Institution: University of Stirling		
Unit of Assessment: 11. Computer Science and Informatics		
Title of case study: Driving rural economic and environmental sustainability through data driven, computational models		
Period when the underpinning research was undertaken: 2000-2019		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Rachel Norman	Chair of Food Security and Sustainability	9/1996 - Present
David Cairns	Lecturer	11/2001 - Present
Period when the claimed impact occurred: 2014 - Dec 2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact

The rural economy in Scotland contributes 27% of Scotland's overall economy and is dependent on its unique ecosystem. University of Stirling research has resulted in changes to Scottish Government policy, business practices, and land-owner behaviour that all drive environmental and economic sustainability in Scotland. Specifically:

Impact 1. Hare management practices have changed on grouse moors due to the Scottish Government providing more protection for Mountain Hares.

Impact 2. Changes to a business model have allowed increased sustainability and economic success of a seafood delivery SME.

Impact 3. Scottish Government policy on the prevention of commercial trapping of the invasive Signal Crayfish has been influenced, preventing the uncontrollable spread of this species and consequent environmental damage.

These three impacts all promote environmental sustainability, with direct and indirect economic benefits in Scotland.

2. Underpinning research

This case study utilises our body of research applying data science and mathematical modelling to a range of practical applications, which all have the underlying purpose of driving rural economic and environmental sustainability. For Impacts 1 and 3 the underpinning computational model was a compartmental model (where, for example grouse are classified as either susceptible or infected) consisting of coupled non-linear differential equations that describe the change in the population density in each compartment over time. These models were analysed using a combination of algebraic analysis and numerical simulations. In Impacts 1 and 3, where data is limited, parameter space was explored to determine the optimal values to solve the problem being addressed. Impact 2 was more data driven and involved the development of a bespoke algorithm which, given several different inputs, determined a solution that satisfied a range of complex criteria.

Impact 1 is dependent on our research (**P1** & **P2**) on Louping Ill virus, which manifests as a disease that primarily affects sheep and grouse in Scotland. Both of these species are economically important. The ticks which transmit the pathogen feed on a wide range of hosts and their population is maintained by deer, mountain hares and sheep. However, they will also feed on grouse. We formulated a contextually unique series of models which determined the relative importance of the roles that these different hosts play in disease transmission. This theoretical work was then verified using data from a large-scale experiment (**P1**). This showed that on some sites, if you remove Mountain Hares, the pathogen is reduced in ticks, and the grouse population recovers. However, in (**P2)** we demonstrated that this only applies to sites without the presence of deer. When deer are present, hare culling is no longer effective as a control method.

Impact 2 involved our development of a bespoke algorithm that used similar parameter search techniques to the work in impacts 1 and 3. This work enabled a subscription-based seafood home

delivery company to meet the orders of its expanding customer base while minimising food waste, and ensuring the contents are responsibly and sustainably sourced. Effectively a 'bin packing' and parameter search problem (**P3**), the company relied on human decisions to fill the boxes of its customers with over 80 different products, with the added difficulty of 3 levels of preference, 3 sizes of box, varied number and portion sizes, and a highly variable supply based on the freshly landed catch at port. We developed a multi criteria, stochastically seeded, algorithm that created an automated shopping list, which satisfied customer preferences with the available produce and enabled orders to be filled more quickly. This was work delivered through funding from Interface.

Using the same modelling, analysis and simulation techniques as were used in Impact 1 (**P2**), our research that underpinned Impact 3 used a different and novel model to describe the population dynamics of a non-native invasive species, the Signal Crayfish. The Signal Crayfish was introduced to England for commercial purposes in the 1970s and has since decimated native crayfish species, causing considerable damage to sites of natural heritage and in excess of GBP2,600,000 per annum in damage to local economies. The model was used to determine the impact of different control strategies in a report for DEFRA (**P4**), highlighting the potential risks of allowing commercial trapping.

3. References to the research (Stirling authors in **bold** text)

P1. Laurenson MK, **Norman R**., Gilbert L, Reid H and Hudson PJ, Identifying disease reservoirs in complex systems; Mountain hares as reservoirs of ticks and louping ill virus; pathogens of red grouse. Journal of Animal Ecology, 72(1) 177-185 2003 DOI: 10.1046/j.1365-2656.2003.00688.x

P2. Gilbert L, **Norman R**, Laurenson KM, Reid HW, Hudson PJ, Disease persistence and apparent competition in a three-host community: an empirical and analytical study of large-scale, wild populations Journal of Animal Ecology 70 (6): 1053-1061 2001 DOI: 10.1046/j.0021-8790.2001.00558.x

P3. Brownlee A, Wu Y, McCall J, Godley PM, **Cairns D** and Cowie J (2008), Optimisation and Fitness Modelling of Bio-control in Mushroom Farming Using a Markov Network EDA In: Keijzer M (ed.) Proceedings of the 10th annual conference on Genetic and evolutionary computation, (GECCO-2008). Genetic and Evolutionary Computation Conference, GECCO-2008, New York, 12.07.2008-16.07.2008. New York: Association for Computing Machinery (ACM), pp. 465-466. DOI: 10.1145/1389095.1389180

P4. Stebbing PD, Longshaw M, Taylor N, **Norman R,** Lintott R, Pearce F, Scott A, Review of Methods for the Control of Invasive Crayfish in Great Britain; 2012; pp.105 Defra report C5471. http://randd.defra.gov.uk/Document.aspx?Document=10172_CrayfishFinalReport.pdf

The research at Stirling was supported by:

Impact 1: grant from SOAEFD (Scottish Office, Agriculture, Environment and Fisheries Department) 1997-2000.

Impact 2: "Fishbox supply chain algorithm" funded by an Interface Innovation voucher and then a Scottish Funding Council Follow On Voucher total value GBP45,000. The two projects ran from Aug 2015-Dec 2015 and Feb 2016-Apr 2018 respectively. PI: Norman

Impact 3: Subcontract from Department for Environment, Food, and Rural Affairs, via the Centre for Environment, Fisheries and Aquaculture Science for modelling 2012. GBP12,000.PI: Norman

4. Details of the impact

The impacts in this case study exemplify our commitment to research that promotes rural sustainability, both economic and environmental.

Impact 1. Protecting the Mountain Hare and Improving Grouse Moor Management

Mountain Hares are native to, and found widely across, upland Scotland, particularly on grouse moors, and are listed on the Scottish Biodiversity List. In 2019 the UK Joint Nature Conservation Committee found UK Mountain Hares to be of "unfavourable-inadequate" conservation status (**S1**, p.7).

Our models have **impacted the joint official positions** of The Game & Wildlife Conservation Trust (GWCT), Scottish National Heritage (SNH), and Scottish Land and Estates (SLE), representing both sides of the highly charged grouse moor management debate, in 2014. All these organisations now recommend **against hare culling** for disease control (**S2**), in accordance with our research.

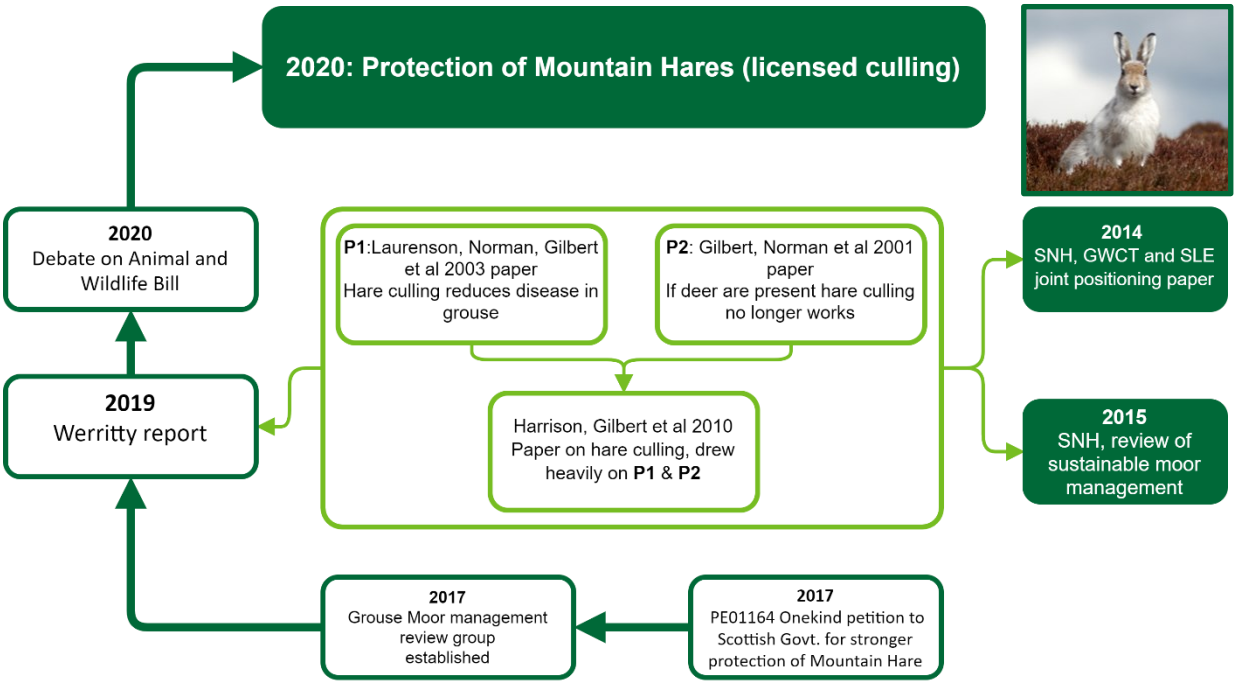

Figure 1. Mountain Hare protection process

A petition was put to the Scottish Government in June 2017 by Onekind for greater protection of mountain hares (**S3**). This resulted in the creation of the Grouse Moor Review Group who produced the 'Werritty report'. The findings of our research **underpinned key points on Mountain Hare management made in this official Scottish Government report** by Professor Werritty (**S1**, published Dec 2019) (see Figure 1 for process). In his letter of support Professor Werritty says our research "*was a key contribution underpinning the Group's recommendation that "the shooting of Mountain Hares should be subject to increased legal regulation"*" (**S4**).

On 17th June 2020, in the debate on the Animals & Wildlife Bill, the Scottish Parliament cited the Werritty report as part of the evidence and voted to **move Mountain Hares onto the protected species list**, which represents an official commitment to the licensing of all Mountain Hare killing (link to legislation: stir.ac.uk/47r). As Prof. Werritty confirms, Stirling research "*played a significant part in the recommendations made by the Scottish Government's Grouse Moor Management Group and subsequent new legislation passed by the Scottish Parliament*" (**S4**).

Our impact on Mountain Hare protection is **supporting the development of a healthy Mountain Hare population**. This directly contributes to **environmental protection and sustainability in Scotland** as the Mountain Hare is an indigenous Highland species and is a key prey species for foxes, stoats, the endangered Scottish Wildcat, buzzards, and eagles.

The conservation of Scotland's mountain hare is widely recognised as a priority (**S3**). They are:

1. Listed on Annex V of the EU Habitats Directive (1992) requiring EU member states to maintain them in favourable conservation status.
2. A priority species for conservation action under the UK Biodiversity Action Plan.
3. On the Scottish Biodiversity List, which means that they are considered by Scottish Ministers to be of principal importance for biodiversity conservation.

4. Protected by a closed season under the Wildlife and Natural Environment (Scotland) Act 2011, which makes it an offence to kill a Mountain Hare in the closed season (1 March to 31 July).

Impact 2. Benefitting the environmental and economic sustainability of a Scottish SME

The Stirling-developed algorithm was intended to reduce waste and improve sustainability through the optimal use of landed catch, and to allow the company to scale up its operations to accommodate its expanding customer base. Our modelling convinced the company that "*our current model was too complex to scale up according to our ambitions and, as a consequence, prompted us to design and implement a different business model for Fishbox*". This resulted in a **streamlining of the business processes in order to achieve greater efficiency whilst continuing to uphold their commitment to responsible sourcing**. The company state that "*the work that we did with the University of Stirling helped us gain recognition as a nationally renowned and award-winning company, dedicated to high quality, zero-waste, sustainable food production*" (**S5**).

Measure of impact: Customer numbers grew from 500 prior in the beginning of the project in 2014, to 1800 in 2018, which could not have occurred without significant change to the business model based on our research (**S5**). The impact of Stirling work with Fishbox was also recognised as part of the Queen's Anniversary prize awarded to the University of Stirling in 2020 (**S6c**).

Pathway to impact: The algorithm was based on a body of work from the department (e.g. **P3**) but was commercially sensitive and written specifically for this project and hence the link from the research to the impact is direct. An added value of this project is the consequent increased profile of the company. **Fishbox has used the algorithm to generate significant publicity "***While we were collaborating on the project we won a number of awards and received considerable media coverage; some of which was because of the novelty of the algorithm".* This occurred through social media and through a workshop held by Scottish Funding Council-backed Interface in 2016. Following this, in 2016 they entered and won both the Guardian's "Start Up of the Year" and "Digital Innovation Challenge" (S6) referencing our algorithm in their applications. They have also featured in a blog from Interface, along with articles in the Business Quarter magazine and the Guardian. All of these articles explicitly discuss the collaboration with Stirling (**S6a** & **S6b**).

Impact 3. Protecting Scottish rivers from non-native Crayfish

Native to North America, the invasive Signal Crayfish (*Pacifastacus leniusculus*) (Figure 2) was brought to the UK in the 1970s for farming; its spread to rivers (in England and Wales, and after 1995 in Scotland) has caused the widespread elimination of whole populations of the native White-clawed Crayfish (*Austropotamobius pallipes*) (which is listed on Annex II of the Habitats Directive) through predation, competition and transmission of crayfish plague. In running water, extensive burrowing by Signal Crayfish destabilises banks, causing erosion, and bank collapse. Signal Crayfish further predate juvenile fish, reducing native salmon and trout populations. In 2015 Signal Crayfish occupied approximately 87 km^2 of freshwater in Scotland, with an annual cost to the Scottish angling industry of GBP325,000 (**S7**).

Figure 2. The Signal Crayfish

In 2016 the Scottish Government responded to a petition (**S8**) calling on parliament to amend the existing licensing regime to allow for the commercial trapping of American Signal Crayfish in Scotland (it is commercially trapped in England). The Government used our modelling (**P4**) to underpin its conclusion "that allowing the commercial trapping of these American signal crayfish, even as a control measure, would lead to expansion of its range". Therefore, the petition was rejected and commercial trapping of Signal Crayfish remains banned in Scotland.

Timeline and contribution of Stirling research	
1970s	Signal Crayfish brought to UK for farming; subsequent spread in rivers
1981	UK Wildlife and Countryside Act makes it an offense to release or allow Signal Crayfish to escape
1992	It is an offence to sell signal crayfish without a license in England
1995	Signal Crayfish first recorded in Scotland
2007	Scottish Govt. list Signal Crayfish under Species Action Framework
2009	Signal Crayfish recorded as occupying 58km of Scottish rivers but 80% of rivers in England and Wales
2012	CEFAS report (**P4**) on signal crayfish published: Norman led modelling aspect
2015 Feb	Petition PE1558 is lodged with Scottish Parliament seeking legalisation of commercial trapping of Signal Crayfish
2015 July	SNH and SEPA responses to petition referenced CEFAS report (**P4**)
2016 Feb	SPICe '*Review of Literature cited in the Petition and Submissions*' published: referenced CEFAS report Petition rejected: Scottish Parliament concluded that allowing the commercial trapping of American Signal Crayfish, even as a control measure, is likely to lead to expansion of its range.

Measure of impact: Our work has led to the prevention of further spread of the invasive crayfish, preserved native species, and prevented environmental damage. It has thus played a role in protecting the GBP126,000,000 angling industry in Scotland. The estimated cost of the invasive crayfish to the British economy is approximately GBP2,700,000 million per year (source: http://stir.ac.uk/4s0), thus indicating the likely savings that have been made in Scotland.

Pathway to impact: DEFRA commissioned a report on Invasive Crayfish in Great Britain (**P4**) which was published in 2012, it contained our mathematical model which explored a range of different control methods including trapping. In February 2015, the petition described above (PE1558 I) was lodged (**S8**). The Public Petitions Committee called for a briefing from SNH and the Scottish Environment Protection Agency (SEPA), as well as an evidence review by SPICe (Scottish Parliament Information Centre) to inform its decision. The SNH/SEPA statement does not directly cite its evidence, however it makes clear reference to our DEFRA report (P4) by saying: "A recent review of signal crayfish invasions in the UK concluded that although trapping can reduce the abundance of trappable animals, it does not necessarily reduce their total number or the biomass" (**S7**, p.2, para.10); **P4** was the only recent UK review, meaning this can only refer to our research. The SPICe review (**S9**) identifies only seven pieces of research of relevance (none of which supported the petition), of which our DEFRA report (**P4**) is one. The Public Petitions Committee particularly cited the SPICe review as influential in swaying its opinion to reject the petition (**S10**).

5. Sources to corroborate the impact

S1. Grouse Moor Management Review Group Report to the Scottish Government (Nov 2019), otherwise known in the media as the "Werritty Report". http://stir.ac.uk/56i
S2. Scottish National Heritage (SNH), Game and Wildlife Conservation Trust (GWCT), and Scottish Land and Estates (SL&E) Joint Position.
S3. Petition PE01664: Greater protection for mountain hares. http://stir.ac.uk/56o
S4. Testimonial from Prof. Alan Werritty, Chair of Grouse Moor Management Group.
S5. Testimonial from Fishbox.
S6. a. Awards won by Fishbox (Start Up of the Year, and Digital Innovation Challenge).
b. Media articles featuring Fishbox at the University of Stirling (Guardian and Business Quarter Magazine).
c. Queens Anniversary Award, featuring Fishbox impact.
S7. SEPA and SNH joint response to Crayfish Petition.
S8. Petition PE01558: American Signal crayfish. http://stir.ac.uk/4rx
S9. Governmental response to petition with key evidence (SPICe Review). http://stir.ac.uk/56r
S10. Scottish Parliament Public Petitions Committee (9 Feb 2016). Minutes: http://stir.ac.uk/56l