring a “Spatial Multicriteria for Woodland Expansion” (SMWE) tool has been developed. This tool enables users to explore options for woodland expansion through interactive maps, providing the means of changing the relative importance of various spatial criteria. A beta version focussed on [riparian woodlands](http://abshy02.hutton.ac.uk/Riverwoods7/) is being used by SEPA and Scottish Wildlife Trust ([Riverwoods Initiative](https://www.riverwoods.org.uk/)) to explore options for woodland expansion.

**Establishment of the ELPEG and ELSEG**

The [Ecosystem and Land use Policy Engagement Group](https://www.hutton.ac.uk/research/srp2016-21/elpeg-ecosystems-and-land-use-policy-engagement-group) (ELPEG) and Ecosystem and Land use Stakeholder Engagement Group (ELSEG) were established in the Strategic Research Programme 2016-22 to increase knowledge exchange and integration between SEFARI researchers in the SRP and stakeholders. ELPEG comprises stakeholders from the Scottish Government and key government agencies including SEPA, NatureScot, and the Forestry Commission. [Meetings and bulletins](https://www.hutton.ac.uk/research/srp2016-21/elpeg-ecosystems-and-land-use-policy-engagement-group) were organised every six months to provide updates for policy stakeholders on research activities undertaken in the SRP, particularly in the areas of Biodiversity and Ecosystems, and Integrated Management of Natural Assets. The ELSEG involved a wider group of stakeholders including representatives from business and environmental organisations, meetings of which were held once a year comprising talks, workshops and discussions ([further details](https://www.hutton.ac.uk/research/srp2016-21/elpeg-ecosystems-and-land-use-policy-engagement-group) can be found here).

**2.1.2 SUPPORTING INNOVATION AND THE ECONOMY**

**Root hairs for improved tolerance to drought and phosphorus deficiency**

The length of the roots hairs on plants is known to correlate with phosphate uptake under dry conditions. Phosphorus is an important mineral for plant growth. RCUK (BBSRC-SARISA) funding was obtained to add value to SRP studies on the interactions between barley root hairs and soil in the development of the rhizosheath using synchrotron X-ray CT and fine scale soil physical conditions, in collaboration with the Universities of Aberdeen and Southampton. Findings showed that root hairs had large impacts on the porosity of the rhizosphere ([*New Phytologist*](https://nph.onlinelibrary.wiley.com/doi/full/10.1111/nph.14705)) having impacts on water dynamics and aeration in this zone. This information has parameterised models of rhizosphere development and phosphorus use under future field conditions ([*Plant & Soil*](https://link.springer.com/article/10.1007/s11104-019-04308-2)).

Of greatest importance was the finding that the presence of root hairs was critical for the ability of the crop to maintain water and phosphorus uptake under the severe drought conditions experienced in the field in 2018 ([*Annals of Botany*)](https://academic.oup.com/aob/article/128/1/1/5920680?searchresult=1). This has garnered interest in using root hairs as a selective phenotype for breeding in cereals from breeding companies, including KWS. The research has also led to collaborations with researchers at Lancaster University, and in Germany and Australia on work with other species including sorghum and wheat. The research has been developed to look at the evolutionary development of the trait to assess its applicability to a range of other species ([*Plant & Soil*](https://link.springer.com/article/10.1007/s11104-017-3220-2)). This work has been highlighted as having impact in an editorial commentary ([*Plant & Soil*](https://link.springer.com/article/10.1007/s11104-017-3358-y)).

**Natural assets, data and tools, and natural capital accounting**

SRP research on natural capital accounts investigated the potential for their disaggregation by sectors (agriculture, forestry, coastal and marine) to regional levels. Accounts of urban greenspace explored its potential impact on mental health, which identified important relationships with respect to ethnicity and deprivation, with positive benefits arising from proximity to greenspace. Work on these accounts informed an analysis of policy proposals for a Green Recovery.

Research on the Natural Capital Asset Index (NCAI) focussed on refining the data and indicators in collaboration with NatureScot. This work identified important gaps and reviewed the sensitivity of the index, and its ability to represent ecosystem services, to changes indicators. Research activities also helped promote the index to a wider stakeholder audience. Recommendations to inform future development of the NCAI and indicator monitoring were made to NatureScot’s Science Advisory Committee. A spreadsheet-based tool was developed that enables analysis of the impact of future policy scenarios on the NCAI. Options in the tool include changes in habitat extent (e.g., woodland expansion) or condition (e.g., peatland restoration).

New data sets and tools have been produced, and existing data sets made more readily available. Using machine learning, Digital Soil Mapping (DSM) approaches were used to produce maps of peat depth and soil carbon stock at 100 metre resolution for Scotland. The results have been used by NatureScot to characterise potential restoration sites. The work was included in the development of a Climate Action Plan for Perth & Kinross Council, and a presentation made to the UK Government’s LULUCF Scientific Steering Committee on 3rd March 2022.

The “Natural Asset: Data Portal” provides access to 44 data sets with c.120 individual resources consisting of downloads and [web services](https://openscience.hutton.ac.uk/). It provides a means to review and download data produced in the SRP for use in research, consultancy, education, and public information. From launch in September 2018 to March 2022, there have been 24,000 page views.

**Private sector involvement in landscape level partnerships**

The last decade has seen increasing interest in how private sector actors, and their resources, can be involved in work towards sustainability. More attention has also been directed to the potential of catchment and other landscape-level partnerships, with the Scottish Government commissioning 5 pilot Regional Land Use Partnerships in 2021. Researchers in the SRP worked with ESCom Scotland to facilitate an online workshop for stakeholders across all parts of the UK, in which those involved in or enabling partnerships could share their experiences, ideas and expectations for when and how to better involve the private sector in partnerships. As well as advancing thinking, the workshop fostered new stakeholder connections. Examples of key themes emerging from the discussion ([see briefing for an overview](https://www.hutton.ac.uk/sites/default/files/files/research/srp2016-21/rd124_143/22_03_20_%20RD124_1_GoingWithTheFlow.pdf)) include: i) the need to differentiate different groups within the private sector (e.g. agri-business versus water companies versus investors) all of which have different motivations; ii) for stable partnerships (e.g. in funding a skilled coordinator or project officer, that enables them to reach out to ‘new’ groups in the private sector).

**Potential of Bere barley diversity for sustainability in marginal soils** Collaborative research between SEFARI, University of Highlands and Islands and University of Copenhagen has shown that extant barley landraces selected over many generations on marginal soils have adapted to tolerate limited micronutrient availability. This finding along with information on the cultural heritage, nutritional value and commercial opportunities associated with Bere barley was presented at stakeholder events held in Orkney with attendance from across the value chain (food and drink industry, growers, agricultural scientists, archaeologists, historians, human nutritionists, artists). Research findings and the interest generated show that Bere barley constitutes a valuable resource of untapped adaptive genetic variation, with the opportunity to identify useful cultivars and genes controlling the key adaptive traits to underpin crop improvement in marginal soils.

The heritage and sustainability value of Bere barley, which the research has strengthened and promoted, has direct value to the Scottish rural economy through use in high-value products such as Bruichladdich Bere single malt, Raasay Distillers, Bere barley beer, Bere meal and bannocks. The population of Bere barley genotypes safeguarded in this work is now being used by individual crofters in participatory breeding and assessment programmes, and by new distillers and maltsters (Raasay, Crafty Maltsters) to select the best varieties for their commercial purposes. The impacts of the research on strengthening the value chain for Bere will be assessed in the coming years with work funded by the EU Horizon 2020 RADIANT project (2021-26).

**Just the tonic**

It is challenging to realise crop-diversification in an arable cropped system which dedicates two thirds of its area to the production of barley for key industries of distilling, brewing and animal protein production. Additionally, Scotland’s high-protein legume grain import dependency is estimated at 80% of requirements for animal feed since legume grains have not yet been developed for brewing or distilling. [Consequently, environmental, and socioeconomic benefits which would have accrued via the cultivation of legume grains in Scotland, are forfeited](https://doi.org/10.3389/fsufs.2021.692137). Furthermore, Scottish producers are disadvantaged financially and environmentally, as legume grain protein import prices are volatile due to stochastic factors that impact global trade such as crop failure, and value chain breakdown due to war or pandemics. In the absence of policy measures to limit legume grain import dependency and promote [crop diversification](https://journal.hep.com.cn/fase/EN/10.15302/J-FASE-2021437), some producers have developed short-value chains, increasing the range of crops grown and processed on-farm to realise ground-breaking products.

The [climate positive Nàdar products](https://arbikie.com/pages/nadar-collection) were developed using peas, which yield without synthetic nitrogen fertiliser application, and new biorefining methods, *via* an international and multidisciplinary research collaboration. This provided an [independent peer-reviewed evidence base](https://www.sciencedirect.com/science/article/pii/S0160412019308773), and the resultant [news](https://www.bbc.co.uk/news/uk-scotland-tayside-central-51559180) and [media](https://www.forbes.com/sites/felipeschrieberg/2020/03/12/scottish-distillery-releases-worlds-first-climate-positive-gin/?sh=515f0fa92db8) coverage helped the popularity of the Nadar products which are now sold internationally, strengthening the ‘sustainable Scotland’ brand. The environmental credentials were also realised as the high-protein co-product is used to feed livestock. The biorefining approach has been adopted for [brewing](https://doi.org/10.1002/jib.632), with beers that also [satisfy consumers' taste expectations](https://doi.org/10.1002/jib.568).

**Collaborative research with farmers to improve agrobiodiversity**

Intercropping is a practice that could improve sustainability and safeguard biodiversity in agricultural habitats. While intercropping has been tested and demonstrated at research scales, innovative ways are needed to transfer findings into practical application by farmers, and to share knowledge widely in the Scottish farming community. Collaborative trials were carried out with farmers across Scotland who were looking for practices that reduce inputs, increase future sustainability, and minimise their environmental footprint. Trials were monitored to assess mixture performance and ecological benefits such as biodiversity, weed control, soil nutrient availability, and crop yield.

The results were disseminated widely through webinars, on-farm events, and through the [Crop Mixtures Data Explorer](https://ics.hutton.ac.uk/seams/#/) tool, which is an open data platform co-developed with agricultural stakeholders. Users can search trial data sets using filters such as crop species in the mixture, soil tillage, or farm management, enabling them to visualise the data in different formats and use the information to make decisions about cropping. The research has supported the growing uptake of intercropping by farmers who gain from access to scientific advice in conducting and evaluating research trials. This collaborative approach to research improves understanding of how research translates into practical use. Increased connectivity and accessibility benefits society by deepening appreciation of the mechanisms needed to support sustainable farming and the potential rewards.

**Social innovation for sustainability transformation**

Rural areas often face challenges such as weak economies and ageing populations, intersecting with those of climate change and biodiversity losses, all requiring urgent solutions. In conditions where markets are fragile and public budgets constrained, civil society strives to revitalise the development through social innovation. SRP research advanced the definition of social innovation, knowledge of its [diverging development paths](https://onlinelibrary.wiley.com/doi/10.1111/soru.12337), and reconstructive [social innovation cycles](https://www.mdpi.com/2071-1050/13/3/1231/pdf) in women-led initiatives. Institutional [analysis and reconfiguration](https://www.mdpi.com/2071-1050/13/8/4360) frameworks were developed, together with methodological approaches to assess the [impacts](https://doi.org/10.3390/su13041823) of social innovation, specifically for multi-[functional forestry](https://doi.org/10.1139/cjfr-2015-0399) and [carbon forestry](https://doi.org/10.1016/j.forpol.2018.10.012), and in the context of [community forestry](https://www.mdpi.com/2071-1050/13/8/4359) and [community energy](https://www.frontiersin.org/articles/10.3389/fenrg.2019.00031/full) in Scotland, and beyond (29 journal [articles](https://doi.org/10.1111/soru.12337) published, and Guest Editors of special issues of [*FORPOL*](https://protect-eu.mimecast.com/s/b-r1CxGO9SJwnlMUwyvdV?domain=sciencedirect.com)2019 and[*Sustainability*](https://protect-eu.mimecast.com/s/iB2SCzmV9IR9Q1gSwGyFA?domain=mdpi.com) 2021).

[Explaining](https://www.sciencedirect.com/science/article/abs/pii/S1389934118301114?via%3Dihub) and enhancing the role of social innovation in revitalising rural areas and communities, and [its implementation](https://www.mdpi.com/2071-1050/12/22/9674) and spread, have underpinned [science-policy-practice dialogues](https://doi.org/10.1007/s10113-019-01537-0), and informed changes in perceptions and raises awareness of decision-makers and civil society. Science-stakeholder workshops ([2018](https://www.hutton.ac.uk/sites/default/files/files/Social%20Innovation%20in%20Rural%20Areas%20in%20Scotland%20-%20workshop%20report.pdf); 2019) were held (at SEFARI sites and EC offices, in collaboration with the EC [Horizon 2020 SIMRA](http://www.simra-h2020.eu/) project on social innovation in marginalised rural areas), and topical inputs provided to ELPEG and ESLEG meetings.

Pathways to impact included:

1. dialogue with national leaders (e.g. at [Netherlands Royal Palace](http://www.simra-h2020.eu/index.php/2017/07/)), and adding value to science-policy-practice events (e.g. OECD Rural Development Conference; International Union of Forest Research Organisation [IUFRO], Congress and its World Day; COP26), [with 12](https://www.iufro.org/uploads/media/news19-8-awards-special.pdf) conference sessions co-organised (e.g. [ESG 2021](https://www.earthsystemgovernance.org/2021bratislava/)**;** [Forums Carpaticum](https://www.hutton.ac.uk/news/forum-carpaticum-discusses-sustainability-wellbeing-and-social-innovation-marginalised-mountain)2018 and 2021; and IUFRO conferences);;
2. bringing social innovation into Research and Policy Agendas (e.g. Horizon Europe; Science for the Carpathians; the EC Long-term Vision for Rural Areas), and business plans (e.g. Perth & Kinross Council Climate Action Plan);
3. contributions to government and non-government advisory committees (e.g. [UK Expert Committee on Forest Science](https://www.gov.uk/government/groups/expert-committee-on-forest-science); [European Forest Institute Scientific Advisory B](https://efi.int/about/sab)oard; EU Rural Action Plan; [IUFRO Unit](https://www.iufro.org/science/divisions/division-4/40000/40500/40505/)), and public agencies (e.g., UK Forestry Commission; Scottish Forestry; [FAO IPROMO;](https://blog.iufro.org/2021/09/09/the-power-of-social-innovation-to-increase-the-wellbeing-of-forest-dependent-communities-in-the-carpathian-and-other-mountain-regions/) the [UN](https://www.linkedin.com/feed/)).

Researchers in the SRP also built capacities andstrengthened partnerships of innovators in academia, policy, practice, and businesses through mechanisms such as the [MOOC 2021](http://www.fao.org/mountain-partnership/our-work/capacitydevelopment/ipromo/course-2021/en/) educational, open access modules, addressing the green recovery through social innovation, which were produced for government and development practitioners from around the world.

**Managing catchments locally for the provision of multiple benefits**

The objective of the [PESLES project](https://www.hutton.ac.uk/research/projects/payments-ecosystemservices-) has been to build understanding of what management tools and supporting institutional arrangements are effective in enabling stakeholders to adopt water management measures in selected Scottish catchments. SEFARI work focused on two lowland catchments, the Lunan Water in Angus, and Loch Leven in Perth and Kinross. It explored the potential of Payment for Ecosystem Services (PES) schemes, which are based on voluntary payment arrangements between individual beneficiaries and service providers to establish or increase the supply of an ecosystem service of improved water management. The Lunan Water Catchment Management Group was formed (Angus Council, SEPA, SNH, Scottish Wildlife Trust, Dundee University, NFUS, Esk Rivers and Fisheries Trust, and James Hutton Institute), with Angus Council chairing, to help oversee the project and act as a forum for catchment management issues.

A hydrological model predicting stream and groundwater inflows to the Lunan Water and its wetlands was developed and supported decision making for water body management by the Catchment Management Group, to alleviate flood risks and enhance water quality in local wetlands. A scenario-based modelling approach was developed to inform water level management at Loch Leven, with the aim of reducing algal blooms. The challenges of implementing such changes in water levels management through a local PES scheme were identified.

**Targeting funding can improve the efficiency of agri-environment schemes**

For the Agri-Environment and Climate Scheme a simple method of targeting resources to some arable and grassland options was tested; funding was made available if more than a set threshold of priority species was present in the 10 km x 10 km square in which the farm was located. SEFARI research showed that this approach was efficient. Other methods were found to be more efficient, but with those a choice would have to be made as to whether to focus on the mean representation of priority species’ ranges across all options, or to ensure a high minimum representation of priority species. A summary of the work was presented at a parliamentary breakfast and a paper published in [Global Ecology and Conservation](https://www.sciencedirect.com/science/article/pii/S2351989419300253).

A second phase of the work assessed whether agri-environment targeting could benefit both biodiversity and other ecosystem services. Results from a spatial analysis showed that multifunctionality encompassing both ecosystem services and species richness does not occur consistently at the local level but does at the landscape scale. Conclusions were that it is possible to define a zonation that encompasses areas that offer higher levels of biodiversity and ecosystem services (a paper is in review). [Estimates of opportunity costs](http://www.hutton.ac.uk/research/srp2016-21/wp143-practical-interventions-realise-multiple-benefits-and-manage-trade-offs) to farmers of 3 potential measures (widened field margins, deintensification, and integrated farming) showed no clear geographical clusters combining both high ecosystems services potential and low opportunity costs. So, to minimise the costs of ecosystem services provision, additional approaches to targeting would need to be investigated.

**2.1.3. COLLABORATIVE AND MULTIDISCIPLINARY RESEARCH**

**Citizen science and DNA methods for exploring alpine soil biodiversity**

Soil biodiversity is critical to ecosystem function but understanding of soil organisms lags far behind that of above ground biodiversity. Difficulties of detecting soil organisms and a shortage of scientists able to identify them contribute to this lack of knowledge. In alpine ecosystems, these issues are compounded by difficulties accessing remote locations.

In a collaborative project with the charity Plantlife, SEFARI researchers explored how DNA based methods (a cost-effective means for characterising soil organisms) could be combined with a citizen science approach to expand knowledge of soil biodiversity, and to inspire public participation in biodiversity [science](https://sefari.scot/research/going-underground-testing-the-potential-of-citizen-science-and-dna-to-explore-alpine-soil). The collaboration enabled the researchers to benefit from Plantlife’s extensive experience of public engagement and volunteer management, whilst Plantlife benefited from scientific expertise in sampling design, DNA based methods and data interpretation. The project investigated fungal communities on the 58 Munros (i.e. mountains in Scotland over 3,000 ft) within the Cairngorms National Park.

The researchers reached out to hillwalking communities to adopt a Munro and collect soil samples for DNA analysis. During summer 2021, 73 volunteers visited 55 Munros and collected a total of 219 samples, from which 2,748 fungal taxa were detected, increasing knowledge of alpine fungi and their distribution. The project raised awareness of soil biodiversity amongst the public, including project volunteers, passers-by encountered during sampling visits, and attendees at an online lecture as part of the Plantlife Spring into Action series, which attracted 150 live [viewers](https://tixoom.app/plantlife/4mgvilkm) and over 200 subsequent views on YouTube. Graphical user interface, text, application, chat or text message

Description automatically generated

Summary of volunteer effort during field sampling 2021 of soil samples on Munros in the Cairngorms National Park.

**Soil assessments for public benefits**

Soils provide a range of critical services and functions for society. SRP funding supported collaborative and multidisciplinary research in developing tools and knowledge to protect soils. Collaboration with geotechnical engineers enabled the [development of tools to quantify the contribution of roots to soil stability](https://www.mdpi.com/1999-4907/10/12/1135) adjacent to key transport corridors.

Collaborative working is critical when responding to what can be rapid changes in the soil’s environment. To ensure effective communication, the Soil Engagement Group was established to link stakeholders with research and policy. The value of such connections was highlighted in 2020 when farmers were expected to sow crops in compliance with the three-crop rule to achieve funding through the Basic Payment System. A team of SEFARI staff responded to a request from Scottish Government policy to collate information which showed that a combination of a wet winter in 2019 followed by a wet spring in 2020 resulted in conditions unconducive to planting and, using risk mapping, demonstrated there was potential for substantial harm to Scotland’s soils. This resulted in the successful [derogation of the three-crop rule](https://www.thescottishfarmer.co.uk/news/18300763.three-crop-rule-dropped/). SEFARI researchers also worked with SEPA to improve [soil erosion risk maps](https://soils.environment.gov.scot/maps/risk-maps/map-of-soil-erosion-risk-partial-cover/) by incorporating field observations of erosion by SEPA staff and, through a soil [erosion reporting app](https://sefari.scot/research/what-is-the-cost-of-soil-erosion-in-scotland) for use by the general public.

**Peatland restoration**

Peatland restoration is part of the suite of tools to mitigate Scotland’s greenhouse gas (GHG) emissions, maintain and improve the supply and quality of water, and enhancing the condition and aesthetic appeal of these iconic landscapes, alongside other benefits such as job creation directly within the sector. From the outset, the research involved key agency stakeholders such as RESAS, NatureScot (both Natural Resource Management and Peatland ACTION), Scottish Water, Forest Research and SEPA. Links were through direct contacts, data exchanges and discussions on the focus of work within the framework of the National Peatland Research & Monitoring Group. Over 90 outputs were produced through the 6 years of thre SRP. Outputs included modelling solutions to assess the likely [current condition of peatlands at national scale](https://www.sciencedirect.com/science/article/pii/S0048969718352124), [direct assessment of GHG emissions](https://link.springer.com/article/10.1007/s10533-022-00923-x), [development of modelling approaches to estimate GHG emissions](https://www.sciencedirect.com/science/article/pii/S0048969720361428), and assessments of the [costs and merits of peatland restoration](https://www.climatexchange.org.uk/media/3141/peatland-restoration-methods-a-comparative-analysis.pdf) (via ClimateXChange).

In addition to the biophysical outcomes of restoration, human perceptions of the services, benefits and disbenefits also form part of the assessment of the success of peatland restoration. Qualitative research identified importance of protecting peat bogs near urban areas to improve and maintain nature connections, and balancing individual (e.g., fuel) with community (e.g., water quality) needs alongside public access and habitat protection.

Wider engagement to which the SRP contributed included the production of [UK-specific emission factors for peatlands](https://uk-air.defra.gov.uk/assets/documents/reports/cat07/1904111135_UK_peatland_GHG_emissions.pdf), a [global synthesis of water table depth as a driver of carbon emissions](https://www.nature.com/articles/s41586-021-03523-1), a lead for the [updated State of the UK Peatlands](https://www.iucn-uk-peatlandprogramme.org/sites/default/files/2019-11/COI%20State_of_UK_Peatlands.pdf) report, evidence the [House of Lords Nature-based solutions for climate change](https://committees.parliament.uk/oralevidence/2751/pdf/) Inquiry, and as lead for the UK chapter in the global [FAO Peatland mapping and monitoring report](https://catalogue.unccd.int/1446_fao_peatlands_CA8200EN.pdf).

**Investigating and communicating the impacts of Natural Flood Management**

Natural Flood Management (NFM) is a method for reducing flood risk by the alteration, restoration, or use of landscape features. During the SRP, investigations were undertaken on measures such as log jams, river restoration, ponds and flood embankment lowering. Empirical evidence was gathered through collaborations with groups implementing measures (e.g., Tweed Forum, Dee Catchment Partnership, MacRobert Estate). In some cases, results showed positive responses locally and will help to inform future monitoring and modelling work.

Through close engagement with the Scottish Government and SEPA, researchers set up the NFM Network Scotland ([www.nfm.scot](http://www.nfm.scot)). This is an example of collaborative work with CREW, whereby CREW funded the website development at the start of the SRP, and the SRP managed and maintained the network. The Network has over 320 registered members who can submit news and case studies and can receive news and events related to NFM. It has become an international hub for those interested in applying NFM in catchments. Coupled with this, SRP researchers engaged with European and International initiatives to share knowledge. For example, they contributed to the Scottish Government led work in the Interreg project ‘Building with Nature’, closely engaged with the EU Cost Action Land4Floods, co-convened the international symposium on Nature Based Solutions in Edinburgh, 2021, and cases from the SRP were used in the US Corp of Engineers atlas ‘Engineering with Nature’.

**The Cumbernauld Living Landscape partnership**

A group of people posing for a photo in the woods

Description automatically generated with medium confidenceA partnership with Scottish Wildlife Trust in Cumbernauld facilitated the development of a five-year multi-partner project, Creating Natural Connections, funded by the Heritage Fund as part of the [Cumbernauld Living Landscape](https://cumbernauldlivinglandscape.org.uk/) partnership. SEFARI researchers led development and trialling of new ways of monitoring and evaluating the impacts of the project on people and communities. By working closely with trusted community groups, the partnership enabled researchers to test methods such as participatory video, citizen social science and digital storytelling. This enabled new, and often hard-to-reach, voices to be heard such as adults with support needs and [young people](https://besjournals.onlinelibrary.wiley.com/doi/10.1002/pan3.10236). It also demonstrated the benefits of conducting such participatory research by enabling meaningful and transformative [human-nature interactions](https://theoryandpractice.citizenscienceassociation.org/article/10.5334/cstp.389/), enhancing individual and group efficacy, and increasing

Filming personal experiences of nature-engagement programmes in Cumbernauld

confidence and a sense of empowerment. The training provided to the partners and community researchers has given them new participatory evaluation methods which they have started to apply to other projects in Scotland.

**New European network of economists**

A new network of economists, practitioners and policy makers was established (Research Network in Economic Experiments for the Common Agricultural Policy, [REECAP](http://www.reecap.org)), in 2017, with members from 12 European countries. The objective of REECAP is to contribute to constant improvement of European agricultural policies by providing robust evidence on the net impact of interventions and help design well-adjusted and effective policy interventions in fields such as income support, investment policies, risk management and agri-environment. It aims to identify and evaluate policies which are well accepted by farmers, improve the effectiveness of expenditure of public money and create more satisfactory outcomes for food consumers and citizens.

The SRP enabled participation in the creation and growth of REECAP through involvement in the network’s Board and by hosting REECAP’s 2021 annual meeting (online). REECAP won the 2021 Center for Behavioural & Experimental Agri-Environment Research (CBEAR) Prize for Agri-Environmental Innovation for its leadership in bringing together researchers, evaluators and policy makers interested in the use of economic experimental approaches for more evidence-based policy design and evaluation. This annual prize recognizes outstanding leaders who are at the leading edge of using behavioural sciences and experimental design to improve programmes related to agriculture and the environment. The network has developed links with authorities at European (e.g., DG-Agri) and national (e.g. NatureScot) levels and has facilitated collaborative and methodological developments which are included in the SRP 2022-27.

**Delivering ecosystem services and benefits at the catchment scale**

Working with farmers in the Balruddery catchment (Angus), SEFARI researchers explored the potential of landscape scale management to promote functional biodiversity and ecosystem service delivery in an arable setting. The results illustrated that the catchment had an ecosystem service profile typical of arable dominated landscapes and that interventions in the form of the introduction of beneficial habitats, including ‘magic margins’ around areas of potato crops, can improve regulatory services including pest regulation, pollination, and erosion control. These outcomes were valued by farmers although were not all translated into management practices.

Findings were shared with the Balruderry Catchment farmers as practitioners and the policy audiences (e.g., Ecosystems and Land Use Policy Engagement Group). The study and its findings have also been shared with local, national, and international research and innovation communities. These include the Strathmore Wildlife Farmer Cluster, Bioregioning Tayside, and the International Organisation for Biological Control – West Palaearctic Regional Section (IOBC-WPRS) Working Group “Landscape management for functional biodiversity”. The study led to further research on the Balruddery catchment including a partnership with Edinburgh University to support undergraduate projects, and PhD projects with the Universities of St. Andrews, Edinburgh and Greenwich. The study informed international research initiatives into the decline of biodiversity in agriculture, including EU funded research coordinated by SEFARI staff.

**Bloomin’ Algae app helps to reduce risks to public and animal health**

Blooms of blue-green algae in reservoirs, lakes, ponds, and water courses present a serious risk to human and animal health due to their toxicity. Such algal blooms are most common in summer months, the spread of which is linked to poor water quality and climatic factors. The [Bloomin’ Algae app](https://www.ceh.ac.uk/our-science/projects/bloomin-algae) was developed by UKCEH as a citizen science tool to enable the rapid mapping of harmful algal blooms to assist public agencies and better inform members of the public. The app produces a real-time open access map showing locations of algal blooms across Scotland. The data gathered led to more rapid deployment of public warning notices by local authorities and landowners (including Scottish Water and NatureScot), in collaboration with SEPA, so reducing risks to public and animal health. An improved version of the app was developed with RESAS funding and released in May 2021. The app was co-developed with SEPA, Scottish local authorities (environmental health departments) and Scottish Water.

A training session was held for SEPA staff who have agreed to be notified automatically and verify Scottish records of the app, thus providing a more joined-up approach for monitoring harmful algal blooms across Scotland. An online information session on the app was presented to members of the Royal Environmental Health Institute of Scotland (REHIS; December 2021), attended by over 70 local authority environmental health officers. In 2021, 163 records were submitted from across Scotland with 63% (103 sites) considered correct records of harmful algal blooms, 17% (28) were clearly incorrect, and another 20% (33) were plausible. This means that in only 20% of records further sampling was required to check risks to public and animal health.

**2.1.4 SCIENTIFIC EXCELLENCE**

**Global soil nematode abundance and functional group composition**

Soil organisms are a crucial part of global soils. Despite their importance for ecosystem functioning, few quantitative, spatially explicit models of the active belowground community exist. Nematodes, the most abundant animals on Earth, filling all trophic levels in the soil food web, were the organism of choice for the study. Approximately 7,000 georeferenced soil samples were used to model and generate the first maps of the abundance of soil nematodes and the composition of their functional groups at a global scale. The maps showed that nematodes had a total biomass of approximately 0.3 gigatonnes and inhabit surface soils across the globe, with higher abundances in sub-Arctic regions (38% of total) than in temperate (24%) or tropical (21%) regions. Regional variations in these global trends also provided insights to local patterns of soil fertility and functioning.

The high-resolution models provided the first steps towards representing soil ecological processes in global biogeochemical models and will enable improved prediction of elemental cycling under current and future climate scenarios. The study, published in Nature, has been impactful with c.400 citations since publication in 2019. Currently it has an Altmetric score of 655 which is ranked in the top 5% of all research outputs scored by Altmetric and resulted in an invitation by Nature to write a follow-up publication for a sister journal, Nature Scientific Data which was published in 2020.

**Building catchment to national understanding of water quality threats**

Water quality in terms of the physical, chemical, and microbiological condition of rivers remains threatened by unresolved nutrient issues, emerging contaminants, and superimposed climate impacts. Mechanistic research focussed on two key aspects: pollution by sewage effluents and DNA approaches for evaluating river microbial impacts. Effluents from different sources remain a poorly understood driver of water quality variation. Four papers published in scientific journals (two in Environmental Pollution, accessible [here](https://pubmed.ncbi.nlm.nih.gov/28550797/) and [here](https://www.sciencedirect.com/science/article/pii/S0269749116318966?casa_token=0X2l-Neq_IsAAAAA:mI-qTV5G3myQA61fD9gcR3FbOLkfZMYswNNFT14Ib9ha9ipDmEaZywXQhZx-82IzxQ0HG1R6uw), and two in Science of the Total Environment impact, accessible [here](https://www.sciencedirect.com/science/article/pii/S0048969716316126?casa_token=0OKlhC8uCCIAAAAA:qRIlUSS6SUQwtKTa-ch6nQXA0J6TNymKCYFASS4kNv7qoofttQoaXm9_E9ojdqyjc3JBVclRDg) and [here](https://www.sciencedirect.com/science/article/pii/S0048969715309761?casa_token=mWMar7SUX5UAAAAA:zMqOqvmMqvaadPdVgIORQHBMwYTBBurRGcSlaqQTCB_foqkYAugbSIx8UnEmnHTuezktdFgEPw)) evaluated spatio-temporal variability in septic tank effluent composition, controlling factors, potential tracer techniques for source apportionment and impacts in receiving waterbodies. This underlying research also informed CREW policy reports.

Effluent sources from wastewater treatment works (WWTW) were evaluated and published in the [*Journal of Environmental Management*](https://www.sciencedirect.com/science/article/pii/S0301479722004649?via%3Dihub). Water, sediment quality and microbial change along 1 km river transects following five WWTW challenged notions of pollution plumes from such sites and constantly discharging point sources. Direct downstream effluent impacts were only clear for several WWTW on some dates, whilst river condition and background pollution sources were shown to be highly influential. A study of two catchments examined the influence of environmental drivers on the emerging threat of antimicrobial resistance (AMR) prevalence in agricultural catchments, finding a high variability in AMR prevalence over time in the absence of point source discharges.

Linked AMR modelling showed that AMR gene abundance was more strongly associated with season and environmental variables than with microbial community composition. Novel techniques were investigated for source tracking specific faecal indicator organisms in the environment. E. coli genome clustering was undertaken in a livestock dominated catchment. Similarities in E. coli from the stream with isolates from sheep and cattle faeces indicated transmission from faeces to water. Similarities in isolates from soils and fresh cattle poached areas suggested the method could detect recent run-off and persistent soil sources as transmission pathways.

Integrative research of processes was undertaken at two spatial scales: At a 50 km2 catchment scale experiments on phosphorus release from sediments were combined with stream energy (erosion-conveyance) predictions from spatial data, siltation, and riparian condition surveys to explore mechanisms behind a decadal rise-fall in stream phosphorus from long-term monitoring. The [paper](https://www.sciencedirect.com/science/article/pii/S0048969721038626?via%3Dihub) (published in *Science of the Total Environment*), reports predictable zones of P-enriched sediments capable of multi-year elevation of stream P following larger storm events.

Research on national Scottish water quality developed an empirical statistical ‘toolkit’ of metrics (e.g., concentration vs river discharge over time) used on c.50 rivers. The [paper](https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2021WR029692)(published in *Water Research*) shows how solutes change behaviour, which could be related to soil and land cover properties. It provides insight to, and limitations of, regulatory national data sets; the ‘toolkit’ has since been utilised by several European groups and in publications.

Modelling work focussed on the major Water Framework Directive parameter phosphorus for which a risk-based phosphorus pollution model was developed, using a hybrid Bayesian Belief Network. This encompassed multiple mechanistic findings and spatial data calculations from the research. The spatial implementation of the model enables the mapping of critical source areas and different source apportionment within a probabilistic framework. SEPA are adopting this modelling approach and exploring using the model as one of their suites of modelling tools.

**Climate change and habitat niches in temperate rainforest**

Temperate rainforest is a globally rare ecosystem. Where it is found in Scotland it is characterised by a very high diversity of epiphytic lichens and mosses. Its effective conservation is a Scottish Government priority: “*Scotland is home to its own Atlantic rainforest boasting a variety of rare species and habitats. We want to protect and expand this precious environment and we have committed to do so in the life of this Parliament*” – Ms Mairi McAllen (Scottish Government Environment Minister).

Outputs from the research during the SRP include 16 peer reviewed papers relating to this habitat and its conservation. Scotland’s rainforest was characterised geographically ([*Ecological Indicators*](https://www.sciencedirect.com/science/article/pii/S1470160X16303016)) while demonstrating a persistent decline among its threatened species ([*Edinburgh Journal of Botany*](https://www.cambridge.org/core/journals/edinburgh-journal-of-botany/article/abs/five-decades-of-decline-for-oldgrowth-indicator-lichens-in-scotland/11DE522FE41C21577871C80941B375B8)). This work was selected as evidence in the [*UK State of Nature Report 2019*](https://nbn.org.uk/stateofnature2019/reports/)*,* as well as highlighting its vulnerability to ongoing climate change ([*Scottish Geographical Journal*](https://www.tandfonline.com/doi/abs/10.1080/14702541.2016.1197964?journalCode=rsgj20)), in part because of species response to future non-analogue climates ([*Restoration Ecology*](https://onlinelibrary.wiley.com/doi/abs/10.1111/rec.12517)*,* [*The Bryologist*](https://bioone.org/journals/the-bryologist/volume-122/issue-1/0007-2745-122.1.098/Interactions-of-climate-and-solar-irradiance-can-reverse-the-bioclimatic/10.1639/0007-2745-122.1.098.short)). Two solutions were identified to increase the resilience of rainforest diversity, relevant to both extant and future forests.

1. Landscape topography and stand structures can maintain the necessary high moisture conditions despite projected future summer droughts ([*Forest Ecology and Management*](https://www.sciencedirect.com/science/article/pii/S0378112719320663), [*The Lichenologist*](https://www.cambridge.org/core/journals/lichenologist/article/abs/climate-change-refugia-landscape-stand-and-treescale-microclimates-in-epiphyte-community-composition/AD2F7228423F4CA7A619DB426375EDDD), [*Global Change Biology*](https://onlinelibrary.wiley.com/doi/abs/10.1111/gcb.15514)).
2. Extending rainforest within local dispersal distances (<100 metres) was most effective for the recovery of vulnerable species populations ([*Restoration Ecology*](https://onlinelibrary.wiley.com/doi/abs/10.1111/rec.12517), [*Biological Conservation*](https://www.sciencedirect.com/science/article/pii/S0006320717311072)).

These results have helped shape the spatial-temporal planning by members of the Alliance for Scotland’s Rainforest. Collaborating with Forest Research, training and monitoring schemes have been developed that extend concern for rainforest diversity into Scotland’s wider forest estate, e.g. for continuous cover forestry (published in [*Edinburgh Journal of Botany*](https://www.cambridge.org/core/journals/edinburgh-journal-of-botany/article/abs/epiphyte-response-to-woodland-habitat-condition-assessed-using-community-indicators-a-simplified-method-for-scotlands-temperate-rain-forest/C26DA57C910459B68515006261AB2553)).

**Increased camouflage mismatch in mountain hares due to climate change**

There is growing evidence that many wildlife species are failing to adapt to rapid climate change. Understanding species' capacity to move and adapt to climate and land-use change is critical to implementing effective mitigation. Working with colleagues in the United States (University of Michigan, University of Montana, Pennsylvania State University), research that was part-funded by North Carolina State University showed that mountain hares in Scotland have an increasing camouflage mismatch due to less snowy winters. Mountain hares moult from a dark coat in summer to a white coat in winter to maintain camouflage against snowy landscapes. Due to climate change the duration of snow cover is decreasing. However, mountain hares do not appear to be changing the timing of their moult to coincide with this change, leading to a 'phenological mismatch' in seasonal camouflage. The observed lack of change in the timing of important life events, or 'phenological shift', an organism's ability to adapt the timing of their life events like moult to changing environmental conditions, can endanger the survival of a species.

The reasons for the lack of adaptation are unclear but could be because of a lack of natural predator pressure in Scotland, a lack of genetic diversity amongst mountain hare populations, or the rapid rate of climate change is outpacing the capacity of the hare to adapt. To mitigate the risks of climate change, it is important to maintain landscape connectivity to enable species to redistribute themselves in a changing landscape. Findings were published in the [Proceedings of the Royal Society B](https://royalsocietypublishing.org/doi/10.1098/rspb.2020.1786), and have been downloaded over 2,000 times, with a current Altmetric score of 113.

**Global biodiversity crisis**

The global biodiversity crisis affects many taxonomic groups in different regions of the world. Decoupling local versus global patterns of biodiversity, and analysing multiple taxonomic groups, gives vital information about where, what, and at which scale management or conservation efforts should be targeted. Multi-taxon and multi-locational analyses of biodiversity trends are rare and so a Europe-wide collaboration including SEFARI researchers gathered and analysed 161 biodiversity time series trends ranging from 15 to 91 years, covering 6,200 marine, terrestrial, and freshwater species from 21 European countries. The results were published in [Nature Communications](https://www.nature.com/articles/s41467-020-17171-y.pdf) in 2020. The paper has been downloaded over 13,000 times and currently has an Altmetric score of 175. The results showed that local trends in biodiversity often deviate significantly from global patterns. In particular, the composition of species communities has undergone extensive changes at the local level.

For northern Europe, the trend is towards an increase in diversity and species numbers which is being driven by rising temperatures, and the replacement of traditional fauna and flora with new species that are usually adapted to warmer conditions. The results highlighted declines in the abundances of insect species in the Atlantic biogeoregion, corroborating recent reports of worldwide declines of local terrestrial insect communities. The study also highlighted the complexity of biodiversity dynamics, and that gathering standardised long-term data, and environmental data alongside biodiversity, is key to understanding trends and enabling better predictions of trends and drivers of biodiversity change.

**Natural pest management as an alternative to pesticides**

Natural pest management has considerable potential as an alternative to pesticides. Parasitoids are an important part of sustainable pest control. However, a better understanding of pest-natural enemy interactions is essential to fully harness the potential benefits and prevent unintended disruption to natural ecosystems.Aphid populations are a major crop pest and parasitoids are a potential means of chemical-free control. However, some lines of aphid are resistant to attack by parasitoid wasps and populations of aphids often contain a mix of susceptible and resistant lines. Previous models cannot explain the coexistence with realistic fitness costs of resistance. It is essential to be certain that the use of parasitoid controls does not lead to the extinction of susceptible aphid lines and dominance of the resistant lines, and that population size is stable rather than following cycles of boom and bust.

Work in the SRP (published in [*Journal of Animal Ecology*](https://besjournals.onlinelibrary.wiley.com/doi/10.1111/1365-2656.13189)) identified a mechanism whereby stable coexistence of both susceptible and resistant lines is promoted if parasitoids are more efficient at handling the aphid phenotype they encounter most often. It was found that searching efficiency and fecundity were key to system stability, but that development time was not important. This informed experiments to obtain accurate estimates of aphid fecundity and drought stress, results from which suggest that consequent reductions in fecundity could cause population cycles. Insect movement is notoriously hard to observe so spatially explicit models have been used to elucidate the results of the most proposed parasitoid searching strategies so that experiments can be performed to identify those which are plausible. The research identified a mechanism which strongly promotes stability in complex systems and is applicable to a broad range of consumer-resource systems in competitive environments. It can lead to effective predictive models of ecosystem resilience and highlights the importance of generalist consumers in promoting biodiversity in natural systems.

**Monitoring eDNA in a sentinel species for environmental contamination**

The grey seal (*Halichoerus grypus*) is an important indicator species of environmental contamination. Development of methods to study faecal material from grey seals, collected from around Scotland in collaboration with the University of St. Andrews, enabled a global analysis of antimicrobial resistance (AMR) gene carriage by seals. The findings provide valuable information on the circulation and accumulation of these genes in Scottish coastal waters and address an important knowledge gap regarding the spread of AMR genes through the environment.

Cutting edge Nanopore sequencing technologies were employed to further characterise microbial risks. This methodology enables the rapid identification of bacteria and AMR genes in complex samples enabling a wide survey of microbial contaminants to be carried out, with analysis of sequence data revealing potential transmission routes. Research findings were presented at four conferences including the [6th World One Health Congress (Virtual Edition)](https://protect-eu.mimecast.com/s/-e4PClOjDHojgrmtGtfWz?domain=moredun.org.uk), and two publications are in preparation. This work underpinned the development of an EASTBIO PhD studentship, which commenced in 2021 and focusses on assessing Nanopore technology as a novel tool for monitoring environmental contamination. Methodologies developed in the SRP can potentially be applied more widely to investigate transmission events at the wildlife-livestock interface and the effects of climate change and other environmental pressures on microbial carriage by a range of indicator species. SEFARI scientists contributed to a related study that revealed that the seal microbiome may be influenced by age and when young, their terrestrial habitats [Watkins et al. (2022) MicrobiologyOpen, e1281](https://protect-eu.mimecast.com/s/rShYCmwlGF59Ex8COouU8?domain=onlinelibrary.wiley.com).

**The impact of invasive and non-native species on plant health and biodiversity**

Healthy and diverse plant communities are fundamental to global biodiversity, but many pests and pathogens threaten plant health and ecosystem function. SRP work to identify the risks from invasive and native pests and pathogens used novel methods to identify the range of threats and their potential impacts to Scottish ecosystems. A method for DNA-based barcoding of an important group of plant pathogenic species of Phytophthora has detected known and unknown species in plant nurseries and natural ecosystems. This work was published in [PeerJ](https://peerj.com/articles/6931/) and has an Altmetric score of 22.

Research improved the software for processing large data sets, available [here](https://thapbi-pict.readthedocs.io/en/latest/index.html). Modelling tools were developed to predict the spread of pests across heterogeneous landscapes based on reported pest presence at given times and locations and have, for example, informed the implementation of the Scottish Forestry control policy for the pest *Dendroctonus micans*. Applications to other pests are being explored in collaboration with the University of Strathclyde.

If a plant pest or pathogen causes a significant decline in the population of a plant species this can have a wide range of cascading effects on both the biodiversity associated with that plant species and on ecosystem functioning. SEFARI researchers published 11 peer reviewed papers related to this topic during this SRP. Work on the impact of declines in oak, ash and box on biodiversity and ecosystem function was published in the [New Journal of Botany](https://doi.org/10.1080/20423489.2016.1171454), [Baltic Forestry](https://www.slu.se/globalassets/ew/org/inst/mykopat/forskning/stenlid/advances-in-ash-dieback-research.pdf), [Biological Invasions](https://doi.org/10.1007/s10530-018-1799-8), [Biological Conservation](https://www.sciencedirect.com/science/article/pii/S0006320718317920?via%3Dihub) and [Data in Brief](https://doi.org/10.1016/j.dib.2019.104120). A data set of all 2,300 species associated with UK oak trees was published at [EIDC](https://catalogue.ceh.ac.uk/documents/22b3d41e-7c35-4c51-9e55-0f47bb845202). The research also sought to identify how to replicate the functions and biodiversity of threatened plant species, which were published in [Ecosystems](https://link.springer.com/article/10.1007/s10021-015-9953-y), [Applied Vegetation Science](https://onlinelibrary.wiley.com/doi/full/10.1111/avsc.12569) and [Trees Structure and Function](https://link.springer.com/article/10.1007/s00468-020-02035-1). The impact of tree loss due to disease on species dispersal was assessed in a collaboration with the University of Aberdeen and published in [Ecological Informatics](https://doi.org/10.1016/j.ecoinf.2017.10.010). Most recently, SEFARI researchers showed how the cumulative impact of multiple host species loss from plant diseases causes a disproportionate reduction in associated biodiversity, published in the Journal [of Ecology](https://doi.org/10.1111/1365-2745.13798). Throughout the SRP the work was presented to practitioners and policy makers through a variety of talks and workshops e.g. to Woodland Trust, Small Woods Association, CIEEM, and in publications aimed at practitioners such as [Forestry](https://doi.org/10.1093/forestry/cpy040) and Forest Research notes (see [here](https://www.forestresearch.gov.uk/publications/ecological-implications-of-oak-decline-in-great-britain/)).

**Developing new insights on governing for multiple benefits**

Managing the environment for multiple goals and benefits, through an integrated approach, is an objective which is challenging in practice. By using multiple methodologies in two parts of the SRP over 5 years, and in close collaboration with policy and agency staff within Scotland and across Europe, new insights have been developed on where and how this may be achieved. These are articulated in publications in leading journals (e.g. [Land Use Policy](https://doi.org/10.1016/j.landusepol.2020.104709), [Water](https://doi.org/10.3390/w11030598)), book chapters developing integrative insights (e.g. [Degradation of Soil and Water Resources: Regional Strategies for Assessing and Addressing a Lingering Global Issue](https://books.google.co.uk/books?id=ddZbEAAAQBAJ&dq=Napier.+(ed.).+Degradation+of+Soil+and+Water+Resources:+Regional+Strategies+for+Assessing+and+Addressing+a+Lingering+Global+Issue.&source=gbs_navlinks_s)), and recommendations for practice and methodologies [Participatory Approaches - Principles and Practices for River Restoration Projects](https://onlinelibrary.wiley.com/doi/10.1002/9781119410010.ch14)). The implications for future high-level biodiversity and water policies in Europe also fed into high profile papers with researchers from other academic institutions across Europe in [*Conservation Letters*](https://doi.org/10.1111/conl.12771) and [*Science of the Total Environment*](https://doi.org/10.1016/j.scitotenv.2018.12.255)*.* Recent work (in submission with Political Ecology and Environmental Policy & Governance) draws attention to the governing practices of individuals.

**2.1.5. SCIENTIFIC RESILIENCE**

**International research on plant-mediated regulation of soil functions**

A group of people sitting in a circle in the woods

Description automatically generated with low confidenceNovel isotope approaches developed as part of the SRP have demonstrated genotype-specific impacts of barley cultivars on soil processes underpinning nutrient cycling and soil carbon storage. This new understanding of the bases for plant-soil interactions was used as proof of concept for application to maize production systems in southern Africa under the BBSRC Global Challenges Research Fund initiative. Three projects, a Foundation award, Standard project, and Translation Grant were funded (in 2017, 2018 and 2020 respectively, total value £2.85M, SEFARI value £0.65M). The research demonstrated maize genotype-specific impacts on soil organic matter (SOM) mineralisation and soil storage of plant-derived carbon, including within varieties developed for drought tolerance and suited to the southern African environment. Subsequent research identified, for the first time, genetic locations of maize genes mediating plant-soil interactions impacting soil biogeochemical processes. This resulted in engagement with the largest seed supply company in the region (SeedCo) and a series of trials on smallholder farms across Zimbabwe and Malawi. The smallholder communities supporting on-farm trials were engaged through community meetings to discuss the aims of the research and benefits to sustainability of the soil resource. The research was done within the context of locally applied soil management practices (Conservation Agriculture and legume intercropping) and used a combination of field and laboratory experimentation to demonstrate the efficacy of maize cultivar selection to promote beneficial soil functions. The funding enabled the application of SRP research in a global context, providing training in the approaches to UK and African researchers,

**Greenhouse gas monitoring and modelling networks**

Scientific capability developed in the SRP on the measurement and modelling of greenhouse gas emissions levered over £7M of funding during the period of the SRP. In 2018, funding was received from the Norwegian Research Council (SEFARI value £0.27M) to design ‘Climate smart management practises for Norwegian organic soils’. At that time, the Norwegian Parliament was about to vote on prohibiting the cultivation and drainage of peatland areas, and this project was launched to provide evidence to inform this policy. In 2020, SEFARI researchers were part of a £1.03M grant (SEFARI value: £0.59M) from NERC (RETINA), which will help design strategies to monitor and improve environmental quality and reduce Greenhouse Gas (GHG) emissions from managed ecosystems to meet the target of net zero GHG emissions in the UK by 2050. Plans for this project are to launch a spin-out company in 2022 (CarbonXtras) to exploit the outputs of RETINA, creating more green jobs and societal impact.

In 2021, SEFARI researchers were awarded a NERC-Capital grant (£1M) to build the first tall tower in Scotland to monitor GHG emissions. This state-of-the-art facility, envisioned as a 100-metre-tall tower, seeks to enhance Scotland’s ability to mitigate climate change by enabling environmental scientists measure the composition of greenhouse gases and model future changes. It will enable researchers to answer key questions such as whether the UK and Scotland are meeting their GHG emissions reduction goals, what role the agricultural sector plays in atmospheric pollution, and how climate change is impacting GHG levels in the UK and Europe. In 2022, SEFARI researchers secured funding (2022-25; total value c.£1.2M; SEFARI value £100K) for an international project on “Synergies in integrated systems: Improving resource use efficiency while mitigating GHG emissions through well-informed decisions about circularity (SENSE)”. The aim of the project is to identify measures that improve circularity in crop-forest-livestock integrated systems and mitigate GHG emissions. SENSE brings together 10 Institutions from 7 countries (4 from Europe, 3 from South America).

The unique capacity of a SEFARI institute to act as network co-ordinators for eddy-covariance based greenhouse gas flux research and national scale modelling efforts for Scotland has led to a significant number of major funding successes that cement its leading role and expands capabilities in several areas. The SEFARI-led [NERC MOTHERSHIP](https://twitter.com/PeatMothership) project is a £3.7 million (SEFARI value £0.9M), 5-year, Large research grant collaboration with UKCEH, University of Exeter, University of Leeds, University of Nottingham and University of the Highlands & Islands, and 23 project partners from around the world. The project creates a UK-wide network of greenhouse gas flux and ancillary observations, Earth Observation, and hydrological modelling to understand the impacts of management on contemporary peatland functioning. It will operate alongside the development of a peat-specific version of the UK land surface model JULES to predict how peatlands will behave under climate change and current land use, and what strategies should be taken to minimise future carbon losses.

Further success included the recent WET HORIZONS collaborative award from EU Horizon Europe (2022-26; total value c.£5.1M; SEFARI value £1.1M), in which two SEFARI partners are in a consortium of 14 organisations. The project will improve the current data available from pristine, drained, and rewetted peatlands, floodplains, and coastal wetlands, model the effects of typical restoration measures under variable conditions, and analyse the potential socio-economic impacts, finally delivering guidelines on best management practices.

SEFARI were also awarded several capital equipment grants to expand the eddy covariance network on peatlands with a further total of 7 towers, taking the complement to 12 stations (£200K in 2017-18 from Scottish Natural Heritage, £453K in 2019-20 from NatureScot Peatland ACTION, and £1M in 2022-23 from Scottish Government). This funding safeguards the long-term data capture from such networks where not covered under SRP or by other externally funded projects (£114K in 2020-22, NatureScot Peatland ACTION).

**Co-creating transformation with economic sectors**

The EU Horizon 2020 project ‘Mainstreaming Ecological Restoration of freshwater-related ecosystems in a Landscape context: Innovation, upscaling and transformation’ ([MERLIN](https://project-merlin.eu/)) (2021-25; total value >£20M; SEFARI value £740K), involves 45 partner organisations across Europe, including a SEFARI institute and UKCEH. The project is evaluating 17 demonstration freshwater restoration projects clustered into peatlands/wetlands, small rivers and large (trans-boundary) basins. These clusters will then identify ways to innovate and become Nature-based Solutions (NbS), expanding their scope beyond ecological function. The innovations will be modelled in terms of where they can be out scaled, with related work on how they can be financed.

SEFARI led work will identify how to mainstream freshwater NbS across the EU, working with six economic sectors (Agriculture, Hydropower, Insurance, Navigation, Peat Extraction and Water Supply). To date, the research has set up a community of practice, held roundtables and interviews with sector representatives and undertaken desktop research to establish the challenges and opportunities in making aquatic landscape scale upstream NbS part of normal business practice.

**Diversity is resilience**

SEFARI researcherscoordinated theEU H2020 project on [TRansition paths to sUstainable legume-based systems in Europe](http://www.true-project.eu/) (TRUE, 2017-21; total value £4.1M, SEFARI value £0.56M). The project delivered a multi-actor and transdisciplinary approach, the foundation for which was the formation of Legume Innovation Networks across three different biogeographical zones (Continental, Mediterranean and Atlantic), and which also comprised a suite of 24 innovative Case Studies. The strategic workplan determined the role of legume-based systems indicators to elucidate how ‘three pillars of sustainability’ (environment, economics, and society), may be best resolved.

In a second EU H2020 project, ‘[A novel and integrated approach to increase multiple and combined stress tolerance in plants using tomato as a model’](http://www.tomres.eu/) (TomRes,total value £4.95M, SEFARI value £0.37M) SEFARI researchers delivered a transdisciplinary-based approach for a system level synthesis of the project findings, and two user friendly Decision Support Systems for practitioners to ensure resource use efficient production of tomatoes in field- and glasshouse-based production environments. Both projects prove highly successful, producing a wide range of Open Access project outputs which can be found on the project websites, and dedicated project Communities on [Zenodo](https://zenodo.org/).

**Building on the Strategic Research Programme to achieve global reach**

SEFARI researchers who have been studying the integrated and sustainable management of Scotland’s agricultural systems are applying this experience in settings around the world. The EU funded project FRAMEwork, led by SEFARI researchers, aims to promote biodiversity sensitive farming through a collective, landscape scale approach. The team of natural, economic, and social scientists is working with farmers and other actors from across Europe to co-design, test, and implement the approach. In a second EU funded project, IPMWORKS, the focus is on developing national and European wide farmer networks to drive the adoption of integrated pest management as a key contributor to the development of sustainable farming systems.

Climate change is already having a significant impact on the smallholder farmers of sub-Saharan Africa. The SEFARI team has been funded by UKRI to form a partnership with the Kenya Agricultural and Livestock Research Organisation and together they are exploring methods to evaluate and promote system-wide, climate smart changes to farming. Taking a one health approach, the team will also be linking their expertise with public health scientists to tackle the problem of nutritional disease in small island states in the Caribbean, South-east Asia, and the South Pacific, through improved, more sustainable food production.

These projects have a combined value of more than £16M of which £1.7M is for SEFARI, and together they illustrate how, with the support of the SRP, Scotland’s researchers can make a significant contribution to tackling global challenges.

**Nature based Solutions and green infrastructure**

Knowledge on Nature-Based Solutions and Green Infrastructure developed within the SRP contributed to leveraging £103K on [Green infrastructure: Enhancing biodiversity and ecosystem services for territorial development](https://www.espon.eu/green-infrastructure) (GRETA) funded by EU [ESPON](https://www.espon.eu) (European Grouping on Territorial Cooperation). Green Infrastructure consists of interconnected multifunctional green spaces and green features. This project facilitated the development of new research partnerships and disciplinary collaborations to explore and compare Scotland to other settings. The resulting principles and challenges for implementing Green Infrastructure in the UK are reported at <https://sefari.scot/research/making-green-infrastructure-socially-inclusive-principles-and-challenges>.

**2.2. PRODUCTIVE & SUSTAINABLE LAND MANGEMENT & RURAL ECONOMIES THEME**

**2.2.1. SUPPORTING POLICY AND PRACTICE**

**Stakeholder Engagement and Knowledge Exchange for crop research**

Accessing decision makers within industry is crucial to the successful transfer of innovations emerging from SRP research. Outputs were showcased at grower and industry events throughout 2016-22 (e.g. [SEFARI](https://sefari.scot/plant-and-animal-health), [Potato IPM Virtual Tour](https://ipm.hutton.ac.uk/), [Agronomy Roadshows](https://www.sruc.ac.uk/all-news/agronomy-winter-roadshows-go-digital/), [AHDB Agronomy Conferences](https://ahdb.org.uk/events/agronomists-conference-2021)). Three major crop events were held annually. At [Arable Scotland](https://www.arablescotland.org.uk/) (online [2020](https://www.arablescotland.org.uk/virtual-event-2020)and [2021](https://www.arablescotland.org.uk/virtual-event-2021); previously known as Cereals in Practice) SEFARI researchers participated in sessions to discuss Scotland’s commitment to [net-zero](https://youtu.be/fCbTGVBVupY), [sustainable rotations](https://youtu.be/xKZLwQ4T-nc), [IPM](https://www.youtube.com/watch?v=FL_RJ94MOQQ) and [new cash crops](https://youtu.be/MKxGiriZbNg), using research findings from the SRP. [Potatoes in Practice](https://pip.hutton.ac.uk/), the UK’s largest field event for potatoes, returned to an on-site event in 2021 with a focus on new potato varieties, IPM and trade challenges. [Fruit for the Future](https://www.hutton.ac.uk/events/fruit-future-2022) (online [2020](https://www.hutton.ac.uk/news/fruit-future-2020-programme-announced)), the annual showcase of soft fruit research, included scientific presentations, field demonstrations and walks through experimental plots. Opportunities on the day included growers participating in an annual Spotted Winged Drosophila Soft Fruit clinic, and activities for  [advice](https://www.hutton.ac.uk/news/blueberry-growers-advised-remain-alert-about-recently-detected-pest) to be widely disseminated to the [soft fruit industry](https://horticulture.ahdb.org.uk/publication/0617-management-and-control-spotted-wing-drosophila), SASA and policy makers.

**Reducing pesticide use in practice**

Research on potato Late Blight and Ramularia in barley was conducted by SEFARI research grouped under Integrated Pest Management (IPM). Pathogen population changes were communicated to a wide range of industry stakeholders via engagement activities such KE events, uploads to the [EuroBlight](https://agro.au.dk/forskning/internationale-platforme/euroblight/currently/news/nyhed/artikel/monitoring-2021) database and articles in the farming press. The evolution of the late blight pathogen population has influenced IPM strategies via updates to the [FRAG-UK](https://media.ahdb.org.uk/media/Default/Imported%20Publication%20Docs/AHDB%20Cereals%20&%20Oilseeds/Disease/FRAG%20Potato%20late%20blight%20guidelines%20(May%202018).pdf) guidelines that have shaped growers’ choices of fungicide products. Over the 2016 to 2020 growing seasons the area of seed and ware potatoes treated with Fluazinam has fallen from 50,943 ha to 10,602 ha (Scottish Pesticide Surveys Database, [SCOPES](https://www.sasa.gov.uk/content/scottish-pesticide-surveys-database-scopes-arable-crops)). This has prevented crop losses and prolonged the effective life of the active ingredient. SEFARI research also led to the development of a new improved national warning system for potato late blight ‘[the ‘Hutton Criteria](https://www.hutton.ac.uk/news/hutton-criteria-potato-late-blight-risk-analysis-unveiled-ahdb-conference)’) which has been demonstrated to inform reductions in the use of fungicide without crop losses.

The Hutton Criteria forms part of a [commercially run advisory tool](https://www.syngenta.co.uk/news/agronomy-issues/blightcast-2020-vision) that promotes effective and timely fungicide application. IPM approaches to late blight control have also been trialled in collaboration with industry, achieving a reduction in fungicide costs of 28% through use of host resistance. The Ramularia population has shown changes in fungicide susceptibility to succinate dehydrogenase inhibitor and azole fungicides, and the loss of an effective multi-site fungicide has impacted on growers [(FRAG-UK 2021)](https://projectblue.blob.core.windows.net/media/Default/Imported%20Publication%20Docs/AHDB%20Cereals%20&%20Oilseeds/Disease/FRAG/FRAG%20fungicide%20resistance%20management%20in%20cereals%202021.pdf). IPM field trials demonstrated that priming crops for disease resistance can potentially reduce fungicide use by 50% in spring barley.

**Management of Potato cyst nematode (PCN) for industry sustainability**

Research on potato cyst nematode (PCN) within the SRP has been associated with close collaborative ties with nematologists at SASA and the wider stakeholder community. The SEFARI research team leads a working group, managed by Scotland’s Plant Health Centre, aimed at identifying policy, industry, and actions to minimise the threat of PCN to Scottish potato growers. In collaboration with industry and SASA, future research priorities were identified directly from work in the SRP and external funding, including development of PCN resistance marker, tolerance, and breeding; PCN biology; economic analysis; and Integrated Pest Management practices. Following a [PCN working group report](https://www.planthealthcentre.scot/publications/pcn-working-group-final-report#:~:text=Abstract%20Following%20a%20Ministerial%20round%20table%20meeting%20on,clear%20strategy%20for%20dealing%20with%20the%20PCN%20crisis.), the Scottish Government announced funding for a major [project](https://www.gov.scot/news/safeguarding-scotlands-bulb-and-potato-sector/) worth c.£2.2M over 5 years to ensure implementation of these and other priorities.

**CT-measured rumen volumes of sheep to predict methane emissions:** Rumen volume, as measured by Computerised Tomography (CT), positively correlates with increased methane emissions from sheep. Using CT image archives, statistically significant breed differences in rumen volume were identified between divergent sheep breeds reared together on low-ground pastures, with a hill breed (Scottish Blackface) having a 30% larger rumen, on average, than a terminal sire breed (Texel), at the same live weight. Genetic analyses of rumen volumes of Texel lambs from the national breeding programme found this measurement to be heritable, uncorrelated to growth traits, but favourably correlated to carcass composition, carcass weight and muscularity ([implying that lambs with higher muscularity, or proportion of weight as carcass, have smaller rumens](https://www.publish.csiro.au/AN/AN21423)). Different terminal sire breeds also differed significantly in rumen volume at the same live weight, and smaller rumens were generally associated with higher breeding values for composition and muscularity. This suggests no within-breed trade-offs for these production traits.

Methodologies were applied to data from the international [Grass To Gas](https://www.eragas.eu/en/eragas/research-projects/grasstogas.htm) project, and preliminary results suggest no effect of rumen volume on feed efficiency. However, relationships with economically and environmentally important traits should be investigated in different production systems before breeding recommendations are made. Findings were communicated to national and international stakeholders and resulted in further research applications and funding, as well as industry interest and uptake. This work is helping to inform international strategies to breed sheep for reduced methane emissions.

**Behavioural and economic benefits of enrichments for free-range hens**

Laying hens are given enrichments inside the shed to encourage foraging and reduce feather pecking. SRP research studied which are most favourable in relation to hen behaviour and of least cost to producers. Of four enrichments provided to eight commercial flocks of 16,000 free-range hens, pecking blocks (£6,720/flock) and Lucerne (alfalfa) hay bales (£2,080/flock) provided consistent interest to birds, based both on observations of hens in the vicinity of the enrichments, interacting with the enrichments, and least inactivity near the enrichments. Hens were most interested in pelleted feed (£3,008/flock) at the time of scatter (which was twice per day), but pelleted feed was consistently of greater interest than ropes, which hens found least attractive. Feather scores (a proxy measure for feather pecking) worsened with age, but differences between treatments were small and variable between ages. While ropes were the significantly cheaper enrichment (£6.64/flock), behaviour at ropes was indistinguishable from behaviour away from any enrichments, and thus did not sufficiently encourage foraging and other desirable behaviours. A balance between encouraging positive hen behaviour and cost to the producer needs to be considered in the practical use of any enrichment.

This work was shared with all participants in the study (i.e., farmers and enrichment providers). It was showcased in British Free Range Egg Producers’ magazine “The Ranger” and at the Pig and Poultry Fair, May 2022 (approximately 10,000 attendees). The findings from this work have also been shared with the RSPCA, reflecting its relevance to their accreditation scheme on enrichment requirements for hens. The full paper can be found [here](https://www.mdpi.com/2076-2615/12/8/995).



*Enrichments:**From top left clockwise, Lucerne hay bales, pecking blocks, jute ropes, and pelleted feed scattered in litter.*

**Tools for future sustainable control of sheep scab** [Includes pre-2016 funding]

Tools for the sustainable control of sheep scab have been developed over successive SRPs. Their availability is particularly timely following the identification of *Psoroptes ovis* mites resistant to the macrocyclic lactones, agro chemicals normally relied upon for control. Optimisation and roll-out of a diagnostic test, along with development of a prototype vaccine were prioritised. The diagnostic test ELISA is now being used nationwide, leading to funding from the Veterinary Medicines Directorate to develop strategies for its use in regional and national (UK) control programmes. Additional funding was leveraged from:

1. Rural Development Programme for England (RDPE) ([For Flock’s Sake](https://www.nationalsheep.org.uk/nsa-and-for-flocks-sake/) control programme in England), enabling the recruitment of 300 farmers across 3 hotspot regions;
2. a BBSRC-funded control scheme in Northern Ireland;
3. two proposed Government-funded control schemes in Scotland and Wales.

These additional funds enabled coordinated control across all four UK nations.

In conjunction with the Scottish Sheep Scab Industry Working Group, discussions are ongoing with policy contacts in Scottish Government on the focus area for a Scottish control scheme. The vaccine will have an important role in sustainable control, work on which has improved efficacy to >80%. One of the vaccine components is used in the diagnostic ELISA, meaning that the test cannot discriminate between infested and vaccinated animals. SEFARI scientists expressed a novel diagnostic antigen with comparable levels of performance. Once the vaccine is released this novel diagnostic antigen will be used, overcoming the problem of differentiating between vaccinated and (previously) infested animals.

**Recommendations on alternative land management and tillage adaptation** Understanding the impact of soil tillage and nature-based solutions, such as cover crops for maintaining soil health, is important for reducing soil degradation, and maintaining crop productivity and yields. Work in the SRP levered funding from the [AHDB](https://ahdb.org.uk/) for the [Management of Rotation](https://ahdb.org.uk/11140023-ahdb-rotations-research-partnership) project which included fundamental and practical implementation of research on plant/soil management interactions including tillage and cover crop systems (e.g. [VESS](https://www.sciencedirect.com/science/article/pii/S016719871630126X), [Carbon](https://link.springer.com/article/10.1007/s11368-020-02799-6), [Cover crops](https://www.sciencedirect.com/science/article/pii/S1161030121001349), [Differential Yield responses to Tillage](https://www.mdpi.com/2073-4395/10/5/686), [manuring](https://www.sciencedirect.com/science/article/pii/S0048969721029016?via%3Dihub)). Knowledge exchange also included conference attendance (ISTRO, [A](http://webistem.com/ISTRO2018/output_directory/cd1/data/articles/000121.pdf), [B](http://webistem.com/ISTRO2018/output_directory/cd1/data/articles/000154.pdf)), [project reports](https://ahdb.org.uk/platforms-to-test-and-demonstrate-sustainable-soil-management-integration-of-major-uk-field-experiments) and [practical implementations of knowledge](https://www.terranimo.uk/).

Exchanges of ideas between farm related stakeholders, researchers and policy makers were undertaken to enable the development and expansion of soil analysis methods such as [VESS](https://www.sruc.ac.uk/business-services/sac-consulting/agricultural-production/soils/soil-health-testing/#VESS), which also appeared in the [Royal Society Evidence Synthesis on Soil Structure](https://royalsociety.org/-/media/policy/projects/soil-structures/soil-structure-evidence-synthesis-report.pdf) report to inform the UK Government’s upcoming Agriculture Bill. Research and practice findings were reported at [technology based events](https://www.agri-tech-e.co.uk/agri-tech-week-2020-ahdb-technologies-to-enhance-soil-monitoring-and-crop-management/), industry events (LEAF Technical Day [2016](https://www.hutton.ac.uk/learning/leaf/technical-day-2016); Potatoes in Practice [2016](https://www.hutton.ac.uk/news/research-partnership-set-unearth-secrets-profitable-soils-throughout-rotation), [2018](https://www.hutton.ac.uk/news/potatoes-practice-looks-future-tatties); Cereals 2016, 2017; “Tillage Live”) and in the media ([Farmers Weekly](https://www.fwi.co.uk/arable/land-preparation/cover-crops/scottish-cover-crop-trial-shows-lift-in-spring-barley-yields), [from theory to field](https://www.cpm-magazine.co.uk/wp-content/uploads/2017/08/SoilAug17.pdf)). A multidisciplinary team developed [virtual tours](https://www.arablescotland.org.uk/virtual-tours) of farm trials which were presentedas part of [Guided Digital Crop Tours](https://thefarmingforum.co.uk/index.php?threads/3pm-guided-digital-crop-tour-session.321662/) (over 2,300 views) with additional interactions through [Arable Conversations](https://www.youtube.com/watch?v=xKZLwQ4T-nc&t=1s).

**Learning and change through Monitor Farms**

SRP research evaluated learning and change by farmers based on two Monitor Farms, in the Lothians and Morayshire. Findings were based on observations and interviews conducted across the three-year Monitor Farm programme period (2017-2020) and a virtual workshop conducted one year after the programme concluded (April 2021). The study provided in-depth qualitative insights into key features of successful on-farm demonstrations found to underpin community engagement and support capacity building among farmers. These included the acquisition of knowledge, approaches to decision-making, and challenging norms towards achieving individual and community legacy. The [final project report](https://www.hutton.ac.uk/sites/default/files/files/Monitor%20Farms%20final%20report%20Aug%2021.pdf) and [summary report](https://www.hutton.ac.uk/sites/default/files/files/Monitor%20Farms%20summary%20report%20Aug%2021.pdf) were shared directly with key stakeholders. An additional interactive seminar with AHDB was conducted to discuss findings with their research and knowledge exchange teams. This included an introduction to an online virtual farm tour developed with stakeholders to communicate results of the project. A further report presents [guidelines for virtual tour development and future work recommendations](https://www.hutton.ac.uk/sites/default/files/files/Virtual%20Tour_guidelines_CH_2022.pdf).

**Supporting guidance on joint ventures with new entrants**

The Scottish Land Commission funded a SEFARI organisation to undertake a project on ‘[Increasing land availability for new entrants](https://www.landcommission.gov.scot/downloads/5dd6a2d2ac866_McKee-et-al.-Final-report-to-SLC-Increasing-land-availability-for-new-entrants-2.5.2018.pdf)’ to inform their preparation of ‘A Guide To Joint Ventures with New Entrants’. The project team interviewed owners and managers of 30 large farms and estates in Angus, and Skye and Lochalsh during Summer and Autumn 2017. The interviewees were asked to describe the existing tenancies on their land and any innovative models and/or partnerships, e.g., joint ventures and contract farming. They also described whether they were willing to let land to new entrants and/or to enter new partnerships, such as contract farming arrangements. This provided a valuable insight into the motivations of, and barriers facing, landowners and existing farmers in enabling new entrants into agriculture, informing the development of the final [SLC Guidance document](https://www.landcommission.gov.scot/downloads/5dd809da1a89f_SLC-JV-GUIDE_v4.pdf). The [research briefing on new entrants](https://www.hutton.ac.uk/sites/default/files/files/research/srp2016-21/rd242outputs/Research_Note_New_Entrants_final_RD242_published.pdf) based on analysis of the Farmer Intentions Survey was included in the briefing notes for the Cabinet Secretary for Rural Affairs and Islands for the Scottish Parliament’s Rural Affairs and Islands Portfolio Questions on 2 September 2021:<https://www.gov.scot/publications/foi-202100245106/>.

**Support for policy – options appraisals (2016-19)** [includes pre-2016 funding]

SEFARI scientists provided ongoing support to Scottish Government on areas facing natural or other specific constraints (ANCs), which was a potential replacement for the existing Less Favoured Areas Support Scheme (LFASS). The options analysis included revisions of the biophysical data underpinning the designation of the ANC region, and [regionalisation options](https://ics.hutton.ac.uk/research/land-systems-research-team/cap-analysis/anc-analysis/) (defining rates and other bases of payments). This built on capacity developed through funding from the Scottish Government pre-2016. The materials generated were discussed in workshops with Scottish Government officials and formed the basis of advice to ministers and a Scottish Government led stakeholder workshop. The BREXIT referendum result paused the implementation of ANCs, and between 2017 and 2019, SEFARI researchers provided a series of options analyses on more incremental changes in LFASS payments, e.g., capping of payments, degressivity and parachute payments. All of these were used as part of advice to Scottish Government ministers. The analyses were co-funded from Underpinning Capacity via the Policy Advice with Supporting Analysis function.

**Supporting future agricultural policy decisions**

Diagram

Description automatically generatedSEFARI researchers provide analytical support and expert advice regarding future agricultural policy decisions in Scotland. This work informs RESAS analysts, policy leads, stakeholders, and Scottish Government ministers. Researchers led, and contributed to, the debate on design of future agricultural support mechanisms for better delivery of Scottish Government objectives. They provided expert and analytical support for the [Agriculture Champions](https://www.gov.scot/publications/future-strategy-scottish-agriculture-final-report-scottish-governments-agriculture-champions/), the [Farmer Led Groups](https://www.gov.scot/policies/agriculture-and-the-environment/farmer-led-climate-change-groups/#:~:text=Farmer%20led%20groups%20were%20established,upland%20farming%2Fcrofting)%20sectors.) and the [Agriculture Reform Implementation Oversight Board](https://www.gov.scot/groups/agriculture-reform-implementation-oversight-board/) (ARIOB). They informed stakeholder and policy thinking on the design of future Scottish agricultural policy, for example through a conceptual framework for future [environmental conditionality on direct agricultural support,](https://www.gov.scot/binaries/content/documents/govscot/publications/factsheet/2021/01/suckler-beef-climate-scheme-research-papers/documents/sruc-report-environmental-conditionality/sruc-report-environmental-conditionality/govscot%3Adocument/SRUC%2BReport%2B-%2BEnvironmental%2BConditionality%2BFINAL.pdf) and in working with NFUS on the [transition to future conditional agricultural support](https://www.nfus.org.uk/userfiles/images/Policy/0521%20NFUS%20Proposals%20For%20Future%20(Conditional)%20Support.pdf), reflecting the collective thinking of farmer led groups.

SEFARI researchers were commissioned to provide support on the development of future agricultural and land management policy. The policy advice provided is varied, drawing on different strands of research undertaken in the SRP. Topics on such support included the [Greening Review](https://ics.hutton.ac.uk/resources/land-systems-research-team/00523863.pdf); analysis on [Areas facing Natural Constraint](https://ics.hutton.ac.uk/resources/land-systems-research-team/00502612.pdf); assessment of [GHG emissions and mitigation potential for main Scottish farm sectors](https://www.gov.scot/publications/disaggregating-headline-smart-inventory-figures/); [estimation of support flowing to farm enterprise types](https://www.gov.scot/publications/estimation-sectoral-cap-payment-envelopes-2019/pages/5/); metrics and explanatory factors regarding [agricultural productivity](https://www.ruralbrexit.scot/wp-content/uploads/2020/04/Report-on-Scottish-Agricultural-Productivity_SRUC.pdf) and [farm business viability](https://www.sciencedirect.com/science/article/abs/pii/S0264837719308154);and the [re-distributive impacts of CAP 2014 reforms](https://ics.hutton.ac.uk/resources/land-systems/ARD_Stakeholders_2014_2019_as_presented.pdf). This work has fostered strong relationships between SEFARI researchers, RESAS and agricultural policy teams.

**Understanding the role of farming in the environment and reaching Net Zero** SRP expertise has enhanced policy understanding around transition to Net zero farming, including use of the farmer intentions survey to explore options for [agro-forestry and renewable adoptions](https://www.sciencedirect.com/science/article/pii/S0264837721005846). SEFARI researchers helped inform climate targets for agriculture for DEFRA through the Clean Growth through Sustainable Intensification project. In this, a range of stakeholders were engaged, leading to outcomes that included the development of environmental standards in agro-forestry and livestock for the [Environmental Land Management schemes](https://www.gov.uk/government/publications/environmental-land-management-schemes-overview), in particular the [sustainable farming incentive](https://www.gov.uk/government/collections/sustainable-farming-incentive-guidance). The work has also been used by organisations such as [WWF](https://www.wwf.org.uk/sites/default/files/2022-01/Farm-level%20interventions%20to%20reduce%20GHG%20emissions_Final%20Report_v8.pdf). It informed the Committee on Climate Change for [Non CO2 Abatement](https://www.theccc.org.uk/publication/non-co2-abatement-in-the-uk-agricultural-sector-by-2050-scottish-rural-college/) and the [6th Carbon Budget for agriculture and land use change](https://www.theccc.org.uk/wp-content/uploads/2020/12/Sector-summary-Agriculture-land-use-land-use-change-forestry.pdf), as well as underpinning measurements for calculating carbon potential in farming ( e.g. [hedgerows](https://www.whatdotheyknow.com/request/750215/response/1786766/attach/html/5/EIR2021%2011294%20Response.pdf.html)).

SEFARI capacity and expertise in the farm accountancy data network (FADN) led to a novel methodology to understand the [diversity of GHG emissions in Scottish farming systems](https://www.climatexchange.org.uk/media/5263/cxc-greenhouse-gas-emissions-from-scottish-farming-an-exploratory-analysis-of-the-scottish-farm-business-survey-and-agrecalc-march-22.pdf). This work coupled the Federation of Small Business in Scotland and [Agricalc](https://www.agrecalc.com/) estimates as a first of its kind analysis this is of economic and environmental variances, and led to estimates of [emissions intensity](https://pure.sruc.ac.uk/en/publications/exploring-the-emissions-intensity-of-scottish-sheep-and-cattle-li) with Scottish livestock farming.

**2.3.2 SUPPORTING INNOVATION AND THE ECONOMY**

**Innovation for the development of resilient soft fruit crops**

The soft fruit industry faces challenges from biotic and abiotic stresses, climate change, lack of pesticide choice and labour constraints. SRP research is helping address those challenges through the development of new varieties that can grow in low input regimes and tolerate multiple and complex stresses. Genetic research in the SRP has enabled the development of a range of tools, both [genetic/genomic](https://bmcgenomdata.biomedcentral.com/articles/10.1186/s12863-018-0666-z) and [imaging technologies](https://link.springer.com/article/10.1186/s13007-017-0226-y) across soft fruit crops, that increase understanding of how plants react to complex stress and to identify genetic markers for [traits of importance](https://www.mdpi.com/2073-4395/11/4/794) to use in breeding programmes. A good example of this has been in the development and release of the raspberry [Glen Mor](https://www.huttonltd.com/services/plant-varieties-breeding-licensing/raspberry/glen-mor) which is [resistan](https://www.fruitnet.com/fresh-produce-journal/jhl-hails-raspberry-breakthrough/182733.article)t to the major raspberry pathogen Phytophthora root rot. This work identified mechanisms of resistance and levered [additional funding](https://gtr.ukri.org/projects?ref=131890) from InnovateUK to understand this mechanism and to utilise it in sustainable suppressive substrate production. Other examples of research to help the industry tackle challenges are examination of the limitations on [yield in blueberry production](https://gtr.ukri.org/projects?ref=102130), which led directly to [on-farm solutions](https://onlinelibrary.wiley.com/doi/full/10.1002/jsfa.10967) to increase photosynthetic capacity.

**A potato pipeline – from gene discovery to commercial deployment**

In Scotland 28,000 Ha of potatoes (value £209M) are grown annually. The potato genome project, co-funded by the SRP, culminated in the [publication of the potato genome](https://www.nature.com/articles/nature10158/) (>1,000 citations). This has underpinned the development of [new potato cultivars](https://www.huttonltd.com/services/molecular-diagnostics/drenseq) with improved quality, yield and resource efficiency traits and resilience to key biotic and abiotic stresses. [A new genomic tool](https://onlinelibrary.wiley.com/doi/full/10.1111/pbi.12997) (RenSeq) was developed in the SRP which enables the identification of major pests and disease resistance genes against [late blight](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5945768/pdf/122_2018_Article_3078.pdf), [PCN](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6449323/pdf/122_2019_Article_3278.pdf) and [viruses](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7021755/?report=reader), used with theUnderpinning National Capacity funded [Commonwealth Potato Collection](https://ics.hutton.ac.uk/germinate-cpc/#/home). The development of RenSeq levered funding from [BBSRC](https://gow.bbsrc.ukri.org/grants/AwardDetails.aspx?FundingReference=BB/S015663/1), with industrial partners leading to the successful development of markers for key resistance genes which are being used by a SEFARI commercial subsidiary, and companies [McCain](https://www.mccain.co.uk/) and [Greenvale](https://www.greenvale.co.uk/).

Building on the understanding of genetics developed in the SRP, funding was leveraged from Innovate UK, BBSRC and the [EU](http://www.g2p-sol.eu/Dr-Glenn-Bryan.html) for genetic studies into traits including [reduced tuber greening](https://sefari.scot/research/approaches-to-reducing-potato-waste-by-improving-home-storage-and-minimising-greening) (a major cause of potato waste amounting to 290,000 Tonnes per annum in the UK), [enhanced tuber dormancy](https://sefari.scot/research/potato-tuber-development-and-quality) and [heat tolerance](https://onlinelibrary.wiley.com/doi/10.1111/pbi.12760). Markers for greening have been developed with Branston/B-hive and markers that control tuber sprouting in storage through an industrial collaboration ([PepsiCo](https://www.pepsico.co.uk/) and [Bartletts](https://www.albertbartlett.co.uk/)). The impacts of markers in potato breeding include a rapid and reliable progeny screening for resistance traits and considerable cost-savings compared to field-based evaluations. A conservative cost estimate for the development of a new cultivar is c.£500K. Markers for ‘must-have’ traits, such as late blight resistance can reduce this cost by c.15% for each new cultivar.

**Diagnostics and monitoring for crop health**

Within a landscape of increasing disease threats, developments in diagnostics and monitoring of pests and pathogens underpin integrated pest management and Scotland’s good reputation for plant health. Blackleg is the main cause of downgrading and rejections in the seed potato industry. The development in the SRP of software toolssuch as [‘Pyani’](https://pypi.org/project/pyani/) enabled diagnostics to be developed for the identification of blackleg causing bacteria (downloaded and installed >14K times worldwide in 2017-18). The development of [rapid technologies](https://www.microbiologyresearch.org/content/journal/jgv/10.1099/jgv.0.001210) for [nucleic acid sequence analysis](https://www.frontiersin.org/articles/10.3389/fpls.2017.01770/full) enabled SRP researchers to design molecular diagnostic tests for a range of viruses infecting soft fruit crops, including [raspberry](https://link.springer.com/chapter/10.1007/978-3-319-99031-6_4), blueberry and blackcurrant. These are being used in-house and by commercial companies to ensure [fruit crop health](https://www.cabdirect.org/cabdirect/abstract/20183245145). Spotted Wing Drosophila threatens soft and stone fruit production; improved detection and monitoring protocols have been developed and provide an early alert to growers, facilitating timely and appropriate [control measures](https://link.springer.com/chapter/10.1007/978-3-319-99031-6_5). Advice on these pests and pathogens has been widely disseminated to the soft fruit industry, to SASA and to [policy](https://link.springer.com/chapter/10.1007/978-3-319-99031-6_6) teams. In response to an increase in *Fusarium* in harvested grain and associated risks of mycotoxins entering the human and animal food chain, techniques for the rapid and accurate identification of *Fusarium* species were developed. This facilitated testing informs Food Safety Scotland, processors, food testing labs and grain merchants on the health risks posed by *Fusarium* mycotoxins. Additionally, [studies](https://www.foodstandards.gov.scot/downloads/Chemical_contaminants_-_FSS_Mycotoxin_Workshop_report_final_-_December_2015.pdf) relating test results to environmental conditions provides greater understanding of disease epidemiology, in turn helping growers identify conditions which may necessitate management interventions to control disease.

**Development of potato varieties that are resilient to environmental stress**

For most potato varieties tuber yield is highly susceptible to even moderately elevated temperatures, with heat tolerant varieties important for Scottish seed exports (c.90K tonnes per annum) to growing markets in warm countries. SRP [research](https://onlinelibrary.wiley.com/doi/full/10.1111/pbi.12760) has identified heat tolerant varieties and the genetic code responsible for this trait. The work was extended via co-funding from the [Global Challenges Research Fund](https://www.ukri.org/research/global-challenges-research-fund/) for the [Quikgro](https://sefari.scot/news/quikgro-developing-potato-varieties-suited-to-sub-saharan-conditions) project. In collaboration with partners in Kenya and Malawi, the potato types carrying traits for heat tolerance, rapid maturity and virus resistance were [trialled](https://www.hutton.ac.uk/news/quikgro-developing-potato-varieties-suited-sub-saharan-conditions) in warm and dry environments, underpinning efforts to expand potato production in hot environments and mitigate potential impacts of climate change. All these link to maintaining yield, reducing inputs, and increasing food security for climate change mitigation.The field trial results in both Kenya and Malawi indicated that some of the sixty genotypes that were trialled performed well in these environments. End-user acceptability studies identified varieties preferred by both farmers and consumers, with traits such as short-dormancy and fast cooking particularly appreciated. Several genotypes were identified that had good processing traits and five genotypes were put forward for National Performance Trials in Malawi. In December 2021, these clones were officially accepted in Malawi for cultivation. This study provides an example of translation of SRP molecular physiological and genetic studies to the development of new varieties for the target environment.

**Commercial roll-out of Qualitative Behaviour Assessment (QBA)**

The on-farm roll-out of QBA across 12 ‘own brand’ supply chains of major UK retailer Waitrose was consolidated through an intensive collaborative programme of training and on-farm data collection. This was facilitated by the new QBA [mobile app](https://www.waitrose.com/ecom/content/about-us/our-farming/waitrose-animal-welfare-app). The app was completed with an in-built algorithm for data normalisation contributed by SEFARI statisticians, and with a range of functional adjustments and additions based on feedback from participating supply chain assessors. Supply chain teams developed their own lists of QBA descriptors and were given training in the use of the app to apply these descriptors to scoring emotional well-being in pigs, cows, sheep, goats, chickens, ducks, turkeys and salmon. Data collection for these species was initiated on over 1,500 farms. The evaluation of interim outcomes with participating assessors indicated that the app was effective in identifying outlying farms showing either excellent or reduced animal emotional well-being relative to the sampled pool of farms. The roll-out of the QBA app was well-received by businesses in supply chains which identify its value in helping to publicise their animal care skills to consumers and increase the economic benefits attached to their investment in high animal welfare standards. This potential was explored in a policy brief ([A Good Animal Life: Bringing awareness of animal sentience into farming practice, from SEFARI](https://sefari.scot/document/a-good-animal-life-bringing-awareness-of-animal-sentience-into-farming-practice)) and supported by extensive media coverage following the project’s winning of the BBC’s 2021 ‘Farming for the Future’ Award and the Compassion in World Farming’s 2022 Best Retailer Innovation Award. The animal welfare and socio-economic benefits to farmers developing a sentience-based practice is a subject of investigation being carried into the SRP 2022-27.

**Whole flock ultrasound screening, a major step forward**

The use of ultrasound screening to identify sheep with preclinical Ovine Pulmonary Adenocarcinoma (OPA; a transmissible lung tumour of sheep caused by Jaagsiekte sheep retrovirus) was developed during the 2016-2022 SRP and is a major advance towards control of this disease. The research, co-funded by the SRP and the Clyde Wind Farm Development Fund, established a test-and-cull programme on 20 different farms of which 10 remained in the programme for 4 or more years. The results showed that in most flocks the proportion of sheep testing positive reduced over time, with some flocks establishing a very low disease level thereby decreasing the risk of the sale of sheep carrying OPA. Results have been shared via leaflets, talks, [webinars](https://moredun.org.uk/resources/videos/2386) and a [Youtube video](https://www.youtube.com/watch?v=d_pMIDepay4).

This new option towards OPA control means that flock-owners have begun to discuss the disease openly, and to seek help to improve sheep welfare and farm profitability. Preliminary training has been provided to more than 100 vets to enable them to offer OPA screening to their clients, with discussions taking place with industry leaders and policy makers about how to move forward to an OPA assurance-type scheme. During this study it was possible, for the first time, to monitor the rate of OPA tumour growth in individual sheep, showing that [in some sheep the disease develops very quickly](https://link.springer.com/article/10.1186/s13620-018-0134-0). It was also possible to demonstrated that JSRV can be detected in exhaled breath of OPA- affected sheep. This new information is important towards understanding transmission of OPA and developing formal disease control or assurance schemes.

**New bovine respiratory disease complex test now accessible commercially** Bovine respiratory disease complex (BRDC) poses a significant threat to the dairy and beef industries throughout the world. BRDC is usually the consequence of primary viral and secondary bacterial infections, carrying an estimated cost of £50 M/year to the UK cattle industry. Early identification of the pathogens associated with each outbreak is beneficial to the timely management and control, and could reduce the prophylactic use of antimicrobials. SRP research identified, developed, validated, and transferred to a commercial partner, a new, fast BRDC diagnostic test which enables the early identification of pathogens present in an animal or a herd simultaneously (multiplex test). This has enabled better targeted treatment of disease outbreaks.

The test was initially developed by SEFARI scientists in collaboration with a commercial diagnostic company (Ausdiagnostic) and is based on a proprietary technology. It was validated and run in-house to support veterinary clinical investigations, and then transferred to a commercial veterinary testing laboratory where it superseded the previous methodology. The use of this test in the field enables faster disease diagnosis and intervention, reducing veterinary and medicinal costs and usage, allowing better herd management, animal welfare and disease prevention, and thus delivering savings to what is currently a very economically challenged business. A similar test, although not linked to the same proprietary technology, has been developed for abortifacient pathogens of cattle.

**Development of an open-source network for environment monitoring**

The use of low power sensors in agriculture and environmental monitoring has grown rapidly over recent years. A key component of such systems is the ‘end node’, which is any device which is capable of generating data (e.g. a sensor), sending that data over a low power wireless connection to a ‘gateway’, which in turn forwards it via wifi or 3/4G sim card to a server for processing. Commercial companies can supply components, expertise, and computing infrastructure, but some of these are expensive, and the data processing is opaque to the client. Additionally, there are potential issues around sending sensitive data to a third-party platform.

SEFARI research has created simple end nodes which record information about animal movement. Commercial gateways are used and been installed, [a novel open-source network server](https://www.chirpstack.io/) configured, and sensors integrated [from several different projects](https://glensaugh.hutton.ac.uk/climate-positive-farming/overview). [Data and visualisation outputs are provided using other open-source tools](https://lorawan.hutton.ac.uk/). Setting up this system is non-trivial and would require a significant level of expertise for an end user. A system is now in place at three SEFARI farms which allows rapid deployment and has generated interest from a commercial sensor developer.

**Outcomes-based monitoring for transition to agroecological cropping systems**

Traditional agri-environment incentive schemes, based on prescribed management interventions, often do not deliver the intended biodiversity or sustainability outcomes. Research at the [Centre for Sustainable Cropping](https://csc.hutton.ac.uk/) (CSC) located at a long-term [experimental platform](https://www.mdpi.com/2073-4395/9/8/438) at a SEFARI farm, and associated [farm networks](https://doi.org/10.3390/plants10122657), has produced a framework for [outcomes-based approaches](https://www.cabi.org/environmentalimpact/abstract/20210002801).The indicator-based tools used for monitoring must be cost effective, easy to use by [non-experts](https://doi.org/10.1016/j.gecco.2019.e00781) and provide rapid, unbiased, accurate and representative data. Automated monitoring, [phone-based apps](https://www.hutton.ac.uk/news/new-soil-carbon-app-scottish-farmers) and spectral imaging devices to help achieve this have been demonstrated at the CSC, SEFARI platforms and commercial farms throughout the UK.

The NERC funded [RETINA](https://www.hutton.ac.uk/news/groundbreaking-research-develop-soil-carbon-sequestration-monitoring-system) project with University of Aberdeen and CEH is developing smartphone technology to combine remote sensing, ground based sensors and high-performance computing to monitor changes in soil carbon and GHG emissions under different management systems, tested at the CSC platform. Biodiversity indicators are difficult to monitor using automated techniques, but a seedcorn funded pilot study in collaboration with Syngenta and NatureScot is exploring deep learning image analysis approaches for on-farm biodiversity monitoring. Cost-benefit analysis across indicators has shown an [initial financial cost](https://doi.org/10.1080/21683565.2018.1537986) to the farmer of adopting agroecological practices and compensation is therefore necessary until the new farming system becomes more profitable and environmentally sustainable than the comparable future standard. The research has demonstrated how outcomes-based [incentive schemes](https://www.hutton.ac.uk/sites/default/files/files/Report%20AES%20payment%20designs%20simulations_March21st2022.pdf) can be used to encourage initial uptake, deliver better results, and help realise the potential for an [agroecological approach to farming in Scotland](http://dx.doi.org/10.7488/era/1912).

**Developing key performance indicators for cattle herds using statutory data**

During the SRP, SEFARI researchers developed new expertise in utilising statutory bovine tracing data (Cattle Tracing System, CTS) in conjunction with [EPIC](https://www.epicscotland.org/) and [EGENES](https://www.sruc.ac.uk/research/research-areas/genetics-genomics/) scientists and [SAC Consulting](https://www.sruc.ac.uk/business-services/sac-consulting/) dairy and beef specialists. Building on work [assessing individual herd performance metrics](https://www.gov.scot/binaries/content/documents/govscot/publications/factsheet/2021/01/suckler-beef-climate-scheme-research-papers/documents/sruc-report-structure-and-efficiency-of-the-scottish-beef-herd/sruc-report-structure-and-efficiency-of-the-scottish-beef-herd/govscot%3Adocument/SRUC%2BReport%2B-%2BStructure%2Band%2BEfficiency%2Bof%2Bthe%2BScottish%2BBeef%2BHerd%2B-%2BCTS%2B-%2BFINAL.pdf) to help inform the [Suckler Beef Climate Group,](https://www.gov.scot/groups/suckler-beef-climate-group/) researchers were commissioned by AHDB to develop a prototype performance dashboard for farmers (value c.£50k). During the evaluation phase a new metric that measures ‘productive life days’ was tested and developed using CTS data. This single metric has the potential to rank the technical performance of all cattle herds using statutory data sets and assesses ‘unproductive days’ by four root causes: (i) mortality; (ii) growth; (iii) fertility, and (iv) end of productive life.

Both greenhouse gas emissions and production costs can be allocated to assess waste emissions and expenditure across a herd (and root causes of inefficiency), farming system, region, or at national level. In addition, a prototype interactive, web-based app was developed showing more traditional key performance indicators. The work for AHDB was demonstrated to Scottish Government officials and ScotEID, and the productive day metrics have subsequently been extracted for Scottish herds for 2015-21. Using these new data, extract summaries have already been provided to the Scottish Government to support the climate change plan update process. The data processes will also underpin ‘modelling the socio-economic, greenhouse gas and natural capital impacts of land use policy and opportunities' in the SRP 2022-27.

**Improving climate change foresight to support innovation and adaptation** Communicating how climate change will manifest itself in terms of altered agrometeorological conditions which could influencing land management decisions and consequences for supply chain is a key step in supporting innovation and adaptation by the land use sector. The development of over 30 agrometeorological indicators estimated using the [UKCP18](https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/index) climate projections at a 1km resolution from 1960 – 2098 for the whole of the UK has enabled the visualisation of future conditions within which land uses will likely need to operate. This information has been aligned with research assessing [climate change impacts on barley](https://www.hutton.ac.uk/sites/default/files/files/RD2-4-1%20Barley%20Responses%20to%20Climate%20Change%20-%20Final%20report%20to%20RESAS%20-%20signed%20off.pdf) and utilised by land use stakeholders (e.g. Scotch Whisky Research Institute, World Distilled Spirits Conference) to enable improved adaptation planning. Time series animations of the Agrometeorological Indicators have been used in presentations to the Scottish and UK Governments, stakeholder and at public events including COP26 public Green Zone and TB Macaulay Lecture exhibition at which the First Minister was an attendee (November 2021). The underpinning development of this capability (high resolution spatial and temporal data sets, calculation and mapping) enabled additional impact assessments of climate change on [private water supplies,](https://www.crew.ac.uk/sites/www.crew.ac.uk/files/publication/CRW2018_05_Policy_Brief_FINAL.pdf) the [buffering capacity of Scotland’s wetlands](https://www.crew.ac.uk/sites/www.crew.ac.uk/files/publication/CRW2019_03%20Moderating%20extremes%20-%20Main%20Report%20vFINAL%2020220302.pdf) to high and low water flow (CREW), [snow cover](https://www.climatexchange.org.uk/research/projects/snow-cover-and-climate-change-in-the-cairngorms-national-park/) (CXC and CNPA) and the [Land Capability for Agriculture](https://www.climatexchange.org.uk/research/projects/the-land-capability-for-agriculture-building-a-tool-to-enable-climate-change-assessments/) under future climates (CXC).

**2.2.3 COLLABORATIVE AND MULTIDISCIPLINARY RESEARCH**

**Control of Potato Blackleg**

Research relating to the control of blackleg of potato within the SRP led to a major multi-funder (BBSRC, Defra, NERC, and Scottish Government) research project (total value £2.2M) as part of the Bacteria Plant Diseases Programme through the Strategic Priorities Fund. The project, [DeS-BL](https://www.blackleghub.ac.uk/) ‘A Decision Support Tool for Blackleg Disease’ is led by a SEFARI and includes partners from academia (Universities of Strathclyde, Newcastle, Glasgow, Durham and Dundee, and NIAB), industry (Bayer Crop Science, SoilEssentials, Scottish Agronomy, Mark Stalham Consulting and SA Consulting), and SASA, and an Advisory Group (Grewar Farming, British Potato Trade Association, B&C Farming Limited and University of Sheffield). The Universities of Strathclyde and Newcastle provide social science inputs focussing on optimising uptake of the decision support tool in collaboration with industry. SEFARI researchers are involved across disciplines including pathology, soil science, modelling, and microscopy.

**Potato research with partners in Africa**

External research collaborations have been developed with partners in Africa funded by Innovate UK. The [‘Resolve’](https://www.huttonltd.com/services/contract-research/resolve) project, “Development and assessment of nematode resistant potato cultivars for East Africa”, addresses the urgent need to tackle the emerging threat of potato cyst nematodes to potato production in the region. The work builds on SRP research in which nematode resistant germplasm, suitable for the target environment, has been developed using genetic approaches. Working with the [International Institute for Tropical Agriculture in Kenya](https://www.iita.org/iita-project/development-and-assessment-of-nematode-resistant-potato-cultivars-for-east-africa-kenya-2/), SEFARI researchers have identified and trialled resistant germplasm in a 24 month project. This project also undertook surveys to understand barriers to uptake of new disease resistant cultivars as well investigating the perceptions of growers and local women to the new varieties. In a second project, entitled [“Game-changing aeroponic system for seed potato production in Kenya”](https://gtr.ukri.org/projects?ref=105657), collaboration was developed with a UK SME, [Airponix Ltd](https://airponix.com/) and a Kenyan potato seed producer [Kisima Farm](http://www.kisima.co.ke/). The aim of the work was to trial a new aeroponic seed potato production system in Kenya to address the urgent requirement for clean potato planting material. The 30-month project will conclude in November 2022, providing recommendations for the adoption of the new aeroponic system.

**BARIToNE Collaborative Training Partnership (CTP) PhD programme**

Funding was received for the [BARIToNE Collaborative Training Partnership](https://www.hutton.ac.uk/news/barley-scientists-future-get-%C2%A39m-boost#:~:text=The%20BARIToNE%20CTP%20will%20create%20a%20new%20generation,in%20industry%20and%20academia%20over%20the%20coming%20decades.) is a substantial PhD programme, which aims to combine scientific excellence with the development of personal and transferable skills that will be important across the entire barley supply and value chain. It is a multi-partner PhD programme provided by SEFARI and University of Dundee scientists and associate and industrial partners from across the UK. It will train the next generation of scientists at the forefront of international barley science. Students will join supportive and positive research cultures with the opportunity to select collaborative research projects centred around three main themes which build upon research in the SRP 2022-27: Climate Resilience, Reducing Inputs, and Healthy Soils. The programme will support cohorts of ten students per annum (2022-24), who will benefit from comprehensive skills training across the entire barley supply and value chain, annual barley ‘away days’, industry visits and at least one 6-month placement with the industrial partner. BARIToNE is committed to being part of an evolving community of practitioners who will develop and share practice to bring science and culture together, placing both firmly at the heart of how and what research is done.

**Wader Scrapes, agri-environment schemes and liver fluke**

Throughout the 5 years of the SRP, evaluations have been made of the potential risk of liver fluke disease to livestock grazing around wader scrapes at the SEFARI Hill and Mountain Research Centre near Crianlarich. Wader scrapes are shallow ponds dug into farmland to encourage wetland birds, such as snipe, curlew, and lapwing, which are in serious decline in Scotland. There is a requirement for grazing to break up the habitat for birds to feed and maintain the appropriate sward height for nesting. However, wader scrapes are perceived as a risk to the livestock grazing them, as they potentially support the mud snail, intermediate host of the liver fluke parasite.

Tests have been developed and deployed to assess the fluke risk to grazing animals, including PCR to determine mud snail species identity and fluke infection status, and faecal egg counting and coproantigen testing to determine the infection status of grazing sheep. Over the course of the study, there has been a gradual establishment of *Galba truncatula*, the fluke’s preferred intermediate host (mud snail), but none have been found to be liver fluke positive. Sheep grazing around the scrapes remain liver fluke negative, but fluke risk can be determined by grazing management, stocking density etc. and is best supported by regular diagnostic testing. The study features as a case study on the [SEFARI website](https://sefari.scot/research/liver-fluke-risk-and-agri-environment-schemes-a-tale-of-toads-snails-and-wetland-birds) and a Moredun News Sheet ‘Fluke Risk and Conservation Grazing’ (November 2021).

**Plant-based systems for complex vaccine development and delivery**

In the Strategic Research Programmes fruitful links have been developed between plant scientists and vaccinologists within SEFARI to produce novel vaccines to control complex parasites of sheep. Through previous Strategic Research Programmes, and funding from Defra, a synthetic [vaccine to control sheep scab](https://veterinaryresearch.biomedcentral.com/articles/10.1186/s13567-016-0315-3) has been produced. This vaccine is composed of 3 sheep scab mite proteins which were synthetically produced (“expressed”) in bacteria (proteins Pso o 2 and Pso o 20) or yeast (Pso o 1). Although effective when used together in a vaccine, the eventual commercially viable production of these 3 proteins would have needed to rely on a single expression system. Protocols for expressing all these proteins in a tobacco plant system were developed by SEFARI scientists and methods for producing the proteins at scale were optimised. The purified plant-expressed proteins were then transferred to SEFARI colleagues who performed vaccine efficacy trials of the plant-expressed proteins in comparison to the original bacterial/yeast expressed proteins. While the plant-synthesised proteins did not outperform the vaccine proteins produced using other systems, plants may offer future opportunities for cheap [scalable production of vaccine components](https://european-seed.com/2020/04/plant-viruses-may-provide-pipeline-for-increased-vaccine-production/).

The plant-based system was also used with great success to [produce a prototype novel diagnostic protein for sheep scab](https://onlinelibrary.wiley.com/doi/10.1111/pim.12788) before transfer into other expression systems. This diagnostic protein is vital to our [ability to discriminate between infected and vaccinated animals](https://www.thescottishfarmer.co.uk/news/18736936.moredun-hutton-team-up-early-detection-sheep-scab/) once the vaccine is in general use and will be incorporated into the commercialisation strategy of the vaccine.

**SEFARI scientists develop vaccine for bovine malignant catarrhal fever** [includes pre-2016 funding]

Scottish Government-funded research pre-2016 led to the development and licensing of a vaccine for the fatal cattle disease malignant catarrhal fever (MCF) [in Africa](https://www.intvetvaccnet.co.uk/events/development-of-a-vaccine-for-malignant-catarrhal-fever). An attenuated version of the MCF virus alcelaphine herpesvirus 1 (AlHV-1), was found to protect against fatal disease challenge. AlHV-1 is carried by wildebeest and fatally infects cattle that graze alongside wildebeest in eastern and southern Africa. AlHV-1 is also a model for sheep-associated MCF in Scotland and worldwide caused by Ovine herpesvirus 2 which is [endemic in sheep in the UK](https://moredun.org.uk/research/diseases/malignant-catarrhal-fever-mcf), but threatens cattle, deer and bison.Scottish Government support has helped facilitate multiple successful collaborations: Previous work funded by BBSRC (2010) and GALVmed (2016), [involved vaccine field trials](https://doi.org/10.1016/j.vaccine.2019.08.040) in Tanzania (with University of Glasgow, UoG;), University of Nottingham; and Tanzanian partners); and improvements to vaccine formulation and production (with International Livestock Research Institute, Kenya).

[Current work](https://www.gla.ac.uk/research/az/gcid/research/foodsecurity/headline_771943_en.html), funded by UKRI-GCRF, on the [uptake and impact of the MCF vaccine in Tanzania](https://doi.org/10.1016/j.ecolecon.2021.107189), involves a multi-disciplinary team from SEFARI, UoG and Tanzanian institutions (Nelson Mandela Africa Institute of Science and Technology, Global Animal Health Tanzania). It focuses on the acceptance and consequences of MCF vaccine use in pastoralist communities in Northern Tanzania (epidemiology, economics, animal movement, social sciences). SEFARI scientists produced vaccine for over 1,750 cattle and support diagnostic testing and MCF case analysis. Workshops will engage with Tanzanian and wider industry, policy, and community stakeholders.In 2021, a licensing agreement was signed with Onderstepoort Biological Products to produce the [vaccine for use in South Africa](https://www.timeslive.co.za/news/south-africa/2021-03-03-onderstepoort-signs-agreement-to-develop-vaccine-for-deadly-snotsiekte/).

**Building global multidisciplinary networks to tackle sustainability**

The role of agroecological intensification in creating sustainable agricultural and wider land use systems was addressed by SEFARI researchers in the SRP. This included studies of the performance and trade-offs in existing cropping systems, innovations at field, farm, and landscape scale aimed at reducing the environmental impact of farming, and examination of supporting this aim with financial incentives. The research drew on expertise from multiple domains including agronomy, ecology, social science, and economics. The partnerships formed and the experience gained has been instrumental in building a wider research community to tackle similar problems across the globe. Agroecologists, behavioural scientists, and economists are working together with researchers and other actors from across Europe to design, test and implement approaches to biodiversity sensitive farming (EU Horizon 2020 project [FRAMEwork](https://www.framework-biodiversity.eu/), 2021-25, total value €8M, SEFARI value €1.4M). Projects funded by Defra (Malawi-AgroBio, started 2021, SEFARI value £10K) and UKRI (ClimateSmart, started 2020, SEFARI value £40K) have been specifically designed to combine the bio-physical and social sciences and extend the transdisciplinary, participatory approach with collaborators in Malawi and Kenya. The latest development in this process will see SEFARI researchers working with a multidisciplinary team, including social scientists and experts in Public Health, to create a Global Health Research Group on Community Food for Human Nutrition and Planetary Health in the Caribbean, South Pacific, and Southeast Asia ([NIHR Global CFaH](https://fundingawards.nihr.ac.uk/award/NIHR134663): starting in 2022, total value £3M, SEFARI value £417K).

**Agroecological practices for whole-system sustainability**

Biological alternatives to intensive, chemical-based agriculture can only go so far in meeting the multiple and frequently conflicting requirements of food security, biodiversity declines and climate change mitigation. A new, biodiversity-driven, agroecological approach is required, that relies on internal regulation of system functions rather than external inputs to maintain sustainable production. The use of [Nature Based Solutions](https://journal.hep.com.cn/fase/EN/10.15302/J-FASE-2021437) can decrease reliance on inputs, provide resilience to abiotic and biotic stress, enhance plant, microbe and animal biodiversity, and mitigate against climate change. This has been demonstrated through SRP collaborative research at the SEFARI long-term research platforms ([GrievesHouse](https://www.arablescotland.org.uk/grieveshousetour/) and Centre for Sustainable Cropping, CSC) where a whole-system, [indicators-based framework](https://www.mdpi.com/2073-4395/9/8/438) has been developed. Multiple benefits are defined in terms of [indicators](https://www.worldscientific.com/worldscibooks/10.1142/q0088) of:

i) [soil health](https://www.mdpi.com/2073-4395/10/7/973/htm) (CSC is a lighthouse for [UKSoils](https://uksoils.org/living-labs-lighthouses/csc-balruddery-farm-jhi) with the Soil Association as a key stakeholder);

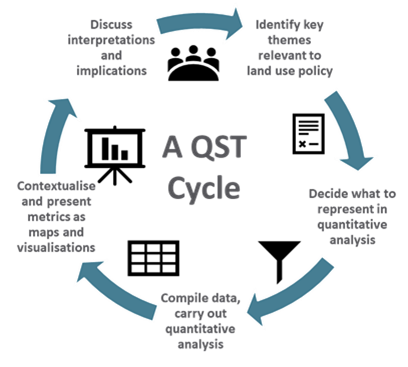
ii) [biodiversity](https://doi.org/10.3390/agronomy8100229) (working with NatureScot on [Piloting Outcomes Based Approaches in Scotland](https://www.nature.scot/doc/piloting-outcomes-based-approach-scotland-pobas-project), and CEH on the [UK Pollinator Monitoring Scheme](https://doi.org/10.1111/1365-2664.13755);

iii) [crop quality](https://doi.org/10.1021/acs.jafc.7b03509) (with SSCR funded projects on [variety trials](https://www.mdpi.com/2073-4395/11/1/30), and direct KE input from the Association for Independent Crop Consultants, Soil Essentials and LEAF).

This work underpins new joint ventures with LEAF, NatureScot, Syngenta ([LivinGroTM](https://www.syngenta.com/en/innovation-agriculture/livingrotm-sustainability-rooted-science)) and Universities of Dundee, Edinburgh and Aberdeen, to produce and ground truth a suite of biodiversity, water quality and soil function indicators. These are used to identify trade-offs between different elements of sustainability in the transition towards regenerative, [agroecological farming practices](https://era.ed.ac.uk/handle/1842/38649) in Scotland and the UK.

**Multi-scale policy analysis: social, natural and computational sciences**

New methods and capability for multi-scale, deliberative policy analysis have been developed between SEFARI scientists and the [EU H2020 MAGIC project](http://magic-nexus.eu/). New sustainability accounting frameworks ([societal metabolism accounting](http://magic-nexus.eu/documents/introducing-societal-metabolism-analysis-%E2%80%98musiasem)) were deployed to assess how the EU CAP interacts with delivery of EU commitments to [UN Sustainable Development Goal 2](http://magic-nexus.eu/documents/deliverable-51-report-eu-sustainability-goals) (Zero Hunger), and especially the degree of externalisation of the EU resource use footprint. The need for [reform of the content of EU farm systems data](https://www.mdpi.com/2071-1050/13/18/10080) (e.g., the Farm Accountancy Data Network, FADN) to better inform policy making was also highlighted (see also [EEA Report on Water and Agriculture](https://www.eea.europa.eu/publications/water-and-agriculture-towards-sustainable-solutions) p90). As part of the analysis the methods of engagement with policy stakeholders were formalised as the [Quantitative Story Telling (QST)](http://magic-nexus.eu/documents/what-quantitative-story-telling) process. The tools and methods developed here will be used in research in the SRP 2022-27 in the [Land Use Transformations](https://landusetransformations.hutton.ac.uk/) project.



*Six stages of the Quantitative**Story Telling cycle*

*Storytelling Process.*

**Understanding resilient farming behaviours and role of interventions**

Collaboration across SEFARI explored [how farmer behaviours are affected by interventions](https://hdl.handle.net/1842/37915). In 2018, a survey of c.2,400 farmers, crofters and smallholders was undertaken which follows up the 2013 Farmer's Intention Survey (pre-2016 funding), This survey produced a significant data set from which several policy briefs and scientific papers have been derived. It supported work on understanding drivers of [Brexit](https://pure.sruc.ac.uk/en/publications/farmer-responses-to-brexit-attitudes-towards-risk-in-scottish-far), [risk](https://pure.sruc.ac.uk/en/publications/farmer-past-and-intended-investment-behaviours-evidence-from-the-) and how intentions between [island and mainland communities differ](https://www.ruralbrexit.scot/future-policy/farmer-intentions-survey-a-comparative-analysis-of-island-and-mainlands-smallholder-farmers-and-crofters/).

Research on farm viability using the Farm Business Survey provided insights to [less favoured areas](https://www.sciencedirect.com/science/article/abs/pii/S0264837719308154) within Scotland and [comparisons with England](http://upland-resilience.org/why-are-some-upland-farms-more-financially-resilient-than-others/). SEFARI experts also formed part of a UK consortium of leading authors providing [understanding of priority questions for digital agriculture](https://www.sciencedirect.com/science/article/pii/S0264837721006852). This built on previous and highly cited work comparing the perceptions of Scottish farmers [towards precision arable farming](https://www.sciencedirect.com/science/article/abs/pii/S0264837717315387%20) with those elsewhere in Europe. SEFARI expertise on measuring [resilience](https://pure.sruc.ac.uk/en/publications/scottish-farm-resilience-robustness-adaptation-and-transformation) also helped support the RCUK’s programme on Global Food Security and led to an understanding [of the concepts and challenges to securing resilience](https://www.research.ed.ac.uk/en/publications/food-system-resilience-concepts-issues-and-challenges) with respect to food systems. Research on understanding farmer behaviour and analysis of European FADN data led to understanding of [farmer’s perceptions of ecological approaches](https://www.sciencedirect.com/science/article/pii/S2666049022000032), [the economic costs of conversion to more ecological approaches](https://pure.sruc.ac.uk/en/publications/an-economic-assessment-of-ecological-practices-in-scotland), and an [overall typology of farming practices](https://pure.sruc.ac.uk/en/publications/agroecological-practices-used-in-scottish-farming-evidence-from-a) applicable to Scotland and comparable across EU countries.

**2.2.4. SCIENTIFIC EXCELLENCE**

**Using Potato Genetics for studying biotic and abiotic stress resilience**

Within the SRP, potato populations for research and pre-breeding have been identified which show significant variation for resistance to both biotic and abiotic stresses that pose a major threat to ongoing and future UK potato cultivation. Several of these populations rely on material derived from the [Commonwealth Potato Collection](https://ics.hutton.ac.uk/germinate-cpc/#/home) (CPC) funded by RESAS Underpinning Capacity. Several potato populations have been studied in order to genetically analyse resistances to the major pests and pathogens affecting potato, such as *Phytophthora infestans* ([late blight](https://pubmed.ncbi.nlm.nih.gov/29560514/)), [potato cyst nematodes](https://www.frontiersin.org/articles/10.3389/fpls.2021.661194/full) and [potato virus Y](https://link.springer.com/article/10.1007/s00122-019-03521-y). Moreover, molecular genetic markers that will facilitate the breeding of these resistances have been provided to commercial breeding programmes in Scotland. Much of this research has utilised a highly novel genomic tool ([RenSeq](https://arborbiosci.com/wp-content/uploads/2022/03/Ingo-Hein-RenSeq-Webinar-2022-Mar-10.pdf)) that will continue to be used for future work on genetic analysis of newly discovered pest and disease resistances. Approaches have been developed for the analysis of resistance to abiotic threats to potato production such as heat and drought stress, for example [novel sources of tolerance to heat](https://onlinelibrary.wiley.com/doi/10.1111/pbi.12760).

**Germinate: informatics capacity leverages significant funding**

Significant [advances](https://acsess.onlinelibrary.wiley.com/doi/10.1002/csc2.20248) have been made to a fully featured open-source plant genetic resources platform, [Germinate](https://germinateplatform.github.io/get-germinate/). The SRP has enabled the development of open-source bioinformatics software to meet the needs of crops important to Scotland, and for use in leveraging significant additional funding for its future development and ensure data is made available quickly and efficiently to researchers.

Such funding was secured from the [Crop Trust](https://www.croptrust.org/work/projects/crop-wild-relatives)/Norwegian Government in projects including CWR and the Crop Trust/[Templeton World Charity Foundation](https://www.croptrust.org/work/projects/the-templeton-pre-breeding-project), EU Horizon 2020 DIVERSify and [BreedingValue](https://breedingvalue.eu/), and INNOVATE UK [CherryBerry](https://www.huttonltd.com/services/contract-research/cherry-berry). The work was recognised in a recent BBSRC [International Partnership Award](https://www.hutton.ac.uk/news/new-uk-europe-partnership-exploit-barley-resources-and-speed-breeding) which will enable the maintenance of European and international links and relationships within the barley community. The SEFARI research team is recognised as a regional hub for PGR informatics by [DivSeek](https://divseekintl.org/germinate-pgr-database-hub) International which increases the profile of the software. These achievements demonstrate that software developed to meet the needs of Scotland can have significant impact worldwide and would not have been possible without SRP funding.

**Insights into host pathogen interactions**

SRP research into Plant-Pest Interactions focused on the molecular and physiological mechanisms underpinning diseases of Scottish crops, with an emphasis on pathogen/pest effector proteins and their plant target proteins and processes. Scientific knowledge in this area has been significantly advanced and new components of crop resistance to pests and pathogens revealed. Example highlights of pathogen effector research include:

1. the most [complete plant parasitic nematode genome](https://genomebiology.biomedcentral.com/articles/10.1186/s13059-016-0985-1) sequence that allows identification of key effector proteins; genome sequences of the barley pathogens [*Ramularia collo-cygni*](https://bmcgenomics.biomedcentral.com/articles/10.1186/s12864-016-2928-3) and [*Rhynchosporium commune*](https://bmcgenomics.biomedcentral.com/articles/10.1186/s12864-016-3299-5);
2. identification of [toxin biosynthetic genes](https://apsjournals.apsnet.org/doi/10.1094/MPMI-12-17-0299-R) from *Ramularia;* non-conventional secretion of [late blight effector](https://nph.onlinelibrary.wiley.com/doi/10.1111/nph.14696) proteins;
3. a [novel fungal elicitor](https://nph.onlinelibrary.wiley.com/doi/10.1111/nph.14542) of plant defence responses;
4. the discovery of novel pathogen secreted enzymes that degrade the [plant cell wall](https://www.science.org/doi/10.1126/science.abj1342);
5. involvement of numerous [late blight effector](https://academic.oup.com/jxb/article/70/1/343/5133253?login=false) proteins in disease development.

Plant immunity research highlights include the discovery of the first [plant susceptibility factors](https://www.nature.com/articles/ncomms10311) that are exploited by the late blight pathogen *P. infestans* to cause disease; [positive regulators of plant immunity](https://nph.onlinelibrary.wiley.com/doi/10.1111/nph.15635) that are inhibited by pathogen effectors; a link between plant immunity and development mediated through [brassinosteroid signalling](https://academic.oup.com/plphys/article/180/1/571/6117772?login=false), an association of [blue light sensing with immunity](https://nph.onlinelibrary.wiley.com/doi/10.1111/nph.17929); and characterisation of a structural component of [plant intercellular channels](https://www.embopress.org/doi/full/10.15252/embr.201847182) targeted by almost all types of plant pathogens. In addition, SEFARI researchers have published reviews and books on plant pests and pathogens (e.g. [cyst nematodes](https://bsppjournals.onlinelibrary.wiley.com/doi/10.1111/mpp.13047), [*Ramularia*](https://onlinelibrary.wiley.com/doi/10.1002/9780470015902.a0028896), [*Pectobacterium*](https://link.springer.com/book/10.1007/978-3-030-61459-1)), and on [host-pathogen/pest interactions](https://nph.onlinelibrary.wiley.com/doi/10.1111/nph.16650), which serve as important points of reference for other scientists in these areas.

**Mass Spectrometry for rapid identification of foodborne pathogens**

In recent years matrix-assisted laser desorption ionisation mass spectrometry (MALDI-MS) has emerged as a rapid and reliable method for bacterial identification in clinical microbiology diagnostic laboratories. The technique, known as whole cell MALDI (WCM), uses MALDI to obtain a readout of the most abundant proteins in a bacterial isolate. This protein profile is unique to each species of bacteria, allowing rapid species identification. Tools have been developed to enable differentiation between important sub-groups of the same species, further increasing the resolving power of this method. [Initial studies](https://www.sciencedirect.com/science/article/abs/pii/S0039914018300638?via%3Dihub) during the SRP focussed on differentiating between subtypes of Shigatoxigenic *Escherichia coli,* in particular *E. coli* O157, the strain most prevalent in Scotland, with methods subsequently applied to other foodborne pathogens including *Campylobacter*.

To detect the subtle differences in the profiles of such closely related isolates, a [data analysis software pipeline](https://academic.oup.com/bioinformatics/article/34/3/522/4345644) was developed and made available as an [open-source package](https://github.com/Japal/MALDIrppa). The application of WCM as a tool to rapidly identify antibiotic resistance has been investigated alongside development of a further [open-source package](https://github.com/DorotaAn/Whole-Cell-MALDI). Differences were observed between the profiles of *Campylobacter jejuni* strains that were either resistant or susceptible to tetracycline, upon exposure to antibiotics. This indicates that WCM has potential application as a tool for antibiotic resistance surveillance and to support decision-making within clinical settings.

**Reduced immunity to parasites in ageing sheep**

It is well established that weakened immune systems in old age affect people’s health and fitness. Deterioration of the immune system in old age, a process called immunosenescence, is a significant issue for human health as it reduces the ability to control infections later in life. Whether a similar process occurs in other animals is less certain. [This study](https://www.science.org/doi/10.1126/science.aaw5822), published in the journal *Science*, studied blood samples taken from a wild population of Soay sheep over a 25 year period, capturing individual animals over their whole lifetime. Levels of antibodies to sheep roundworms, an important marker of worm resistance, were shown to decline in older age. This decline was highly predictive of subsequent mortality. This work provided the first evidence that deterioration in immune function in old age plays an important role in wild animal populations. Furthermore, given efforts to extend the productive lifespan of livestock species to improve farming efficiency, the findings provide important information on the likely consequences of farming older animals in terms of their ability to fight infectious diseases.

**Use of *in vitro* organoids to investigate host-pathogen interactions**

Most infectious agents affecting livestock enter or reside at the mucosal surfaces of the respiratory, gastro-intestinal, urogenital tracts and the mammary glands. These surfaces are lined by epithelial cells, which provide a barrier against infection and play a key role in sensing infections and initiating immune responses. Studying pathogen-epithelial interactions are important for the development of new control strategies, for example identifying pathogen components involved in epithelial invasion which can be targeted by vaccines or drugs. Traditional approaches have involved use of *in vivo* challenge studies, or 2-dimensional (2D) cell cultures. While these approaches have merit, *in vivo* studies are complex, with the site of infection often inaccessible and data generated highly variable, and 2D cultures lack structural information and the range of cell types present *in vivo*.

A key recent development has been the ability to generate epithelial organoids from stem cells, which form three-dimensional (3D) tissue constructs that mimic the corresponding *in vivo* epithelium in terms of morphology and cell types. These cultures can be used for the detailed study of host-pathogen interactions in physiologically relevant systems. To this end, SEFARI research developed gastric and intestinal organoids from sheep, and used them to study interactions between parasitic worms, bacterial and protozoan pathogens and the host epithelium. [This work](https://www.frontiersin.org/articles/10.3389/fcimb.2021.733811/full), published in the journal *Frontiers in Cellular and Infection Microbiology*, represents the first example of ruminant organoids being used to study host-pathogen interactions, and has led to multiple collaborations in livestock infectious disease research.

**The use of alternative fertilisers to close nutrient loops**

There are clear opportunities to move towards systems which rely less on inorganic nutrient inputs. However, in the pursuit of zero-pollution agricultural systems it is important to understand impacts on nutrient stoichiometry in soil and the ways to manipulate this with organic inputs. A common alternative to mineral fertilisers is the use of unprocessed rocks. SRP research has shown that some soil dwelling fungi improve nutrient availability from rocks, through both their production of exudates and through physical breakdown of the rock [[*Geomicrobiology Journal*](https://www.tandfonline.com/doi/full/10.1080/01490451.2020.1863525)]. Similarly, the use of waste streams such as sewage sludge are used as alternatives, but lead to increases in toxic elements in soils ([*Environment International*)](https://www.sciencedirect.com/science/article/pii/S0160412018317318). Research findings were that the addition of biochar can act as a soil amendment to negate the negative impact of pollutants in soil [[*Chemosphere*](https://www.sciencedirect.com/science/article/pii/S0045653519324956); [*Applied Geochem*](https://www.sciencedirect.com/science/article/pii/S0883292717300914)*istry*].

Investigation into the use of seaweed ([[*Nutrient Cycling in Agroecosystems*](https://link.springer.com/journal/10705)](https://link.springer.com/article/10.1007/s10705-020-10090-w)) and green manure ([*Journal of Environmental Q*](https://acsess.onlinelibrary.wiley.com/doi/full/10.2134/jeq2017.11.0422)*uality*) from underutilised parts of the landscape as alternative fertilisers showed that their efficacy is determined by the ability of the alternative nutrient source to break down and release its nutrients at a relevant spatial and temporal scale. This means that sources such as seaweed and legume-based green manures are more effective than grass based green manures. The findings indicate opportunities to move to systems which rely less on inorganic nutrient inputs and utilise legacy nutrients more effectively, but it is essential to understand and mitigate the impacts on nutrient stoichiometry, biological interactions, and pollutants.

**Interactions between soil biology and organic Phosphorus**

Organic P (Po) compounds play key roles in biological and ecosystems function in the terrestrial environment, being critical to cell function, growth, and reproduction. At the beginning of the SRP, a study was published outlining the research priorities for Po ([*Plant & Soil*](https://link.springer.com/article/10.1007/s11104-017-3391-x)), followed by those relating to interactions with mycorrhizae and their associated microbiomes. SEFARI research demonstrated that the ability of a crop to utilise Po in soils is impacted by the specific arbuscular mycorrhizal fungal (AMF) associations established with the plant roots ([*mSystems*](https://journals.asm.org/doi/full/10.1128/mSystems.00929-20)), with different AMF species on the same root having different impacts on Po use. The type and function (e.g., phosphatase production) of bacteria recruited by mycorrhizae ([*Environmental Micro*](https://sfamjournals.onlinelibrary.wiley.com/doi/full/10.1111/1462-2920.14289)*biology*) to a hotspot or hot-moment of organic P availability in the soil was shown to be selectable by AMF. Such selections were facilitated by specific hyphal exudates ([*Applied Soil Ecol*](https://www.sciencedirect.com/science/article/pii/S0929139321003978)*ogy*) and the movement of specific bacteria along fungal hyphae ([*New Phytologist*](https://nph.onlinelibrary.wiley.com/doi/full/10.1111/nph.17081)) to the Po hot spots. This work has proven that mycorrhizae and associated bacteria are more effective at utilising Po than other root traits ([*Soil Biology and Biochemistry*](https://www.sciencedirect.com/science/article/pii/S0038071722001705)), and that different AMF species have different strategies to acquire Po. The ability of a crop genotype to form associations with mycorrhizae and other soil biological trophic levels ([*Soil Biology and Biochemistry*](https://www.sciencedirect.com/science/article/pii/S0038071719303591)) will have profound effects on the sustainability of the cropping system. The work has been reviewed for a scientific audience ([*Trends in Plant Science*](https://www.sciencedirect.com/science/article/pii/S1360138521002831)) and communicated to commercial stakeholders ([*Better Crops*](https://www.researchgate.net/profile/Malika-Mezeli/publication/331693902_Soil_'Organic'_Phosphorus_An_Untapped_Resource_for_Crop_Production/links/5c8bc0fda6fdcc381755bfc1/Soil-Organic-Phosphorus-An-Untapped-Resource-for-Crop-Production.pdf) *with Plant Food*).

**New Climate Change and biodiversity insights**

Linked to work in the SRP, SEFARI researchers authored a report for the European Commission (EC-JRC and DG AGRI) in 2020 on the [Future of EU Livestock](https://op.europa.eu/en/publication-detail/-/publication/04af47b0-0c38-11eb-bc07-01aa75ed71a1/language-en). The work examined climate and biodiversity impacts of the livestock sector and provided opinion on potential pathways to improved livestock sustainability. In 2021, the researchers presented at a workshop organised to discuss the future of EU livestock along with other scientists and policy and industry stakeholders, which was attended by over 200 delegates. As aquaculture makes an important contribution to global food security and economic development SEFARI researchers assessed the environmental impact of aquaculture and how it might be mitigated. Publications in a report ([Quantifying and mitigating GHG from global aquaculture](https://www.fao.org/documents/card/en/c/ca7130en/)) and [Nature - Scientific Reports paper](https://doi.org/10.1038/S41598-020-68231-8) quantify global GHG emissions from aquaculture. One of the conclusions of the study was that the immature nature of the sector (compared to agriculture) means there is scope to improve resource efficiency through technical innovation. The paper has been cited in other papers and was reported in industry publications (e.g. [The Fish Site](https://thefishsite.com/articles/putting-a-figure-on-aquacultures-greenhouse-gas-emissions) and [Fish farming Expert](https://www.fishfarmingexpert.com/article/aquaculture-responsible-for-049-of-man-made-greenhouse-gases/#:~:text=In%20the%20first%20study%20of,carbon%20dioxide%20equivalent%20(MtCO2e))). Subsequently, some of the data and models used in the work were used to [quantify emissions from Scottish salmon farming](https://www.sruc.ac.uk/all-news/call-to-better-understand-fish-farm-emissions/#:~:text=Farmed%20salmon%20produces%20the%20same,2019%2C%20mainly%20from%20feed%20production.).

**Landownership and land management**

Detailed analysis of the Farmer Intentions Survey provided understanding of land management regarding [farmer behaviour](https://www.hutton.ac.uk/sites/default/files/files/research/srp2016-21/rd242outputs/Comparing_stated_intentions_and_behaviour_RD242_published.pdf), [afforestation](https://www.hutton.ac.uk/sites/default/files/files/research/srp2016-21/Afforestation-by-Scottish-farmers-Research-Briefing-Martinat-and-McKee-2022-03.pdf), [farmer adaptation due to Brexit](https://www.ruralbrexit.scot/wp-content/uploads/2020/01/Public-Good-Briefing_Final_For_Distribution_2.pdf), [new entrants to agriculture](https://www.hutton.ac.uk/sites/default/files/files/research/srp2016-21/rd242outputs/Research_Note_New_Entrants_final_RD242_published.pdf), and [agritourism](https://www.hutton.ac.uk/sites/default/files/files/research/srp2016-21/Scottish-Farmers-Intentions-to-Develop-Agritourism-Research-briefing-Hopkins-et-al-2022-03.pdf). The study informed the development of the Farmer Intentions Survey and involved in-depth interviews with 30 large scale landowners and land managers in Angus, Skye and Lochalsh. Findings were presented at the European Society for Rural Sociology Congress (October 2021). Land ownership and succession processes were found to be key themes within Women in Agriculture research. The ‘Women in Farming and the Agricultural Sector’ baseline research led to the establishment of the Scottish Government’s Women in Agriculture Taskforce (2017-19) with findings published in two academic journal articles and the [report](https://www.hutton.ac.uk/sites/default/files/files/publications/Changing-Role-of-Women-in-Farming-final-report-Hutton-24_11_21.pdf) ‘The Changing Role of Women in Farming, Crofting, and the Agricultural Industry: 2016-2021' involved many of the original participants in follow-up online focus groups to explore key challenges facing women in agriculture over the previous five years, including the impact of the COVID-19 pandemic.

Research findings illustrated the positive impact of Scottish Government funding to support women’s access to agricultural training. Findings were presented during the European Society for Rural Sociology Congress satellite event at Birnam (June 2022). The report ‘Understanding the impact of scale and concentration of land ownership: community perspectives from the south of Scotland’ seeks to fill a knowledge gap regarding community views. This report will be presented in a public seminar hosted by the Scottish Government, in conjunction with an overview of the Scottish Government public consultation on land reform in a net zero nation (due in summer 2022).

**Woodland expansion**

Data sets and methods developed during the SRP 2016-22 underpinned the analysis published in the paper“[*Not seeing the carbon for the trees? Why area-based targets for establishing new woodlands can limit or underplay their climate change mitigation benefits*](https://www.sciencedirect.com/science/article/pii/S0264837719304041)*”*. The paper reported a novel approach to mapping the net change in carbon stocks (in soil and in trees) for afforestation across Scotland. The results highlighted large areas of Scotland in which losses of soil carbon from tree planting disturbance may not be offset by tree growth. The paper considered 13 forestry management alternatives over 100 years and the effects of climate, soils, and previous land use. In addition to the open access paper the maps from the analysis were presented as a [web-mapping tool](https://woodlandexpansion.hutton.ac.uk/) with visualisations of change through time. The paper highlighted that a policy discourse conducted in terms of areas of trees planted rather than in terms of both the area and the net carbon storage delivered may result in undesirable consequences. The data from the analysis also underpinned subsequent work on a woodland strategy for Glasgow and Clyde Valley and a net zero Strategy for Perth and Kinross Council.

**2.2.5. SCIENTIFIC RESILIENCE**

**BBSRC funding for plant health research**

Key to the current and future success of plant health research has been the ability to use SRP research on a range of key pests and pathogens affecting Scottish crops

to leverage additional funding from UKRI research councils such as [BBSRC](https://www.ukri.org/opportunity/bbsrc-standard-research-grant/). Examples of such funding include an industrial partnership award to study the roles of extracellular vesicle transport in [late blight disease development](https://nph.onlinelibrary.wiley.com/doi/10.1111/nph.16650) (2019-23, total value £0.67M; SEFARI value £96K), a project investigating [new enzymatic virulence factors in *Phytophthora infestans*](https://www.hutton.ac.uk/news/new-research-sheds-light-role-copper-dependent-enzymes-plant-infection) (2021-24, total value £1.03M; SEFARI value £469K), and a study of [co-evolution in agriculture to inform NLR (late blight resistance) deployment](https://gtr.ukri.org/projects?ref=BB%2FS015663%2F1) (2019-22, total value £456K). Funding was obtained to further understand [the molecular basis of how cyst nematodes coordinate their life cycle with their host](https://gtr.ukri.org/projects?ref=BB%2FV00249X%2F1#/tabOverview) (2021-24, total value £513K; SEFARI value £74K) and to build a decision support tool for potato blackleg disease ([DeS BL](https://gtr.ukri.org/projects?ref=BB%2FT010657%2F1#/tabOverview), 2020-23, BBSRC, RESAS, NERC, Defra, total value £2.2M; SEFARI value £0.9M). An equipment grant ‘Live-cell, deep-tissue, low-light, 3D-STED confocal microscopy: a super-resolution imaging platform specifically designed for plant science’ (total value £1.37M) will establish the UK’s only plant science platform in this area.

**EU Horizon 2020 funding for soft fruit and potato research**

SEFARI researchers have secured funding from the EU Horizon 2020 programme for projects that build on work in the SRP, examples of which are:

1. [BreedingValue](https://www.breedingvalue.eu/) (total value c. £7m; SEFARI value £520k, 2021-24) will enable raspberry and blueberry genomics work and germplasm enhancement to be expanded through collaboration.
2. [ADAPT](https://adapt.univie.ac.at/) (total value £6M, SEFARI value £360K, 2020-24) is a consortium of 17 European academic, industry and policy partners which aims to identify new potato breeding targets and match potato varieties to specific challenging environmental growth conditions of the future.
3. SusCrop project ‘[ECOSOL](https://www.suscrop.eu/projects-second-call/ecosol)’ (2021-24, total value £659K, SEFARI value £110K), coordinated by SEFARI researchers, builds on the Hutton criteria tool for the prediction of late blight risk according to weather conditions which was developed in SRP research. The consortium of scientists, with extensive stakeholder involvement, aims to identify effective alternatives to conventional pesticides and to integrate these, with other measures, into practical and effective IPM strategies for late blight and early blight of potato.

**Innovate UK funding support for crop research**

Innovate UK funding has provided additional support for research initiated in the SRP. Additional funding has been levered on soft fruit research on [phytophthora root](https://gtr.ukri.org/projects?ref=131890) rot in raspberry (2015-17; SEFARI value £193K); [plant sensing](https://gtr.ukri.org/projects?ref=104624) (2018-21; SEFARI value £610K) and [berry flavour](https://gtr.ukri.org/projects?ref=132845) (2019; SEFARI value £211K). With industrial consortia, SEFARI researchers will build on SRP research to address significant challenges in the current berry-plant supply chain. These projects will help to mitigate quality, yield and health issues that directly affect productivity and profitability in the production of strawberries, raspberries, and blueberries. Further Innovate UK funding has been secured by SEFARI researchers to develop a new solution to crop protection (2021-23; total value £546k, SEFARI value £158K) in a [project](https://www.apsbiocontrol.com/current-projects) to investigate the biocontrol properties of bacteriophages against the potato blackleg pathogen Pectobacterium. Innovate UK also supported a project entitled “[Strategies to reduce waste due to greening in potato tubers](https://gtr.ukri.org/projects?ref=132342)” (2016-18; total value £500K, SEFARI value £125K) in a project which brought together actors across the potato research and supply chain and led to new understanding of this major cause of food waste.

**Commercial fruit breeding programmes: links to underpinning science**

The evaluation of currently available commercial blueberry cultivars identified problems with yield instability, poor quality and underperformance when grown under UK conditions, and highlighted the need for cultivars to be [better adapted to local climates](https://sefari.scot/news/research-aims-to-boost-scottish-blueberry-production). A SEFARI subsidiary, James Hutton Ltd ([JHL](https://www.huttonltd.com/)), commercially funded breeding programmes enable thousands of selections to be tried and tested under UK conditions whilst linking to SRP research to understand genetic and environmental controls behind key traits of interest ([photosynthetic efficiency](https://academic.oup.com/jxb/article/69/12/3069/4953360?login=true), flavour and establishment). [Results are fed back into the breeding programmes](https://www.youtube.com/watch?v=KlvVPQAH_PE) to develop high quality, climate resilient selections which can be sustainably grown and require less inputs while reducing the UK’s reliance on imports. The first commercially funded [blueberry breeding programme](https://www.huttonltd.com/services/plant-varieties-breeding-licensing/blueberry) based in the UK was [launched in 2017](https://www.huttonltd.com/news/james-hutton-limited-announces-blueberry-breeding-consortium-0) with a total SFEARI value of £375K.

The underpinning genetic analysis carried out as part of SRP led to a collaboration with European partners and funding of the EU Horizon 2020 project BreedingValue “[Genetic resources and pre-breeding communities](https://www.breedingvalue.eu/)” (total value £3.5M, SEFARI value £600K). Advances made within the first five years of the breeding programme led to its renewal in 2022 (SEFARI value, £450K) working towards the trialling and release of new cultivars better suited to a UK environment. A further blueberry breeding programme funded by a single commercial company was also launched in 2022 (SEFARI value £225K).

**Towards commercialisation of a new vaccine against ovine enzootic abortion**

The bacterial pathogen *Chlamydia abortus* is responsible for the disease ovine enzootic abortion (OEA) and is the most common cause of reproductive loss in the UK and in many countries worldwide. OEA results in economic losses estimated at more than £20M per annum in the UK alone. Disease can be controlled through the use of commercial vaccines. However, these commercial live vaccines have been shown to cause abortion in some animals. Therefore, there is a need to develop safer alternatives.

A [novel inactivated vaccine](https://doi.org/10.3390/vaccines9080898) has been developed by SEFARI scientists through a series of animal trials funded through Strategic Research Programmes (pre-2016 and 2016-2018 funding). The vaccine is based on a detergent solubilized protein extract of the pathogen that cannot grow and infect the host animal and thus cannot cause disease. This work led to a collaboration with one of the major commercial producers of the existing live vaccines (Ceva Animal Health, France) to fund work (2020-2021; £90k) to improve the commercial viability of the new vaccine by simplifying and optimising its manufacture on an industrial scale. The validation and commercialisation of this new simplified vaccine was included as a major focus of an EU Innovation Action application ([REPRODIVAC](https://innovation-manager.com/reference-case-horizon-europe/)) to Horizon Europe on development and commercialisation of next generation vaccines and diagnostics for preventing [four livestock reproductive diseases of worldwide impact, including OEA](https://bioagro.sostenibilita.enea.it/en/projects/reprodivac). The project was successfully funded (confirmed 04 February 2022; total funding €6M, SEFARI value €2M) and will lead to commercialisation of the new vaccine.

[**Plants4Nemavax**](https://www.icrad.eu/portfolio-items/plants4nemavax/) **– a European consortium optimising vaccines**

Significant funding was acquired through the European Union-funded programme “ICRAD” (International Coordination of Research on Infectious Animal Diseases) for additional work related to research being conducted on vaccines against complex parasites in the Strategic Research Programme 2016-2022. The UK element of the work was funded by the BBSRC, and the award notified to the principal investigator by ICRAD on 10th November 2020. The project, “Plants4Glyco: Appropriate glycosylation of vaccine antigens expressed in plant systems” runs from 2021 to 2024, with a total value of £643k, of which the SEFARI partner receives £218k*.* The consortium involves 4 European partners, led by parasitologists at the University of Ghent, and aims to produce synthetic proteins which properly mimic the natural proteins present in parasitic nematodes (“worms”) which can be used as vaccine targets.

Synthetic worm vaccine proteins which have been produced historically, in bacterial and yeast-derived expression systems, lack the appropriate surface sugars to properly mimic worm proteins and perform sub-optimally as vaccines. This project involves identifying the sugars present on the natural worm-derived vaccine proteins (by a SEFARI partner, at University of Ghent, and University of Leiden), [engineering tobacco plants to express these proteins with the appropriate surface sugars](https://www.wur.nl/en/project/project-plants4nemavax.htm) (Wageningen University) and, then testing their vaccine potential against parasitic worms of sheep (SEFARI) and cattle (Ghent).

**Improving advice and messaging regarding roundworm control**

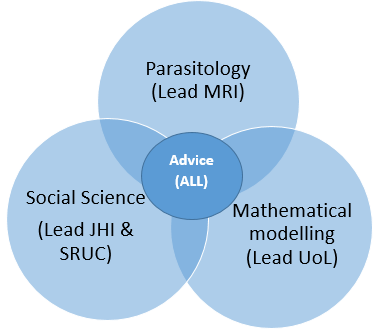
(Includes pre-2016 funding)

A three-year multidisciplinary project *entitled Biosecurity and Roundworm Advice for Cattle Enterprises* (BRACE) secured funding from BBSRC (confirmed in May 2022)to co-develop tools, materials, and recommendations to improve the communication of roundworm control and biosecurity advice to cattle producers in the face of increasing prevalence of anthelmintic resistant roundworms in the UK. . The project involves three partners from SEFARI and one HEI organisation University of Liverpool(total value £807K, total SEFARI value £507K. The project builds upon the first reported cases of anthelmintic resistance detection and characterisation in UK cattle roundworms that was undertaken as a result under-pinning capacity funding in conjunction with APHA colleagues and funds secured from the Veterinary Medicines Directorate (VMD).

|  |  |  |
| --- | --- | --- |
| Nematode | Resistance | Reference |
| *Cooperia curticei* | Ivermectin/moxidectin | [Bartley *et al.* (2012).](https://research-scotland.ac.uk/handle/20.500.12594/12192) |
| *Ostertagia ostertagi* | Benzimidazole | [Bartley, *et al*. (2021)](https://research-scotland.ac.uk/handle/20.500.12594/12295) |
| *Ostertagia ostertagi* | Ivermectin (suspicion) | Investigations ongoing with APHA |
| *Dictyocaulus viviparus* | Ivermectin (suspicion) | Investigations ongoing with APHA/SRUC/Industry |

Published or ongoing anthelmintic resistance research in cattle roundworms, undertaken due underpinning capacity funding

The project will use applied parasitological and cutting-edge molecular tools, quantitative and qualitative social science in conjunction with advanced mechanistic models to better understand and convey messages to farmers. The team will engage with cattle farmers to explore current biosecurity measures and associated stress factors to co-develop advice on biosecurity and roundworm control strategies relevant to the cattle producers to maximise uptake of advice.



Overview of the project interactions

**Research enabling access to Horizon 2020 funding on farming**

SEFARI research on ‘increasing uptake of best practice’ built capacity amongst researchers to develop successful proposals to the EU Horizon 2020 programme. New research identified the processes of learning and change through case studies of Scotland’s Monitor Farms, where farmers, industry stakeholders and agricultural advisors work together to assess, identify, implement, and evaluate on-farm innovations. This work was further developed through the [EU Horizon 2020 PLAID](https://plaid-h2020.hutton.ac.uk/) project (Peer to peer learning: Accessing Innovation through Demonstration; 2016-19). SEFARI researchers coordinated the project (total value £1.7M; SEFARI value £380K). Key outputs included [good practice guides](https://plaid-h2020.hutton.ac.uk/sites/www.plaid-h2020.eu/files/PLAID_WP2_WUR_D2_2_Revised%20conceptual%20framework.pdf) for virtual (using 360° video) and on-farm demonstrations, as well as a searchable [on-line inventory](https://farmdemo.eu/hub/) of over 1,400 demonstration farms across Europe.

SEFARI expertise on farmers’ knowledge systems was instrumental in the awarding of the EU Horizon 2020 [AgriLink](https://cordis.europa.eu/project/id/727577) project (Agricultural Knowledge: Linking farmers, advisors and researchers to boost innovation; 2017-21; total value £4.5M, SEFARI value £470K). AgriLink updated knowledge on how [farmers](https://www.agrilink2020.eu/others/the-role-of-farm-advice-in-farmer-collaboration-for-environmental-benefits) bring knowledge together to support their innovation practices, demonstrating the role of new actors (particularly non-traditional advisors) and the challenges of accessing ‘independent’ advice. EU Horizon PLAID and AgriLink yielded over a dozen academic journal articles authored by SEFARI researchers and are an important foundation of success which is being mobilised to apply for Horizon Europe funding.

**Research enabled access to Horizon 2020 for new entrants and small farms**

SRP research on ‘Economic Adaptation’ built capacity amongst SEFARI researchers to secure EU Horizon 2020 funding. New research identified how [new entrants to crofting](https://www.sciencedirect.com/science/article/pii/S0743016720307440) established their businesses. This expertise underpinned a successful bid to Horizon 2020 for the Newbie project (New Entrant Network: Business models for Innovation, entrepreneurship, and resilience in European agriculture, 2017-21), which brought together expertise to equip new entrants to establish viable farm businesses.

The research was further developed through the H2020 NEFERTITI project (Networking European Farms to Enhance cross fertilisation and innovation uptake through demonstration, 2017-22), which included a stream of work on networking new entrants to farming. Expertise in crofting enabled them to collaborate on a successful bid for the SALSA project (Small-scale farms, small food businesses and sustainable food and nutrition security 2016-20) which assessed the role of small-scale farms in local food systems. Together these projects represented external income to SEFARI of c.£0.71M ([Newbie](http://www.newbie-academy.eu/): €269K; [SALSA](http://www.salsa.uevora.pt/) €415K; [Nefertiti](https://nefertiti-h2020.eu/) €158K).

**Environmental change, technology uptake and farmer behaviours**

SRP work on farmer intentions, resilience, and viability of farming, together with approaches to technological solutions and adoption of sustainable approaches underpinned SEFARI researchers leveraging external funds. These projects focused on farmer behaviour, resilience, and viability, and supporting progress towards Net Zero. Work funded to complement research was through the EU Horizon 2020 ([TechCare](https://techcare-project.eu/), [LIFT](https://www.lift-h2020.eu/)) and RCUK ([BioSmart](https://research.reading.ac.uk/biosmartamazonia/), [ReSults](https://www.foodsystemresilienceuk.org/results/)), in addition to externally funded policy work for the CxC, Defra, and Welsh Government. Overall, these contributed external revenue to SEFARI more than £1.45M.

**2.3. FOOD, HEALTH & WELLBEING THEME**

**2.3.1. SUPPORTING POLICY AND PRACTICES**

**UK position on mandatory folic acid fortification**

In one of the most important UK public health decisions in many years, the UK Government announced in September 2021 it will introduce [the mandatory fortification of non-wholemeal wheat flour with folic acid](https://www.gov.uk/government/news/folic-acid-to-be-added-to-flour-to-prevent-spinal-conditions-in-babies) in order to reduce the incidence of neural tube defect affected pregnancies. This follows decades of deliberation by the UK Scientific Advisory Committee on Nutrition (SACN). It has the potential to affect generations of mothers and babies and the folate status of the entire population. It will have important ramifications for the food industry in Scotland and the UK. SEFARI researchers have made a significant contribution to the evidence base that informed this decision through research over many years. They contributed directly through membership of advisory committees such as SACN which provided the key advice to UK Government ministers.

SEFARI researchers carried out modelling for Food Standards Scotland on folate fortification to inform the decision made by ministers. In recognition of their contribution to the field, a SEFARI scientist was asked by the [Lancet](https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(21)02134-6/fulltext) to provide a commentary on plans for the UK to introduce folic acid fortification of flour, summarising the issues and the science.

**Household food waste related behaviours and food insecurity**

An analysis of the relationship between actual and perceived food insecurity of Scottish consumers, their food waste intentions and behaviours was completed using survey data and econometric techniques. A database was created based on a representative survey of Scottish consumers randomly stratified by age, gender, income, and region. The causal analysis focused on the estimation of a framework for predicting food waste in response to actual or perceived food security at household level in Scotland during the COVID-19 epidemic and following EU Exit. Factors with a statistically significant influence on waste related behaviours included perceived food insecurity, food waste attitudes, shopping patterns (a proxy for indicators of over purchasing/stockpiling), perceived behavioural control and subjective norms. The effect of perceptions of food insecurity on intentions had one of the most substantial effects.

The research findings provide an evidence-based representation of consumer behaviour in response to systemic shocks (COVID-19 and post-EU Exit recovery). As these outcomes are not necessarily representative of intentions and behaviours pre- or post-shock, more research is required to further disentangle the relationship between food insecurity as a driver of waste mitigation and its contribution to waste-producing behaviours such as stockpiling and panic buying post-pandemic.

**Mycotoxin contamination in the cereal supply chain and human exposure** Mycotoxins are highly toxic food contaminants produced by fungi in the field or during storage. Found in all major cereals, they can co-occur with their plant metabolites (masked mycotoxins). Human exposure to mycotoxins, and quantification of the contribution of masked mycotoxins to human exposure was assessed by SEFARI researchers. [They demonstrated that Scottish-grown cereals (especially oats) are contaminated with significant levels of trichothecene mycotoxins and co-contaminated with plant-bound masked mycotoxins.](https://sefari.scot/research/mycotoxin-contamination-in-cereal-products-and-human-exposure-from-the-diet) Studies revealed masked mycotoxins are not absorbed intact and are less toxic in the gut than their free counterparts. However, unabsorbed masked mycotoxins can reach the colon where release of free mycotoxins can occur, which was confirmed in human studies. This body of work has influenced policy, with the European Food Safety Authority (EFSA) concluding in Scientific Opinions ([EFSA 2017a](https://doi.org/10.2903/j.efsa.2017.4718) and [EFSA 2017b](http://onlinelibrary.wiley.com/doi/10.2903/j.efsa.2017.4751/full)) that plant-bound masked mycotoxins pose an equal risk to consumer health as free mycotoxins.

A SEFARI institute and FSS mycotoxin working group was established to share expertise and inform mycotoxin risk analysis within FSS/FSA. [Krystle Boss of FSS noted ‘The [snip] mycotoxin working group has been invaluable to FSS in shaping our research priorities for mycotoxins and informing sampling priorities for current and potential future surveys. It has helped to inform prioritisation of T-2/HT-2 as a particular interest to Scotland following post-EU exit considerations for changes to maximum levels across the UK and will continue to provide expertise and support evidence-gathering for any future reviews of mycotoxins, particularly from a Scottish perspective’.] Mycotoxin analysis of cereal foods and raw materials has established frequent contamination within the Scottish food supply network, but maximum permitted levels were not exceeded. However, this contamination led to human mycotoxin exposure and identified children and high cereal consumers at potential risk to exceed safe intakes.

A SEFARI scientist now serves on the [FSA Scientific Advisory Committee on Toxicity of Chemicals in Food](https://cot.food.gov.uk/COTmembers), Consumer Products and the Environment (COT) to provide advice and expertise on dietary exposure assessment and chemical contaminants in the food chain for FSA, the UK Department of Health and other government bodies. [A stakeholder workshop](https://www.abdn.ac.uk/rowett/documents/Mycotoxin-Workshop-Summary-report-23May2018-final.pdf) with industry representatives and regulators was organised (2018) and resulted in subsequent invitations to an industry-led UK arable mycotoxin stakeholder forum (2021) and an industry-linked research project (Interface Multi-party fund with Scottish Organic Producers Organisation).

**Providing scientific evidence on EU Exit and the obesity epidemic**

SEFARI researchers have provided evidence and presentations to Scottish enquiries on EU Exit and the obesity epidemic. A SEFARI researcher gave evidence at two sessions of the Scottish Parliament Health and Sport Committee (2021); “Provisional UK Common Framework on Nutrition labelling, Composition and Standards” and “Provisional UK Common Framework on Food and Feed Safety and Hygiene (FFSH)”. Written evidence and transcriptions of the discussion highlighted the challenges facing Scotland and the UK in respect of the post-Brexit arrangements regarding food regulation, and the important role SEFARI plays in understanding those challenges and providing solutions based on research.

SEFARI researchers have also re-evaluated projected obesity trends in Scotland and the important role of socio-economic status and long-term health implications to inform the Scottish Parliament’s scrutiny of the Scottish Government obesity strategy. This analysis was presented at an invited Scottish Parliament Information Centre (SPICe)/Scotland's Futures Forum seminar (“Fitter or Fatter”). The most recent analysis of trends reinforces the importance of deprivation in childhood obesity risk in the time of COVID-19.

**Prenatal flavour programming and beneficial taste preferences**

The potential to positively influence the taste preferences of children, and particularly their acceptance of healthy green vegetables, through repeated exposure in early life, requires proof of concept. A test was carried out on whether an intervention which increases the diversity of fruits and vegetables consumed by mothers in the 3rd trimester of pregnancy would positively influence their infant’s acceptance of fruits and vegetables, particularly those with a bitter taste profile, at weaning. Pregnant women ate soups/sauces with and without bitter vegetables for 24-days. Infant taste-tests were videoed by the mothers at the outset of weaning and scored by independent assessors using validated behaviours and facial expressions. These scores agreed with the mother’s assessment of the infant’s liking of the test foods.

The response of babies to a bitter spinach puree test was particularly striking, with the babies’ liking of spinach correlated with the level of bitter flavour exposure achieved via their mother’s diet in the womb. This proved to be the case for mothers whose normal intake of bitter vegetables was already high, and for those receiving more bitter vegetables than normal. Thus, exposure to bitter flavours during late pregnancy via the maternal diet can influence the acceptance of infants of bitter tasting vegetables at weaning, laying the foundations for healthy eating habits. The policy implications are both in the context of pregnancy as a ‘teachable moment’ when mothers are motivated to make lifestyle changes to benefit their baby’s health, and in programming healthy taste preferences. Stakeholder engagement, including Scottish Government Maternal and Infant Nutrition teams, Food Standards Scotland and First Steps Nutrition is on-going in the form of [briefings](https://sefari.scot/sites/default/files/research/Briefing%20note%201%20w%20edit%20(Wallace%26Miller%2C%2029thJuly22).pdf) and presentations.

**Reducing health harms of foods high in fat, sugar and salt**

To address public dietary-health concerns, the Scottish Government published ‘[A healthier future: Scotland's diet and healthy weight delivery plan](https://www.gov.scot/publications/healthier-future-scotlands-diet-healthy-weight-delivery-plan/)’ (2018). The plan includes actions focusing on children, the food environment, weight management services, leadership to promote healthy weight and diet, and reducing diet-related health inequalities. An ex-ante analysis, funded by the Scottish Government Population Health Directorate, was conducted of the impact on sales of restricting all the in-premises price promotions of discretionary foods. The effects of only restricting multi-buy promotions were also estimated. The [report](https://www.gov.scot/publications/economic-modelling-reducing-health-harms-foods-high-fat-sugar-salt-final-report/documents/) by SEFARI researchers (December 2020) indicated that restricting the advertising of all price promotions (i.e., temporary price reduction, Y for £X, multi-buy and other promotions) has the potential to reduce the number of calories, sugar, saturated fats and sodium for most food groups.

The modelled impacts presented in the report can be viewed as an upper bound on the actual impacts. Effect sizes will depend on the types of promotions of discretionary foods restricted, and factors such as future changes in consumer purchasing decisions and retailer behaviour. [Discussion](file:///C:\Users\dm40246\AppData\Local\Microsoft\Windows\INetCache\Content.Outlook\ZKOOFMFA\‘What%20can%20we%20expect%20from%20a%20ban%20on%20junk%20food%20price%20promotions’) of the results is also available on the London School of Economics Business Review website.

**Banning promotions of soft drinks could be more effective than a sugar tax**

In April 2018, the UK Government introduced a soft drinks levy to reduce the consumption of sugar from sugar-sweetened beverages. Post-policy implementation studies suggest that although the average sugar content of soft drinks was reduced (probably due to reformulation), the average volume purchased remained unchanged. Considering these results, it became necessary to consider other avenues to reduce soft drink intake. Retailers use sale promotions to boost their sales, however, this leads to stockpiling and overconsumption. Through analysis of Scottish households' spending on soft drinks in 2019, a comparison was made of the impact of the soft drinks levy with a ban on all forms of promotions for soft drinks. The [outcome of the study](https://www.sciencedirect.com/science/article/pii/S0306919221001706), as discussed in a blog for ‘[The Conversation](https://theconversation.com/banning-the-promotion-of-soft-drinks-could-be-more-effective-than-a-sugar-tax-177288)’, suggests that banning all forms of promotions on soft drinks could reduce the annual quantity of drinks purchased by 35.8% compared to a 1.4% reduction from a soft drinks levy.

**Understanding the lived experience of food insecurity in Scotland**

Studies of food insecurity in Scotland were co-designed with a Steering Group containing policy makers and implementers. A cohort study of adults with lived experience of food insecurity found that this should be considered along two main axes: severity and perceived intensity. This has informed work planned for the SRP 2022-27, which will aim to gain further understanding of food consumption practices of food insecure people and to help build more inclusive food networks. Outcomes noted the limited analytical weight that could be placed on food insecurity data through the Scottish Health Survey, providing support for the Scottish Government decision to discontinue the collection of data by this route.

Research was also conducted into [service providers’ perspectives on the impact of Covid-19 lockdowns on food insecurity among families with school-age children](https://www.communityfoodandhealth.org.uk/2022/guest-blog-impact-of-the-covid-19-lockdowns-in-service-providers-perspectives-of-the-food-insecurity-of-families-with-school-age-children-in-scotland/). A review concluded that it is not practicable to develop a robust map of the availability of culturally acceptable healthy foods in Scotland, and so the focus turned to identifying areas with poor provision of retail services. Almost a quarter of postcode sectors in Scotland’s most remote rural areas lacked access to supermarket delivery. Significant concentrations of emergency food aid providers (e.g., food banks) were found in urban areas with high levels of income deprivation and in small towns in remote rural areas. This suggests that food insecure people living in remote rural areas may have access to food aid in or from ‘nearby’ small towns.

**Understanding short food supply networks in Scotland**

SRP research aimed to build a better understanding of short food supply networks (SFSN) and measures by which they can be strengthened. 'Short' in this context refers both to local foods (produced and consumed within a certain radius) and to 'locality' foods the geographical provenance of which is made known to consumers, e.g., through geographical branding. A review of SFSN research and a Steering Group of policy makers and industry stakeholders informed the design of a large-scale survey of Scottish micro, small and medium sized food, and drink enterprises, providing baseline data on SFSN in Scotland. This was followed-up by qualitative interviews. Together, these gave an evidence-based forward-look, examining costs

and opportunities for Scottish food and drink products with higher value status (e.g., with geographical branding), and informed the design of work which will be undertaken in the SRP 2022-27.

Allied to SRP food supply chains research, A SEFARI project worked with Highlands and Islands Enterprise (HIE) to look at how [food and drink producers might engage with a proposed Arctic Foods Innovation Cluster](https://sefari.scot/research/food-and-drink-innovation-and-clustering-in-scotland%E2%80%99s-highlands-and-islands-review-of) in support of the Scottish Government’s Arctic Policy Framework and how clusters might be harnessed as a component of rural economic and social resilience. This created an opportunity to design further research into ‘locality’ foods and the generation of ‘place-based’ value through food and drink and enabled engagement with the Scottish Government’s Nordic and Arctic Unit.[Commenting on the research, Francesco Bertoldi – Head of the Unit - said it provided valuable insight, identifying key areas for mutual learning, and discussing opportunities to accelerate sustainable innovation in some of Scotland’s key food and drink sectors.’]

**Right to buy land regulations**

Formal evidence was provided to the Environment Climate Change and Land Reform Committee of the Scottish Parliament (March 2020) on the ‘[Right to Buy Land to Further Sustainable Development (Eligible Land, Specified Types of Area and Restrictions on Transfers, Assignations and Dealing) (Scotland) Regulations 2020](https://archive2021.parliament.scot/parliamentarybusiness/report.aspx?r=12554&mode=pdf)’. The draft regulations were discussed in response to questions from the Committee, along with outstanding issues, their significance, and concerns. [Final Regulations](https://www.legislation.gov.uk/ssi/2020/21/made) came into force on 26 April 2020.

**Future of rural youth**

A SEFARI researcher was commissioned as an external expert by the Current Affairs Committee of the [Council of Europe Congress of Regional and Local Authorities](https://www.coe.int/en/web/congress) to report on the future of youth in rural areas. This builds on research into rural poverty and social exclusion for the Standard Life Foundation and Children’s Neighbourhoods Scotland. A [report](https://pure.sruc.ac.uk/en/publications/the-future-of-youth-in-rural-areas-responsibilities-of-local-and-) was presented to the Committee in November 2021 which formed the basis of subsequent debate, informing development of a resolution and recommendation adopted by the Committee in March 2022.

**Community led local development funding replacing EU LEADER funding** Research for the Scottish Government Rural Communities Policy Team, reviewed the Rural Communities Testing Change Fund. This support for community led local development (CLLD) was launched by Scottish Government to replace funding from EU LEADER with funding to LEADER Local Action Groups (LAGs)through allocations and competitive bidding. It is accompanied by a competitive funding stream open to applications from community groups across rural Scotland. Two pieces of work were undertaken:

i) a review of the processes through which the funding was allocated and, most importantly, its impacts, to inform recommendations to Scottish Government for future community led local development activity. The report was submitted to Scottish Government in March 2022, and a Policy Spotlight of key findings is being prepared for public release;

ii) a review of evaluations of LEADER funding from Local Action Groups, with a workshop of SEFARI researchers the output of which highlighted which parts of the LEADER funding could be improved in the replacement Scottish Government CLLD funding. Reports were submitted to Scottish Government in February and March 2022, with the recommendations informing the new Scottish Government CLLD funding arrangements for 2022-23.

**Demographic challenges and repopulation potential in low populated areas**

SRP research has provided new evidence of the threat of population decline and growing demographic imbalances across a large area of Scotland. This work has extended understanding of rural diversity in Scotland by identifying rural areas and small towns which are affected by poor access to people (i.e. population sparsity) and analysing changes in populations, agriculture, economic activity, and service provision within these areas. Population projections for the Sparsely Populated Areas (SPAs) of Scotland, which emphasised their vulnerability to depopulation without considerable migration, [have been revised leading to updated population projections for and within this region](https://www.hutton.ac.uk/sites/default/files/files/research/srp2016-21/rd341briefprojectionsandforesightintro.pdf). This has been accompanied by the development of a novel data-rich modelling approach integrating forecasts of industry-level employment change and economic links between regions into predictions of future population levels across Scotland. The refined model identified potential population levels that could be supported in different parts of the SPAs over a 25-year period (2018-43). An analysis of modelled populations generated using different migration assumptions has identified unrealised potential for population growth within some parts of the SPAs and indicates variation in the feasibility of repopulation across the region.

**2.3.2. SUPPORTING INNOVATION AND THE ECONOMY**

**Food waste and date marking**

A SEFARI researcher authored a section of the University of the West of Scotland - Oxfam Partnership: Collaborative Research Reports Series ‘[On Target for 2030? An independent snapshot review of Scotland’s progress against the United Nations Sustainable Development Goals](http://uwsoxfampartnership.org.uk/wp-content/uploads/2019/06/On-Target-July-2019-Web-FINAL.pdf)’. The section, entitled ‘Ensure sustainable consumption and production patterns’, under SDG 12 (Responsible Consumption and Production), highlighted SRP work on sustainable production and consumption and included a case study on food waste in a circular economy. The case study used representative surveys and causal econometric analysis to identify factors influencing household food waste linked to their understanding of date labelling, particularly ‘best before’ and ‘use by’ labels. Findings are published in three peer review papers on: [date-label use and the waste of dairy products by consumers](https://doi.org/10.1016/j.jclepro.2019.119174); [effect of date labels on willingness to consume dairy products and waste implications](https://doi.org/10.1016/j.wasman.2018.05.021); and [impact of consumers’ understanding of date labelling on food waste behaviour](https://doi.org/10.1007/s12351-017-0352-3) in Scotland and the European Union.

The three studies identified direct and indirect links between consumer perceptions and understanding of date labelling and their intentions to reduce waste in a framework including food risk perceptions, attitudes towards waste, and access to relevant information. The findings contribute to the debate on changing food date marking regulations towards better waste prevention policies.

**Reintroduction of hemp as an environmental and healthy crop**

SRP research on hemp demonstrated that this valuable environmental crop can contribute to meeting climate and biodiversity targets, deliver [high-quality alternative protein](https://pubmed.ncbi.nlm.nih.gov/27299956/) and fibre sources to diversify the diet, and have potential [health benefits](https://pubmed.ncbi.nlm.nih.gov/34716790/). These findings have been widely disseminated to different types of audiences through scientific publications, invited lectures, [trade magazines](https://www.farmads.co.uk/taking-an-alternative-approach-to-crops/), a [SEFARI Gateway blog](https://sefari.scot/blog/2019/10/14/hemp%E2%80%99s-role-in-diet-biodiversification-and-reducing-greenhouse-gas-emissions), a [Google Earth Tour of SEFARI research launched at COP26](https://earth.google.com/web/data=MicKJQojCiExOWIybGptV3VMNjBqNnJvMlc5Y0dXRTJ2VEVaTTM1X0c), and [Leading Ideas booklets on Crops](https://sefari.scot/sites/default/files/documents/SEFARI%20Crops%20Booklet.pdf) and [Food](https://sefari.scot/sites/default/files/documents/SEFARI%20Food%20Booklet.pdf). A [Taste of Plants Recipe Book](https://www.abdn.ac.uk/rowett/documents/A%20Taste%20of%20Plants.pdf) and [Stakeholder Dinner](https://www.abdn.ac.uk/rowett/policy-industry/top_project.php) were designed for policy and public audiences. Hemp items were exhibited at high profile events such as a presentation to the Scottish Government, the Edinburgh International Science Festival, the Royal Highland Show and Arable Scotland. SEFARI Gateway funding supported engagement with designers, artists and producers to utilise co-products of hemp as high-value products through a successful event [‘Hemp Futures’](https://www.thebarnarts.co.uk/article/hemp-futures-past-and-present-history-today) with the multi-award winning organisation The Barn.

Based on the SRP research, SEFARI Gateway funded a fellowship with the Scottish Hemp Growers Association and Scottish Agricultural Organisation Society to identify new market opportunities for Scottish-grown hemp (both grain and fibre). Engagement with businesses has resulted in Green Grow including hemp seeds in their recipes and Good Hemp, the major UK producer of hemp products, investing in a PhD studentship to explore the valorisation of their major co-products and waste streams to deliver zero-waste production processes. The work featured on UK television on BBC Landward, in an [STV Documentary; Climate of Change](https://www.facebook.com/WeAreSTV/videos/scotland-stories-climate-of-change/1221585578013881/). This research was key to establishing the Scottish Hemp Group (renamed Scottish Hemp Growers Association), which brought interested parties across the hemp supply chain together with a mission to support and promote hemp in Scotland for food, feed, energy, biomaterials, and as a cash-crop promoter of circular green economies and new markets. A picture containing cup, outdoor, drink, beverage

Description automatically generated [Castleton Farm said, ‘the research undertaken by SEFARI scientists inspired farmers in the Scottish Hemp Growers Association to grow hemp, which has led to the first commercial oil production in Scotland. Continued collaboration will be key to delivering a valuable hemp industry for Scotland'.] Several Scottish farmers have now produced hemp, and the [first commercial oil](https://www.abdn.ac.uk/news/16105/) has been produced in Scotland. SRP research has shown that this oil is superior to rapeseed and olive oil in terms of its fatty acid content and SEFARI research will continue to play a key role supporting the reintroduction of hemp as a food crop in Scotland in SRP 2022-27, particularly in relation to consumer demand and grow the processing sector.

**Valorising bean hulls to reduce waste and support circular nutrition**

The UK is the largest producer of broad beans in Europe, which results in large amounts of by-products such as hulls that are mostly discarded. Valorising this material as food represents an opportunity to reduce food waste and contribute to a circular nutrition. The broad bean hull was shown to have a promising nutritional profile, being rich in fibre (49%), and could contribute to the achievement of daily recommended intakes of dietary fibre. Initial work focussed on delivering bean hull fortified food by the incorporation of the milled hull into wheat bread. The broad bean hulls were used to replace up to [21% of the wheat flour in the bread, which was achieved without major impact on bread taste, texture and volume](https://pubmed.ncbi.nlm.nih.gov/32872269/).

Nutritional analysis showed that consuming two bean hull fortified bread rolls could contribute approximately 90% of daily recommended dietary fibre intake while delivering important proportions of Recommended Daily Allowances for micronutrients such as phosphorus, calcium, manganese, iron, zinc, copper, potassium, molybdenum and selenium for adult men and women. To understand the nutritional (and health) potential of bean hulls, hulls were incorporated into bread and fed to healthy human volunteers. Consumption of bean hull fortified bread for three days had a positive impact on the gut, with increases in several beneficial microbial metabolites and decreases in harmful microbial metabolites. Furthermore, bean hull fibre was poorly fermented by human gut bacteria and had no major impact on the gut microbiota composition. This work has been presented to major stakeholders including Marks and Spencer Plc.

**Increasing seafood as a healthy, sustainable, and affordable dietary choice**

The nutritional and cardiovascular health benefits of consuming rapeseed oil-fed farmed salmon was evaluated, findings from which showed these do not decrease compared with those of traditionally farmed salmon. The [findings](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8137615/) strongly endorse opportunities for developing more sustainable feeds within aquaculture food systems, and therefore more sustainable salmon food products. This is important considering that the seafood industry contributes significantly to Scotland's food and drink economy, with salmon being the largest food export from both Scotland and the UK.

Research on seafood and strong links between SEFARI and relevant stakeholders in the Scottish aquaculture industry (Salmon Scotland, Sustainable Aquaculture Innovation Centre, Mowi, Biomar, Scottish Seafarms, Seafood Scotland), led to a paid consultancy to develop and evaluate the success of the ‘Salmon in Schools’ project where Scottish salmon was provided as a school meal once a week in six secondary schools in Stirling in early 2022. The ambition is to roll this pilot initiative out on a national scale. As part of this project, the largest survey conducted on fish eating habits and perceptions about fish and salmon consumption, was run with c.1,000 secondary school children, providing valuable insights for A picture containing text, person, indoor, people

Description automatically generatedScottish seafood organisations. SEFARI researchers held the first “SeafoodMattersUK'' meeting with the University of Stirling, aiming to break down barriers between sectors (producers, processors, consumers, NGOs, academia, consultants, policy, and Government). Over 100 participants discussed risks, barriers and opportunities within the seafood sector, global supply chains and farmed seafood from retailers and restaurants, the environmental impact and nutritional outcomes of seafood consumption and transforming seafood demand.

**Microbiome expertise as a catalyst of commercial investment**

Long-standing expertise in anaerobic microbiology and in gut microbiome research has led directly to numerous collaborations and contractual work with industry during the SRP. This has included multi-year projects working with large multinationals such as Danone (2016 to 2019), Heineken (2016 to 2021), [Tate & Lyle (2019 to 2020)](https://www.tateandlyle.com/news/translating-nutrition-science-into-meaningful-change), [By-Health Co. Ltd (2016 to 2020)](http://www.by-health.com/en/innovation/science/), Yakult (2019 to 2022), and [Chr. Hansen (2016 to 2017)](https://www.chr-hansen.com/en/media/press-releases/2017/6/chr-hansen-expands-strain-library-for-next-generation-probiotics). Researchers worked with SMEs such as Probi AB (2017 to 2024) and ZOE Global Ltd (2019), and carried out consultancy work for 4D Pharma and EnteroBiotix Ltd (2020 to 2023), receiving company funding as part of a wider [Innovate UK-funded Knowledge Transfer Partnership](https://www.ktpscotland.org.uk/ViewArticle/tabid/4421/articleType/ArticleView/articleId/13826/ENTEROBIOTIX-LTD.aspx). [Jonathan Wolf of ZOE Global Ltd commented that SEFARI scientists ‘had provided invaluable assistance to their work and the quality of data collected was significantly higher as a result, leading to much higher chances of significant healthcare impact from their new commercial product.’].

The joint research with all the companies listed above was carried out to further their objectives on product development. This included work to identify and characterise novel probiotics/therapeutics, studies to test the impact of dietary supplements, protocol development projects, and studies to enhance production of existing and new food and drink products. Cumulatively, these collaborations have led to over £2M of company investment, most of which has created new jobs and supported staff salaries, which in turn has contributed to the local Scottish economy. [Adam Baker of Chr. Hansen, a leading supplier of probiotics, confirmed that SEFARI research had been‘invaluable in [isolating, characterizing and describing potentially beneficial bacterial strains](https://www.chr-hansen.com/en/media/news/2017/07/100-new-candidates-for-next-generation-probiotics)’] and that Chr. Hansen had [‘concomitantly invested significantly in upscaling their infrastructure and, aided by (SEFARI research), were now in a position where they could begin to develop the new strains further towards new products.’]

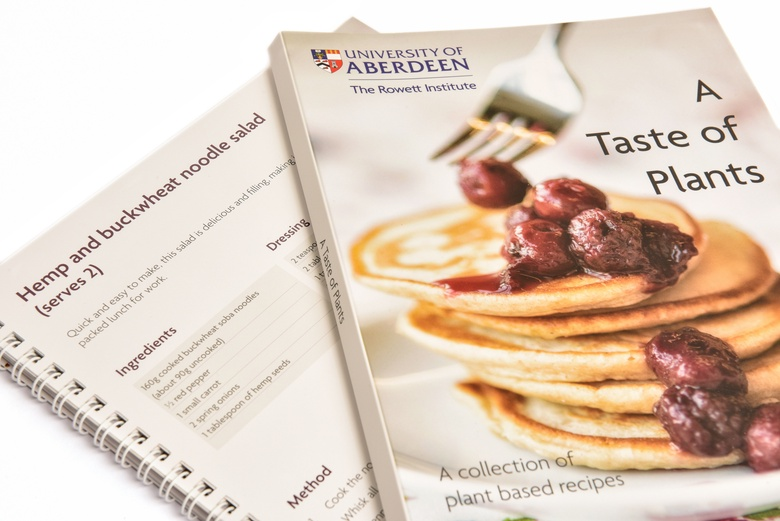
The research has led to several joint publications including ‘[Vitamin biosynthesis by human gut butyrate-producing bacteria and cross-feeding in synthetic microbial communities](https://doi.org/10.1128/mBio.00886-20)’, ‘[Comparative genetic and physiological characterisation of *Pectinatus* species reveals shared tolerance to beer-associated stressors but halotolerance specific to pickle-associated strains](https://doi.org/10.1016/j.fm.2020.103462)’, ‘[Exploring health-promoting attributes of plant proteins as a functional ingredient for the food sector: a systematic review of human intervention studies](https://pubmed.ncbi.nlm.nih.gov/32751677/)’, and ‘[Efficacy of bilberry and grape seed extract supplement interventions to improve glucose and cholesterol metabolism and blood pressure in different populations – a systematic review of the literature](https://pubmed.ncbi.nlm.nih.gov/34067538/)’.

**Underutilised crops and wild species for diet, diversity and climate targets** SRP research demonstrated that wild varieties of commonly consumed vegetables (beet, radish, cabbage, and carrots) are higher in bioactive phytochemicals (shown previously to reduce inflammation) compared to heritage and F1 varieties, in a study at five sites across Scotland, and independent of environmental conditions. Findings suggest a potential benefit of consumption of these crops for human health, as well as environmental benefits (due to less fertiliser and pesticides use), and an ability to grow on more marginal land. Wild plants (and agricultural waste streams) with potential for revalorisation were identified through a stakeholder workshop (IBioIC, KTN, Scottish Integrated Research on Timber, NFUS, SFD, Food Commission and SEPA) and selected invasive species which currently are removed by processes detrimental to the environment were analysed and evaluated. [Invasive plants were shown to be a valuable alternative protein source that could contribute to meeting climate change targets](https://www.frontiersin.org/articles/10.3389/fsufs.2021.575056/full).

The SRP research leveraged Interface Multi-Party funding to work with Scotland’s large fruit and vegetable processors (Kettle Produce, Speyfruit) as well as Eatbalanced and Supernature, which showed that their major side streams had revalorisation potential. Findings have been disseminated in scientific publications, keynote lectures, a SEFARI-Gateway blog [‘Eat Them to Beat Them’](https://sefari.scot/blog/2021/05/12/eat-them-to-beat-them) and [Leading Ideas booklet](https://sefari.scot/sites/default/files/documents/SEFARI_Soil_Booklet.pdf), and to policy teams (Scotland’s Future Forum, Scotland’s Dinner Plate and [Royal Society London; Future Food Meeting](https://royalsociety.org/-/media/policy/Publications/2020/25-03-2019-future-of-food-conference-report.pdf)). A SEFARI researcher was invited to present this work to audiences in business (e.g., Nutritionists in Industry conference) and schools (e.g., an event organised by The Royal Society of Edinburgh). It has also been presented to the public at events and in the media (Edinburgh International Science Festival, Royal Highland Show, BBC Landward). Support for a BBSRC press campaign on the topic also led to widespread media attention (e.g., Guardian, Telegraph, Independent). The technology developed for the [production of leaf protein concentrates to support the agri-food industry](https://link.springer.com/article/10.1007/s11694-021-01136-w) is now being discussed with several potential partners. Funding (from SEFARI Gateway) enabled researchers conduct a national survey to understand Scotland’s current use of and need for wild species, which is providing valuable information for use in the SRP 2022-27.

**2.3.3. COLLABORATIVE AND MULTIDISCIPLINARY RESEARCH**

**Supporting production of novel sustainable and healthy crops**

SRP Research on novel crops has focused on several food crops as sustainable candidates to diversify dietary macronutrients (protein and fibre) in Scotland. With a focus on understanding the agronomy and composition of crops such as [potato bean](https://www.sciencedirect.com/science/article/pii/S0889157521000211), buckwheat and hemp, novel and impactful findings have been delivered in terms of nutrition efficiency and health potential. The knowledge gained has been shared in engagement with businesses (e.g., Aurora Sustainability) and other Scottish stakeholders including farmers, Non-Governmental Organisations (e.g., WWF), the public (through the SEFARI Gateway supported [Taste of Plants](https://www.abdn.ac.uk/rowett/policy-industry/taste_of_plants.php) recipe book, Edinburgh International Science Festival, Royal Highland Show), health professionals and the Scottish Food and Drink Industry. Working with farmers and agronomists, it was demonstrated that potato bean, buckwheat and hemp can all be grown in Scotland. Work in the SRP 2022-27 will build viable supply chains for these products.

Through human studies, both [hemp and buckwheat have been shown to be valuable sources of dietary amino acids](https://pubmed.ncbi.nlm.nih.gov/34716790/), as well as beneficially modulating gastrointestinal hormones and promoting satiety in healthy volunteers. Buckwheat was developed as a novel functional food (patent-pending technology). Working with NHS colleagues the formulation was shown to beneficially modulate sugar metabolism in people with Type 2 diabetes. RESAS-funded research on novel crops contributes to delivering on [UN Sustainable Development Goals](https://www.abdn.ac.uk/about/documents/SDG-Report-2021.pdf). The role of these crops as food, for environment biodiversification and mitigation of climate change is discussed as part of educational events in schools across Scotland.

**Supporting production of barley for the food and drink industry**

SEFARI researchers across the SRP have interests in developing healthy and more sustainable lines of barley for the food and drink (non-alcoholic) industry. Several of the barley lines they produced have been analysed for their macro-, micro-, and non-nutrient (phytochemical) content. These include landraces and other ancient varieties, as well as commercial, mutant, and elite lines. This data is an important resource for producers and processors. One elite line recognised to have superior nutritional attributes (being high in b-glucan and phytochemicals) was tested in an acute human intervention, predominantly to see whether differences in composition are translated into potential health benefits in humans compared to commercial barley varieties.

A BBSRC EASTBIO studentship was awarded to add value to the SRP research by exploring the impact of processing and the potential to influence breeding strategies. Results from the human study demonstrated there is potential to deliver benefits through plant breeding to increase levels of nutrients and bioactives in crops but that these are dependent on processing. The human study provided samples that facilitated an assessment of [mycotoxin load and metabolism](https://www.sciencedirect.com/science/article/pii/S0378427421007761?via%3Dihub) from barley by SEFARI-researchers. New methods for high-throughput screening were developed to facilitate the analysis of a greater number of samples, with a particular objective to identify pathways involved in the regulation of important bioactives that could be impacted upon through breeding strategies. Data collected on 150 barley lines was used for the Genome Wide Association Study (GWAS). This confirmed previous findings validating the novel GWAS approach (as well as the high-throughput screening method developed) and some new associations were identified. Deeper analysis of the results obtained from the human study has highlightedthe importance of inter-individual response across a range of metabolites. This is an important outcome in terms of human health and has informed work planned for the SRP 2022-27.

Findings highlight that both processing and physiological responses to food are important considerations when adapting supply chains, particularly in moves towards climate neutral agriculture. Researchers are in discussions with barley breeders/processors (Craft Maltsters, Scotland the Bread, Aurora Sustainability Group, Murdoch Allan) to look at opportunities to influence primary production to produce healthier and more sustainable barley. While demonstrating the potential of barley as food, the focus shifted to explore lower inputs and raising awareness and supporting [agronomy studies](https://www.sciencedirect.com/science/article/pii/S0733521017300139?via%3Dihub) by SEFARI researchers in field trials. Farm-grown barley, landraces and crosses considered to have lower nutrient requirements were shown to be significantly higher in bioactive phytochemicals understood to be beneficial for human health, as well as their resistance to pests. Results have been presented at meetings for scientific (Monogram, International Cell Wall Meeting) and stakeholder (Arable Scotland, Cereals in Practice) audiences. Applications for further funding have been made (UKRI/Innovate/Interface), with a [Net Zero Challenge](https://interface-online.org.uk/news/160k-funding-awarded-scottish-sustainable-food-and-drink-businesses) project to revalorise barley co-products as food being funded.

**Modelling microbial populations in the human colon**

A mathematical model was developed which provides computer simulations of the response of human colonic microbiota to changes in diet. As part of the work, an R package, microPop, was developed which can be used to model general microbial populations ranging from human gut bacteria to marine algae. The software, which is publicly available on CRAN (R package repository), [was published in Methods in Ecology and Evolution](https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12873) and was taught to PhD and Masters students at an [international summer school on Microbial Community Modelling in Belgium](https://psbweb05.psb.ugent.be/conet/microbemodelschool/index.php). The model has also been applied to methane production in ruminants in the SRP, and contributed to two funding proposals (to NERC and ERC) on the effects of climate change on methane production from lakes led by the University of Warwick (involving UKCEH and Queens University Belfast). MicroPop has been extended to include interactions between the colonic microbes and the host. This R package, microPopGut, is also publicly available and a publication is being finalised**.**

**One Health view of antimicrobial resistance (AMR) research in Scotland** Antimicrobial resistance (AMR) is a priority public health issue. The unintended consequence of pharmaceutical use to control harmful pathogens has been widespread resistance. AMR microbes are transmitted through the same pathways as pathogenic microbes, in indoor and outdoor environments. This means multiple routes for their impact on human, animal, and plant health, encapsulated by the One Health concept. National Action Plans have been developed globally from a World Health Organisation (WHO) framework to combat AMR. The action plans are built on five principles to improve awareness and understanding of the problem, strengthen the scientific evidence-base, reduce the incidence of human infections with AMR microbes, optimise pharmaceutical use in human and animal health, and invest in new diagnostics, vaccines, and interventions.

SEFARI researchers across the SRP have a breadth of expertise and multidisciplinary approach in developing solutions to address AMR. To capture the breadth and scope of the work within the SRP 2016-22 a series of workshops were held, including using SEFARI Gateway funding, to map AMR research activities. The overview produced highlighted where Scottish expertise was contributing to international commitments. The work was published at the international One Health conference (co-sponsored by SEFARI Gateway) at which [SRP and wider Portfolio AMR research was highlighted](https://sefari.scot/sites/default/files/documents/SEFARI%20AMR%20Booklet.pdf) (Edinburgh, November 2020). The overview had a direct influence on the winning of a CREW-funded project to generate a register of all Scottish research activities on AMR: the Scottish One Health AMR register (SOHAR). Since AMR is a One Health issue, the work is relevant to stakeholders from multiple sectors, including Food Standards Scotland, SEPA, EPIC (representing Animal Health) and Public Health Scotland.

Diagram

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**Contemporary current affairs and food policy impact**

Expert analysis of different highly topical food policy issues has been presented in internet blogs (e.g., London School of Economics Business Review). Topics have encompassed the impact of Brexit on issues such as [exports or imports of fresh produce](https://blogs.lse.ac.uk/businessreview/2020/09/16/the-uk-economy-is-recovering-from-the-pandemic-shock-but-not-all-is-rosy/), [the impact of COVID-19 on food supply chains](https://blogs.lse.ac.uk/businessreview/2020/03/25/covid-19-the-underlying-issues-affecting-the-uks-food-supply-chains/) and [their recovery](https://blogs.lse.ac.uk/businessreview/2021/11/03/the-road-to-recovery-for-the-food-and-drink-sector/); [the effect of the Ukraine-Russia conflict on food supply chain costs and the cost of living](https://blogs.lse.ac.uk/businessreview/2022/04/27/producer-price-inflation-for-food-and-drink-the-role-of-fuel-hikes-and-the-war-in-ukraine/); and trends in consumption such as t[he organic food market](https://blogs.lse.ac.uk/businessreview/2021/06/14/upbeat-news-about-the-growth-of-the-uk-organic-food-market-can-be-misleading/), and [eating red meat and processed food](https://blogs.lse.ac.uk/businessreview/2021/10/15/the-british-are-eating-less-red-meat-and-consuming-more-processed-food/#:~:text=The%20British%20are%20eating%20less%20red%20meat%20and%20consuming%20more%20processed%20food,-0%20comments%20%7C%209&text=Red%20meat%20consumption%20has%20seen,also%20contributed%20to%20the%20trend.). Other blogs explored the [evolution of UK food and drink exports to EU and non-EU countries](https://blogs.lse.ac.uk/businessreview/2021/03/18/how-uk-food-and-drink-exports-to-eu-and-non-eu-countries-have-evolved-over-time/); questioned if [food standards should be left to the market in post-Brexit Britain](https://blogs.lse.ac.uk/businessreview/2020/11/30/should-food-standards-be-left-to-the-market-in-post-brexit-britain/); and discussed [options for the UK to make its livestock production sustainable](https://blogs.lse.ac.uk/businessreview/2021/08/26/how-to-delink-the-uks-soybean-imports-and-livestock-supply-chains-from-deforestation-in-the-amazon/).

**SEFARI contribution to achieving Sustainable Development Goals (SDGs)**

The SRP 2016-22 spans multiple disciplines which has helped SEFARI researchers leverage additional funding for multidisciplinary collaborative projects based on SRP related priorities. A notable example is the current Global Challenges Research Fund Action Against Child Stunting Hub. This is a five year, £20m project, spanning three continents and involving 19 research organisations. The Hubs are designed to address previously intractable problems using multidisciplinary approaches. SEFARI researchers lead key work streams within the Hub and sit on its Executive Board as Deputy Principal Investigator for the overall project. The research is designed to address the problem of nutritional deficiency and stunting in children, relevant to the first three Sustainable Development Goals (SDG 1 End poverty in all its forms everywhere; SDG 2 End hunger, achieve food security and improved nutrition and promote sustainable agriculture; SDG 3 Ensure healthy lives and promote wellbeing for all, at all ages).

**Improved characterisation of the cattle rumen microbiome**

Research in the SRP led to new, and highly productive, collaborative research between SEFARI (SRUC, the Rowett Institute) and the Roslin Institute, in which DNA sequencing-based methods were used to study the cattle rumen microbiome. Publications included studies in high impact journals [*Nature Biotechnology*](https://www.nature.com/articles/s41587-019-0202-3) and [*Nature Communications*](https://www.nature.com/articles/s41467-018-03317-6), describing the use of metagenomics to generate novel genomes from thousands of previously undescribed rumen microbes, and on the impacts of [different feeding practices](https://link.springer.com/article/10.1186/s42523-019-0018-y) and [host genetics](https://www.frontiersin.org/articles/10.3389/fgene.2019.00701/full) on the cattle rumen microbiome. Cumulatively, these four studies have received over 600 citations, and resulted in greatly improved understanding of the structure and functions of the cattle rumen microbiome, how it responds to changes in animal feeding practices, and identified rumen microbial genes associated with appetite, growth, and feed conversion efficiency. New collaborative links between the Roslin Institute and Rowett Institute led to successful bidding for a BBSRC EASTBIO-funded Doctoral Training Partnership in collaboration with the Edinburgh-based company Fios Genomics Ltd. The PhD student was based mainly at the Roslin Institute, carrying out work [demonstrating the significant impact that reference databases can have on metagenomics analyses](https://www.biorxiv.org/content/10.1101/2022.04.26.489553v1), which is a finding with major implications for all researchers using metagenome-based approaches to study microbiomes. In the time the student spent time at the Rowett Institute they cultured novel bacteria from rumen samples provided by SRUC. Some of these newly cultured bacteria will be tested for activities such as the inhibition of pathogens during the SRP 2022-27.

**2.3.4. SCIENTIFIC EXCELLENCE**

**Plant-based foods as sources of human pathogens**

Harmful bacterial pathogens are often transmitted via the food chain where they cause serious human illness, emphasising the need to understand transmission pathways. Attention tends to focus on livestock production systems because virtually all foodborne bacterial pathogens come from animals. However, plants play an important role in transmission because of contamination from animals / humans into plant production systems, with between a third and a half of all foodborne illnesses attributed to contaminated plant-based foodstuffs. SRP research showed how these bacterial pathogens colonise crop plants, and the risks involved. This work identified some of the bacterial genes involved in plant colonisation, examined how colonisation patterns differ between different species of crop plant, and shed new light on plant and soil bacteria that are closely related to the pathogens. The work provided fundamental scientific evidence to show how and why transmission via plants occurs, and highlights what is often an overlooked issue since the prevailing view is that the problem lies solely with animal production systems.

The SRP research findings have been publicised in numerous knowledge exchange events engaging the public, academics, and stakeholders (i.e., Food Standards Scotland, EPIC and Public Health Scotland). [Marianne James of FSS said ‘SEFARI research into the transmission of foodborne pathogens through plants has helped go towards filling a key evidence gap for Food Standards Scotland. Although we typically associate many of the foodborne pathogens with contaminated animal produce, outbreaks in recent years have led us to consider in more depth what other commodities may also be playing an important role in the risk of foodborne illness. The team’s research has helped advance our knowledge in this area which

has been incorporated into risk management advice’.] Findings were summarised in a presentation to a joint working group for Animal & Plant Health (Defra, UKRI, APHA, RESAS) to highlight the key issues with relation to crops and the transmission of zoonotic pathogens. It is also discussed in a SEFARI [Gateway blog](https://sefari.scot/blog/2021/04/12/why-we-need-to-consider-the-role-of-plants-in-the-spread-of-zoonotic-pathogens).

**Improving dairy through reformulation**

Reformulation of processed foods offers the potential to improve the nutritional and health attributes of commonly consumed foods such as dairy products. This is particularly important as a cross-sectional study showed that [non-dairy products fall short of key nutrients compared to dairy.](https://journals.sagepub.com/doi/full/10.1177/02601060221105744) Dairy products were more susceptible to formation of Advanced Glycation End-products (AGEs), which are considered detrimental to human health compared to plant-based beverages. Therefore, it was important to understand the impact of seasonal variation and processing. Processing increased AGE formation, with seasonal differences observed in both raw and processed milk. Reformulating with natural products decreased AGE formation. Yogurts were reformulated to contain bioactive-rich salal berries (which [increased the antioxidant capacity](https://www.mdpi.com/2306-5710/5/1/2)) and beta-glucan from spent brewers’ yeast, which had a prebiotic effect on yoghurt bacteria. The yogurt demonstrated significant alpha-glucosidase inhibition, suggesting potential use for people living with, or at risk of, Type 2 diabetes. Sensory studies also offer [potential for commercialisation](https://www.sciencedirect.com/science/article/pii/S0022030218303898).

**Priority research questions for digital agriculture**

A SEFARI researcher was invited to contribute to research that identified the need to formulate and better understand emerging issues relevant to the digitalisation of agricultural production. Aiming to provide a stronger evidence base and to steer policy formulation, the work links to existing RESAS-funded researcher, with a focus on the role of technology in agricultural production through the development and uptake of Controlled Environment Agriculture. Led from the Countryside and Community Research Institute, University of Gloucestershire, the authors engaged in a prioritisation exercise with multiple stakeholders representing different sectors of the food system.

The work on digital agriculture comprised two online rounds of question development and refinement, survey completion and an online participatory workshop to identify the key topics and questions. The [final paper](http://dx.doi.org/10.1016/j.landusepol.2021.105962) (March 2022) identified seven interconnected themes (Data governance; Data management; Enabling use of data and technologies; Understanding benefits and uptake of data and technologies; Optimising data and technologies for performance; Impacts of digital agriculture; New collaborative arrangements) and 27 priority research questions to steer future thinking by policy teams.

**Unpacking the biodiversity-health/wellbeing connection from time in nature**

SEFARI researchers were involved in the development of an integrated framework, drawing on social, natural and health sciences, to identify the pathways for how biodiversity might influence health. Understanding these pathways can inform research, policy and practice focused on [biodiversity conservation and public health interventions](https://www.sciencedirect.com/science/article/pii/S0160412021000441?via%3Dihub). This work builds on contributions to an edited peer-reviewed open-access book focusing on [biodiversity and health in the face of climate change](https://link.springer.com/book/10.1007/978-3-030-02318-8). Chapters examine linkages between biodiversity and various dimensions of health/wellbeing (e.g., mental, spiritual) and implications for policy and practice. The biodiversity-health framework was presented as part of a ‘Tour of Impacts’ roundtable discussion with Scottish Government policy colleagues. The framework paper has been cited 83 times including in the 2021 WHO ‘[Nature, biodiversity and health](https://www.who.int/europe/publications/i/item/9789289055581)’ report.

**Understanding soft-fruit processing to ensure maximum benefit**

There is increasing evidence to support the role of soft fruit bioactives as dietary strategies for alleviating metabolic complications such as Type 2 diabetes associated with obesity, or as alternatives to pharmaceutical interventions, topics to which SEFARI researchers have contributed substantially. They demonstrated that ingestion of an extract obtained from bilberry over a three week intervention period [reduced postprandial glycaemia](https://www.sciencedirect.com/science/article/pii/S1756464619305213?via%3Dihub) without changes in insulin. It was also shown that [processing berries could impact on these reductions](https://www.cambridge.org/core/journals/proceedings-of-the-nutrition-society/article/processing-blueberries-by-homogenising-increases-postprandial-glycaemia-in-response-to-an-oral-glucose-tolerance-test-in-healthy-volunteers-compared-with-whole-berries/95466D37B5BF6D7336544CDA9431008E). Some understanding of the mechanism of action was established through novel insights into the specific binding of dietary phenolics from soft fruits as [inhibitors of protein-tyrosine phosphatase](https://www.sciencedirect.com/science/article/pii/S0006295220303452?via%3Dihub), an important regulator of insulin signalling. Specific [phenolics were also shown to inhibit salivary α-amylase, α-glucosidase, and glucose uptake](https://www.sciencedirect.com/science/article/pii/S0955286319304796?via%3Dihub), with blackcurrants containing the highest amounts of these compounds.

Engagement with a major producer of beverages containing soft fruit (Innocent plc) funded a study to demonstrate that differences in [chemical composition impacted on bioactivity](https://pubmed.ncbi.nlm.nih.gov/32645879/), highlighting the importance of availability from the food matrix. This work demonstrates the potential of the soft fruit industry to contribute towards prevention of prevalent disorders impacting on Scottish consumers, and the importance of working with food and drink processors to ensure that these benefits are realised.

**Early years; breaking the transmission of disadvantage across generations**

Throughout the SRP 2016-22 SEFARI researchers have maintained a process of knowledge exchange and engagement on with Scottish Government policy colleagues in the Health and Wellbeing Children and Families Directorate Division, Diet and Obesity, in face-to-face meetings, presentations, and online discussions. Engagement focused on how SRP research can inform policy in these areas. SEFARI researchers reported on novel ‘biosocial’ mechanisms through which early life adversity may be transmitted across the generations and ways in which such vicious cycles may be broken. Based upon epigenetic changes in the genome, ndicators of health in later life have been identified, and effects of early life exposures and deprivation. Cutting-edge molecular techniques were used to understand the basis for the transgenerational persistence of disadvantage that is increasingly seen in Scotland, the UK, and globally.

The SRP research identified [mechanisms through which processes set in train in early life may influence physical and mental health in later life](https://eur03.safelinks.protection.outlook.com/?url=https%3A%2F%2Fwww.nature.com%2Farticles%2Fs41598-020-78062-2&data=05%7C01%7Ck.crosley%40abdn.ac.uk%7C844a051b51c347b407d408da6b0cf51c%7C8c2b19ad5f9c49d490773ec3cfc52b3f%7C0%7C0%7C637940000636052368%7CUnknown%7CTWFpbGZsb3d8eyJWIjoiMC4wLjAwMDAiLCJQIjoiV2luMzIiLCJBTiI6Ik1haWwiLCJXVCI6Mn0%3D%7C3000%7C%7C%7C&sdata=hEMOp6wXvlL2iNzrsg94hvxGYsN0k3UgX6%2FHrnsD6eU%3D&reserved=0). Findings improve the understanding of early influences on brain development and function, and are potentially relevant to developing novel tests of brain structure and function across the life-course which may help develop strategies to improve cognitive outcomes.

**Plant-food derived chemicals with metabolic health benefits**

Natural resistance in humans to oxidative and inflammatory stress declines with age leading to diseases such as Type 2 diabetes and cardiovascular disease. Substances which enhance these self-defence mechanisms in the body may be of particular benefit in older age groups. Plant-based foods have many health benefits which are often mediated by chemicals synthesised by the plants to adapt to their environmental conditions. Knowledge of these chemicals can help to breed plant varieties with improved health benefits for the consumer and to tailor food processing to retain the activity of these chemicals. However, most such beneficial plant chemicals are currently unknown.

SEFARI scientists have established [cell-based assay systems](https://doi.org/10.1016/j.ab.2020.113583) which allow the rapid, high-throughput analysis of these plant chemicals focussing on chemicals with anti-oxidative and anti-inflammatory effects. Using these cell-based assay systems several plant chemicals which significantly increase cellular resistance to oxidative and inflammatory stress in the absence of toxic side effects were identified. These approaches hold promise for the development of nutritional strategies (in collaboration with policy makers) and food products (in collaboration with the food and drink industry) which support healthy aging and prevent the development of age-related diseases.

**Technologies developed to quantify crop, dietary and microbial metabolites**

A picture containing colorful

Description automatically generatedMany SRP projects utilise SEFARI facilities to quantify important metabolites in crops, food and humans following consumption of particular diets. Several [targeted metabolomic platforms](https://www.sciencedirect.com/science/article/pii/S0308814619305916#:~:text=Using%20simple%20solvent%20extraction%20and%20enzymatic%20hydrolysis%2C%20a,plasma%20and%20urine%20samples%20was%20developed%20and%20validated.) have been developed to add to this capability and support the work. SEFARI researchers have unique expertise in measuring microbial metabolites which led to a second grant from the National Institutes of Health US (£266K). Quantifying microbialmetabolites has provided evidence on the importance of dietary fibre, demonstrating that ['dietary carbohydrate drives colonic microbial fermentation during weight loss'](https://pubmed.ncbi.nlm.nih.gov/29464347/#:~:text=Most%20faecal%20metabolites%20were%20correlated%20with%20dietary%20carbohydrate,designing%20safe%2C%20effective%20and%20healthy%20weight%20loss%20diets.), the ['availability and dose response of phytophenols from a wheat bran-rich diet'](https://pubmed.ncbi.nlm.nih.gov/27356494/), and that ['wheat bran promoted bacteria delivering beneficial metabolites](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4949515/)'. It also contributes to the understanding of [microbial fermentation of protein](https://www.cambridge.org/core/journals/proceedings-of-the-nutrition-society/article/impact-of-protein-on-the-composition-and-metabolism-of-the-human-gut-microbiota-and-health/1BB266B926D3A309E9B60B9D4DCDB99E), and the presence of novel [microbial metabolites in plasma](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7230228/#:~:text=Following%20the%20consumption%20of%20a%20soya-rich%20high-protein%20weight-loss,17.5%20mg%20per%20100%20g%20fresh%20faecal%20sample.). This work will inform development of future food formulations, particularly [microbiota-directed foods](https://ifst.onlinelibrary.wiley.com/doi/10.1002/fsat.3501_7.x).

**2.3.5. SCIENTIFIC RESILIENCE**

**Optimal use of by-products of berry fruit production**

The [OPTIBERRY](https://projects.au.dk/faccesurplus/research-projects-3rd-call/optiberry/) (FACCE SURPLUS [ERA-NET Cofund]; €0.93M; 2020-2022), involving SEFARI researchers with partners in Belgium and Germany, targets innovative processing and biorefinery/extraction concepts to food prototypes and high value added (non)-food ingredients for sustainable use of available berry biomass, especially non-premium raspberry, strawberry, and blackberry fruit. This valorisation will result in a more resilient berry supply chain, creating a secure and sustainable relationship between the berry grower and potential customers. The project started with a comprehensive overview of the unique functional molecules in these three species of berries and the impact of processing on their content. Next a systematic and detailed high-resolution chemical analysis of these target compounds was performed to assess the content of well-defined functional molecules in the (non-premium) berries. Based on these analyses, the suitability of these non-premium fruit for drink and non-food products, here a lipstick ingredient, was assessed. Both approaches, drinks, and cosmetics, have identified, in a preliminary manner, definite and valid homes for the non-premium fruit.

**Adoption and exploitation of ZIRON beans in rural Africa**:

The [ZIRON Pulse BBSRC GCRF-funded project](https://gtr.ukri.org/projects?ref=BB%2FT008865%2F1) (2020-2023), entitled ‘Upscaling adoption and exploitation of a wide diversity of Iron and Zinc-rich beans by rural populations in Africa’ (£1.0M; Project No. BB/T008865/1) involved SEFARI researchers collaborating with the University of Birmingham, Kenya Agricultural and Livestock Research Organization, University of Nairobi, The Food, Agriculture and Natural Resources Policy Analysis Network. It encompassed a range of activities from identifying the basis of iron and zinc improvement in common bean through to the development of new germplasm and finally community engagement. Grower engagements centred on demonstration plots of the enhanced varieties and guides for growing whilst consumer engagement demonstrated the many ways these common beans (existing and enhanced varieties) can be used to prepare a wide range of dishes. At the scientific level, the project has published numerous referred papers (8) and book chapters (4) encompassing areas such as traditional and new technologies in plant breeding, the impact of abiotic stress on plant development, the mechanisms of iron uptake and the impact of common bean cooking methods on iron and zinc availability.

**Novel nano cellulosic composites as antivirals/antimicrobials for PPE**

Started during the COVID-19 pandemic (2020-21), NanocellPPE (Innovate UK; £462K; Project No. 79541) involved Cellucomp Ltd., Halley Stephensons Ltd., and SEFARI researchers, taking a practical and circular economy route to the development of PPE. The research sought to develop reusable PPE based around natural cellulosic materials and their innate ability to complex with sustainable components with biocidal activities toward bacteria and importantly viruses. The project developed multiuse, washable, environmentally friendly PPE materials which have broad ranging and highly effective anti-viral and bacterial activities. Given the commercial importance of this research a commercialisation rather than publication route is being pursued and protection of the inventions is being explored.

**Funding for Circular Bioeconomy Research and Analysis Service Framework**

A collaboration with Zero Waste Scotland (ZWS) has started through a framework grant 'Circular Bioeconomy Research and Analysis Service' won and led by SEFARI researchers in collaboration with Mabbett, AgriEPI and the University of London (2022-26, £800K). The aim is to provide the technical support required to develop a systems model that delivers evidence-led, actionable, high-impact recommendations to guide policy and contribute to sustainable change and a thriving Scottish bioeconomy. The research stems from work on food waste in the SRP, with many elements being built upon in the ZWS grant such as research focused on a review of the available food system data across three pillars of sustainability (environmental, economic, and social) to identify data gaps in Scottish food systems. Such gaps are in socio-economic flows within the Scottish agrifood sector and environment related, more specifically on food waste in a circular bioeconomy systemic approach.

SRP research has identified gaps in the data required to build evidence of food waste and losses in the Scottish agri-food supply chains. These are being addressed in this new grant, and in work on circular economy in the SRP 2022-27.

**Supporting healthy ageing, with a focus on sustainable protein**

RESAS-funded work on dietary fibre and plant proteins has led directly to several funding awards. Funding from Tate & Lyle Plc to SEFARI researchers (£375K; May 2019 to May 2020) explored mechanisms of fibre action on gut health in human volunteers. Pilot funding was also secured from the TENOVUS charity (£10K), and NHS Endowments grant (£10K) (Apr 2017 to May 2018), in collaboration with clinical colleagues, to support RESAS work on the [food-gut-brain axis in human ageing](https://sefari.scot/blog/2020/06/11/food-for-thought-%E2%80%93-exploring-the-food-gut-brain-axis-in-alzheimers-disease), exploring diet and gut health in the care home environment. This pilot work supported a grant application (£300K) to the Scottish Chief Scientists Office (outcome due in Autumn 2022). An award from Friends of Anchor supported a PhD study to examine the role of dietary fibre to optimise gut health in patients undergoing radiotherapy (£286K, October 2022 for 4 years). Finally, an award from the MRC (MECNUT: grant ref [MR/P023606/1](https://gtr.ukri.org/projects?ref=MR%2FP023606%2F1); ‘Impact of dietary exposure to emulsifiers on the intestinal mucosa - implications for inflammatory bowel disease and metabolic syndrome’) was secured by SEFARI researchers, as co-applicants, in 2017, for three years research to support novel work on processed food on gut health.

**Exploring obesity and body weight**

SEFARI researchers and the University of Surrey were awarded a research grant from the Medical Research Council, 'Chrono-nutrition investigation of timing of eating influence on energy balance’ [MR/P012205/1](https://gtr.ukri.org/projects?ref=MR/P012205/1) for £750k, from November 2017 for three years. The results of this research were recently accepted for publication in a high-impact journal, *Cell Metabolism*. This study challenges the myth that eating at different times of the day leads to differential energy metabolism. This new research reveals that the relative size of breakfast and dinner does not have an impact on metabolism. The team found that energy is similarly utilised, regardless of when the calories are consumed. The findings challenge previous studies which suggested that ‘evening eaters’ have a greater likelihood of gaining weight and are less able to lose it.

Analysis of current eating habits in the UK show that many people consume most of their calories during the evening, although this can vary. It found that when calories are consumed can affect appetite and hunger but does not change energy metabolism in obese and overweight, but otherwise healthy adults. This finding has value for a range of stakeholders and contributes to the understanding of the effects of mealtime and nutrition on health. The research shows that under weight loss conditions there is no optimum time to eat to manage weight, and that change in body weight is determined by energy balance. This is a major finding for the field of meal timing (‘chrono-nutrition’) research. Many aspects of human biology change across the day and we are starting to understand how this interacts with food intake. Our new research shows that, in weight loss conditions, the size of breakfast and dinner regulates our appetite but not the total amount of energy that our bodies use. We plan to build upon this research to improve the health of the general population and specific groups, e.g., shift workers.

**Food inequalities and obesity**

SEFARI researchers have been awarded three years funding (March 2022; £1.6M) from the BBSRC Transforming UK Food Systems, Strategic Priorities Fund ([BB/W018020/1](https://www.ukri.org/news/healthy-food-healthy-people-healthy-planet/)) to lead a new study (FIO FOOD), to investigate the role of food inequalities and obesity, with an emphasis on the retail food environment.  In the UK, more than two thirds of the population are living with obesity or are overweight – conditions which are major contributors to poor health including heart conditions, and Type 2 diabetes. These conditions are more prevalent in areas of deprivation. For this study participants from across the UK who are living with obesity and food insecurity will be recruited. Their food choices will be analysed in a variety of ways including an online survey. The research aims to provide actionable evidence for policy on retail strategies to address dietary inequalities in people living with obesity and food insecurity, and to support sustainable and healthier food choices in the UK food system. The project offers interdisciplinary research focussing on food systems research, using ‘Big Data’ qualitative and quantitative approaches to engaging people with the lived experience. This will inform the development of practical solutions to promote sustainable and healthy food choices for this group of people.

**Placing island issues on the agenda**

Based on work on depopulation in Sparsely Populated Areas (SPAs) (see also Demographic challenges and repopulation potential in sparsely populated areas), a Responsive Opportunities Fund project considered the ‘Islands Revival’. A 2-day workshop was held with delegates representing island issues at a national and international level. Subsequently SEFARI researchers won a bid to conduct the first National Islands Plan Survey and subsequently presented the work to the Rural Affairs, Islands and Natural Environment Committee of the Scottish Parliament in October 2021.

**Collaboration for inclusive growth across the Highlands and Islands**

The project ToWards Inclusive Growth was funded by the SEFARI Gateway Responsive Opportunity Initiative (February 2020, £20K), adding value to research funded in the SRP. This was a collaborative project and funding application developed between social scientists across SEFARI and Highlands and Islands Enterprise. The work was in the context of growing policy interest in inclusive growth, mutual analytical interests, and a desire to develop a more detailed and nuanced understanding of rural diversity to better inform place-based interventions. The project used in-person and online collaboration and communication to co-construct a framework reflecting inclusive growth as applied to the context of the north and west of Scotland. This informed a detailed spatial analysis which identified themes and dimensions reflecting aspects of inclusive growth in the Highlands and Islands. The output was a typology which identified groups of locations with similar ‘inclusive growth performance’. The [report](https://www.hutton.ac.uk/sites/default/files/files/Note_Measuring_inclusive_growth_in_the_Highlands_and_Islands_a_typology.pdf) outlines the typology, its geographical distribution, and trends in demographic change. This work has supported the identification of locations for locally led and developed population pilot areas within the Highlands and Islands.

**Supporting production of neglected and underutilised species in Low- and Middle-Income Countries (LMIC)**

SEFARI research and KE on underutilised species supports wider global initiatives to maintain crop diversity, particularly regarding those consumed as part of a traditional diet in Low- and Middle-Income Countries (LMIC). Additional funding was leveraged through a Global Challenges Research Foundation (GCRF) grant (UKRI; £473K) where the potential of underutilised species to contribute to Malawi’s scaled up nutrition programs was demonstrated, and a patented food formulation developed, which had now been licensed and launched. Further funding (£20K) to host a workshop in Zimbabwe led to a policy report, which has influenced the Zimbabwean Government small grain strategy and the work widely disseminated on prime-time TV News and the Zimbabwean National Press. [The Crop Technology Development Organisation said *‘*the SEFARI scientists made an invaluable contribution, analysis and input to the joint workshop which set the tone and action for the country to develop the positive policy frameworks. It is with this kind of support, in-depth analytical analysis capabilities and clear linkages with climate change, ecological agriculture, and the scope for providing consumers affordable and nutritious food that is critical’.] Though a British Council Newton Fund award (£97K), the potential of the mezquite tree is being explored as a sustainable food source in Mexico, and Wellcome Trust funding (£50K) has supported a pilot project exploring fermented ****small grains. This work was recognised by the Scottish Funding Council in their [Scotland’s Research Contribution to National and International Challenges report.](https://www.sfc.ac.uk/nmsruntime/saveasdialog.aspx?lID=23176&sID=14362)

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