Institution: University of Exeter

Unit of Assessment: UoA 5 Biological Sciences

Title of case study: Enabling bovine tuberculosis control in wildlife

Period when the underpinning research was undertaken: 2010-present

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:
Professor Robbie McDonald	Chair in Natural Environment	2011-present
Dr Andrew Robertson	NERC Knowledge Exchange Fellow	2013-present
Professor David Hodgson	Chair in Ecology	2002-present
Professor Darren Croft	Chair in Animal Behaviour	2008-present
Professor Stuart Bearhop	Chair in Animal Ecology	2007-present

Period when the claimed impact occurred: 2013-present

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

Controlling bovine tuberculosis (bTB) in the UK costs an estimated £100 million per annum. In the deeply contentious area of bovine tuberculosis (bTB) control, University of Exeter ecological and epidemiological research, undertaken in partnership with Defra's National Wildlife Management Centre, has generated tools, services and evidence that underpin the design of environmental policy, statutory guidance and practical means for managing bTB risk across the UK. In particular, our work includes evaluation of BadgerBCG vaccine efficacy.

This research contributed directly to the change in Government policy in England, Wales and Northern Ireland to adopt badger vaccination rather than culling, thereby improving animal welfare. Our bTB biosecurity advice and assessment tools have been adopted as statutory guidance, by National Governments and farmers' organisations which has changed the practice of the national TB Advisory Service delivered to > 1,600 farmers across England.

2. Underpinning research

European badgers are a reservoir for bTB and are implicated in transmission to cattle. A better understanding of relationships between badger ecology and bTB epidemiology is crucial for tackling the disease effectively. For the last 10 years, University of Exeter research has played a significant role in achieving this.

The UoE partnership with the National Wildlife Management Centre (NWMC), now part of Defra's Animal and Plant Health Agency (APHA), was formally established in 2010. We have since undertaken a sustained joint programme of applied research, supported by Defra and UKRI grants and CASE studentships, enabling research training of APHA staff (1 PhD, 4 MbyRes) and Early Career Researchers (13 PhDs, 9 MbyRes) and two joint academic appointments (Honorary Professor Richard Delahay and NERC Knowledge Exchange Fellow Dr Andy Robertson). Our collaborative research has focused on developing management interventions, including badger vaccination and biosecurity, to reduce bTB transmission. Our findings inform and underpin policy, and support stakeholders in managing disease risks.

Badger vaccination

The outcomes of a clinical field trial of the safety of BCG vaccination in wild badgers were analysed to reveal the significant protective effects of vaccination on wild vaccinated and unvaccinated badgers **[3.1]**. Using models to evaluate bTB control strategies, we compared badger vaccination and culling and highlighted the greater efficacy, but also the greater associated risks of adverse outcomes of culling, relative to vaccination **[3.2]**. We have engaged in collaborative research towards an orally-administered vaccine, focusing on bait formulation and deployment.

Farm biosecurity

Our research underpins the use of biosecurity measures to reduce potentially infectious contact between badgers and cattle. Initial experimental work using trail cameras demonstrated that badgers frequently enter farmyards, but that this activity can be reduced significantly with practical measures, such as gate and fence installation **[3.3]**. Simultaneous collaring of badgers and cattle with proximity-sensors demonstrated that badgers and cattle rarely come into contact at pasture **[3.4]**. It follows that control measures should be focused on limiting transmission risk at cattle feeding areas, badger latrines and setts. Research into farmers' understandings of wildlife on farms led to our creation of a Farm Assessment Tool for evaluating and communicating biosecurity risks **[3.5]**.

Ecology and epidemiology of bTB

A 2011-13 survey determined badger distribution and population size in England and Wales **[3.6]** and comparative analyses with 1980s surveys demonstrated population increases, with consequences for disease control policy. These data have since been used by UoE researchers to estimate local population sizes, to inform badger management. UoE researchers have contributed to reviews of the scientific evidence base for bTB control (e.g. Godfray et al 2013). By enhancing analysis of the long term Woodchester Park study of badger populations, UoE researchers have discerned and quantified the roles of age, sex, sociality and behaviour in bTB infection dynamics. We have demonstrated the complexities of positive and negative effects of badger culling on cattle disease, and demonstrated wider ecological impacts on other wildlife, including positive effects for hedgehogs and foxes.

3. References to the research

From 2010 to 2020, we published >50 papers on the subject of bovine tuberculosis ecology and epidemiology in international peer-reviewed journals. The following references are particularly relevant to this impact (University of Exeter contributors in **bold)**.

3.1. Carter SP, Chambers MA, Rushton SP, Shirley MD, Schuchert P, Pietravalle S, Murray A, Rogers F, Gettinby G, Smith GC, **Delahay RJ**, Hewinson RG, **McDonald RA**. 2012. BCG vaccination reduces risk of tuberculosis infection in vaccinated badgers and unvaccinated badger cubs. PloS One 7, e49833. https://doi.org/10.1371/journal.pone.0049833

3.2. Smith GC, **McDonald RA**, Wilkinson D. 2012. Comparing badger (*Meles meles*) management strategies for reducing tuberculosis incidence in cattle. PloS One 7, e39250. https://doi.org/10.1371/journal.pone.0039250

3.3. Judge J, **McDonald RA**, Walker N, **Delahay RJ**. 2011. Effectiveness of biosecurity measures in preventing badger visits to farm buildings. PLoS One 6, e28941. https://doi.org/10.1371/journal.pone.0028941

3.4. **Silk MJ**, Drewe JA, **Delahay RJ**, **Weber N**, **Steward LC**, **Wilson-Aggarwal J**, **Boots M**, **Hodgson DJ**, **Croft DP**, **McDonald RA**. 2018. Quantifying direct and indirect contacts for the potential transmission of infection between species using a multilayer contact network. Behaviour 155, 731-757. https://doi.org/10.1163/1568539X-00003493

3.5. **Robertson A**, Judge J, Wilson GJ, Vernon IJ, **Delahay RJ**, **McDonald RA**. 2019. Predicting badger visits to farmyards and making predictions available to farmers. PloS One 14, e0216953. https://doi.org/10.1371/journal.pone.0216953

3.6. Judge J, Wilson GJ, Macarthur R, **McDonald RA**, **Delahay RJ**. 2017. Abundance of badgers (*Meles meles*) in England and Wales. Scientific Reports 7, 276. https://doi.org/10.1038/s41598-017-00378-3

4. Details of the impact

Our research in the field of bovine tuberculosis has been highly impactful, in terms of shaping the policies of UK governments, in parliamentary and public debates, and underpinning and rolling out practices aimed at preventing disease spread. Defra's TB Programme confirm that our work **[3.1, 3.3]** "*has made pivotal contributions to the evidence base we have used, and continue to use, in striving to eradicate bTB from England*" **[5.1]**. Examples include:

Contributing to Government Policy for bTB control

Our collaborative research with the National Wildlife Management Centre (NWMC) is a primary source for evaluating the field performance and deployment of badger vaccination, including our critical demonstration in **[3.1]** of direct and indirect benefits to vaccinated and unvaccinated badgers. Our research was a principal source underpinning the Environment, Food and Rural Affairs Select Committee's recommendation that Government develop a strategy for using vaccination for bTB control **[5.2]**, reiterated in the Government's 2018 Godfray review of bTB strategy **[5.3]**. These led to the emergence of badger vaccination as the key policy innovation in Defra's 2020 bTB control strategy for England **[5.4]**.

Following our findings, badger vaccination has been used for several years. Since 2013: 361 lay vaccinators have been trained, and have administered 6,848 doses in 29 counties in England **[5.5a]**. Badger vaccination has been rolled out as part of high profile, large-scale and long-term government demonstration projects, including: (i) the Badger Vaccine Deployment Project (2010-15) **[5.5b]**, led by our partners at NWMC, and involving treatment of badgers over 100 km^2 with >3,800 doses (~450 annually), (ii) the Intensive Action Area on 288 km^2 of farmland in Wales (2010-present), involving the delivery of 3,786 vaccine doses since 2013 **[5.5c]**, (iii) the Test-Vaccinate-Remove wildlife intervention (2014-18) on 200 km^2 in Northern Ireland **[5.5d]**, and (iv) Defra's Badger Edge Vaccination Schemes 1 (2014-18) and 2 (2018-present) citing **[3.1]** as underpinning evidence for vaccination **[5.5e]**, as well as multiple projects carried out by NGOs.

Work by UoE researchers has contributed vital parts of the evidence base needed to control bTB transmission by managing badgers. Our work established accurate estimates of the distribution and populations of badgers at a landscape scale across the UK **[3.6].** This work has been used to quantify variation in bTB risk from wildlife and, separately, forms the basis for specifying targets in culling licensed by Natural England, and has been used by Defra **[5.6a]** citing **[3.6]** to determine the number of badgers to be culled in 21 badger cull areas, covering >8,000 km^2, 2017 **[5.6a, 5.6b]**.

Supporting and disseminating bTB control measures in the farming sector: farm biosecurity and badger ecology

UoE collaborative research on badger behaviour and its management in buildings and on farmland forms the mainstay of evidence used by governments and the TB Advisory Service to advise farmers how to assess and reduce disease risks from wildlife. Our research **[3.3]** has demonstrated how simple, practical measures (sheet gate and fencing installation etc.) for excluding badgers from farmyards and buildings lead to reductions in opportunities for infectious contact with cattle. This work led to the development and advocacy of advice, in conjunction with Defra and the Welsh Government, including a DVD delivered to farmers and a 2011 video series on YouTube (video 1: >6,000 views, 2014-2020) **[5.7]** and UoE contributions to a joint Defra/industry action plan for farm biosecurity in 2014 **[5.8]**. The use of these biosecurity measures is contained in official advice to farmers as part of Defra's Five Point Plan for Biosecurity **[5.9]**, Point 1 of which is "Restrict contact between badgers and cattle" and draws heavily on **[3.3]**. The Plan is delivered via the joint government-industry TB Hub information site and the associated Land Based Learning online training **[5.10]**. The Five Point Plan and biosecurity measures to limit contact between badgers and cattle form part of Defra's 25 year TB control strategy **[5.4]**.

Changed practice in the National TB Advisory Service

Since October 2017, biosecurity advice based on our research and recommendations, has been delivered to farmers in England as part of the TB Advisory Service, which by September 2020, had delivered >1,700 farm advisory visits to >1,600 farms across England **[5.11]**. UoE are part of the Technical Board for the TB Advisory Service and have helped to shape this project since its outset, with UoE Knowledge Exchange Fellow (Robertson) delivering training to >150 farm advisors responsible for carrying out farm visits across England as part of the service **[5.11]**. This training material covers badger ecology, epidemiology, badger activity in farm environments (and how to assess and reduce this **[3.5]**), much of which is underpinned by our research.

UoE researchers form part of bTB eradication groups, at county and national levels. As part of our NERC-funded Knowledge Exchange programme, we produced a broad-ranging series of factsheets, summarising the scientific evidence base for the epidemiology and control of bTB, not just in wildlife but also in cattle **[5.12]**. These were produced in association with industry advisors and are hosted on the TB Hub, which is a joint industry and government initiative and is "*the go-to place for British beef and dairy farmers to find practical advice on dealing with bovine TB on their farm*" **[5.12]**.

5. Sources to corroborate the impact

5.1. Letter of testimony from Defra TB Programme.

5.2. House of Commons Environment, Food and Rural Affairs Committee. Vaccination against bovine TB. Second Report of Session 2013-14. https://publications.parliament.uk/pa/cm201314/cmselect/cmenvfru/258/258.pdf frequently draws on **[3.1]** study of direct and indirect effects of badger vaccination and consequential herd immunity effect among unvaccinated cubs.

5.3. Godfray, C., Donnelly, C., Hewinson, G., Winter, M., Wood, J. (2018) Bovine TB Strategy Review. Report to Rt Hon Michael Gove MP, Secretary of State, Defra. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/756942/tb-review-final-report-corrected.pdf draws on several of our studies of badger vaccination, biosecurity, badger populations, ecology and impacts of culling, to support overall conclusions of the future importance of vaccination and biosecurity to bTB control.

5.4. Defra (2020). Next steps for the strategy for achieving bovine tuberculosis free status for England.https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/870414/bovine-tb-strategy-review-government-response.pdf This is the government's response to the Godfray review **[5.3]**. Establishes badger vaccination as a central pillar of policy for exiting a badger cull. Cites **[3.1]** as evidence of the efficacy of badger vaccination (p30 para 68). Refers to our work on the evaluation of licensed badger culls (p7, 9, 35). Biosecurity is a key area of activity specified in the joint Five Point Plan, which builds in large part on **[3.3]**.

5.5. Reach of Government-led badger vaccination projects, schemes and trials in the three administrations affected by bTB: 5.5a. Letter from Research Scientist and Project Manager, Animal and Plant Health Agency, reporting 6,848 vaccinations across 29 counties in England, 2013-2020; 5.5b. Badger Vaccine Deployment Project (BVDP) in England, 2015: >3,800 doses over 100 km^2 2010-2014 (~450 doses annually) https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/486330/bvdp-lessons-learned-report.pdf; 5.5c. Intensive Action Area (IAA) in Wales: 5,210 vaccinations across ~288 km^2 , 2012-2015 (2014: 1,316 doses, 2015: 1,118 doses) https://gov.wales/intensive-action-area-iaa; https://gov.wales/sites/default/files/publications/2020-09/intensive-action-area-future-policies.pdf outlines the approach of government-led bTB controls in Wales. The future policies document highlights the specific numbers of doses administered in each project year. 5.5d. Test-Vaccinate-Remove (TVR) in Northern Ireland https://www.daera-ni.gov.uk/articles/test-and-vaccinate-or-remove-tvr-wildlife-intervention-research outlines a state-led project for testing of badgers and selective removal of test-positive individuals and vaccination of the remaining, test-negative individuals across 200 km^2, 2014-2018. 5.5e. Badger Edge Vaccination Scheme (BEVS) in England https://www.gov.uk/government/publications/badger-edge-vaccination-scheme-2-bevs-2/scheme-outline this scheme outline from Defra for the second phase (BEVS2) of vaccination in the 'Edge' area between High and Low Risk bTB areas of England, specifically cites **[3.1]** as part of the evidence for vaccination underpinning the scheme (Section 8).

5.6. Badger culling in England, 2017: 5.6a. Defra (2017). Setting the minimum and maximum numbers in badger cull areas in 2017. Advice to Natural England. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/643608/bovine-tb-2017-badger-control-minmax.pdf exemplar annual report from 2017, detailing the Defra process of setting the minimum and maximum numbers in licensed badger control areas, referencing the use of national badger survey data and approaches **[3.6]**; 5.6b. https://commonslibrary.parliament.uk/research-briefings/sn06837/#:~:text=In%20September%202017%2C%20the%20Government,2017%20was%208%2C560km2

5.7. In addition to the DVD distributed to farmers, six videos posted by Defra and Welsh Government, convey the practical findings of **[3.3]** and are available via YouTube. Video 1 alone had ~6,000 views in the period between 2014 and 2020.

(i) https://www.youtube.com/playlist?list=PLpKYVeQfs6XW2y8j7m0E6gDdRSp785BPo; (

(ii) https://www.youtube.com/watch?v=iKDmCdrU-HM;

(iii) https://www.youtube.com/watch?v=tyt-pTAgBG8&t=1s;

(iv) https://www.youtube.com/watch?v=_IhyJS41F6A&t=1s;

(v) https://www.youtube.com/watch?v=sQruxKTIG0Q&t=1s;

(vi) https://www.youtube.com/watch?v=n2W9CgAo-oM&t=2s;

(vii) https://www.youtube.com/watch?v=c7ErRqeCCIA&t=2s.

5.8. Defra (2014). Cattle biosecurity: a joint Defra/industry action plan for improving herd resilience to bovine TB. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/388100/cattle-biosecurity-action-plan.pdf UoE (acknowledged on page 4) contributed to this action plan, building on our biosecurity research.

5.9. Protect your herd from TB: a review of the science. https://tbhub.co.uk/preventing-tb-breakdowns/protect-your-herd-from-bovine-tb/ ;http://www.tbhub.co.uk/biosecurity/protect-your-herd-from-tb/; Knowledge transfer information site for Defra's Five Point Plan for cattle biosecurity, as delivered by the joint government-industry TBhub. Cites [3.3].

5.10. Bovine TB biosecurity training materials. https://tbhub.co.uk/resources/bovine-tb-biosecurity-training-materials/ Defra and Land Based Learning online training materials, to support implementation of the joint industry-government Five Point Plan. The materials draw heavily on **[3.3]** and UoE advice via our Knowledge Exchange programme. The associated training materials are available at https://landbasedlearningltd.com/course/view.php?id=183

5.11. Letter of testimony from Project Manager, TB Advisory Service; https://www.tbas.org.uk/ Testimony references output 3.3. specifically "This study was critical in demonstrating how frequent badger visits to farm buildings can be, and how best to reduce these with simple measures that are available to all farmers. This work forms the basis of bTB biosecurity advice and assessment tools, that have been adopted as statutory guidance by governments and by the industry, and are delivered to farmers by us."

5.12. TBhub. Factsheets. https://tbhub.co.uk/resources/downloads/ A joint industry-government information hub directly providing UoE Knowledge Exchange factsheets on all subjects from TB testing to infection risks from slurry. The overall site summary, factsheet index and four exemplars are provided. All information sources can also be accessed via the UoE www.tbknowledgeexchange.co.uk