Institution: University of Warwick

Unit of Assessment: UOA5 - Biological Sciences

Title of case study: Transforming the detection of bat species in ecological surveys through DNA analysis: impacts on commerce and conservation

Period when the underpinning research was undertaken: 2007-2020

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 Robin Allaby	Professor	01/07/2006- present

Period when the claimed impact occurred: 2014-2020

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

1. Summary of the impact (indicative maximum 100 words)

Professor Robin Allaby's research into ancient DNA and its applicability to bat genotyping led to the establishment in 2009 of the Warwick-based Ecological Forensics Service, which created a paradigm shift in the market by providing accurate bat identification to professional ecological surveyors. The service has set the standard for bat identification in the UK and as of December 2020 serves 63% - more than 600 companies - of the ecology consultancy sector. The Bat Conservation Trust's best practice guidelines, 'Bat Surveys for Professional Ecologists' (2016) recommend the use of DNA analysis of bat guano for species identification. In 2011 Allaby's Ecological Forensics Service expanded to include other mammals and in 2015 competitors started offering similar DNA-based services. Moreover, the revelation of bat species movements in response to climate change, the discovery of rare bat species and new ecological niches have led to improved bat conservation practices.

2. Underpinning research (indicative maximum 500 words)

In the UK, bats play a vital role in controlling insect populations and are important indicators of biodiversity and ecosystem health. Yet despite being protected by national and international legislation, the 17 bat species in the UK have been declining at a phenomenal rate over the last 50 years due to loss of habitat. The Wildfowl and Wetlands Trust estimates that the pipistrelle, the UK's commonest bat, declined by 70% between 1978 and 1993. However, in recent years populations have shown signs of recovery due to protection and the implementation of conservation practices. Preserving bat roost habitats requires species identification, but, given that bats are largely nocturnal, this is not always possible even in the advent of actual bat sightings. Bat genotyping provides valuable information on genetic diversity within different bat species across the UK, and will help drive future conservation research. This has been made possible through the cumulative research of Professor Robin Allaby, an expert in ancient DNA.

In 2006 Allaby began a programme of UKRI-funded research exploiting Next Generation Sequencing (NGS) technologies to understand and utilise ancient DNA, examining the archaeogenomics of ancient Egyptian cotton, barley and sorghum [G1-4] and the survival of ancient environmental DNA [3.1, 3.2, 3.4]. This work ultimately led to a new model for understanding DNA decay in terms of the timing and extent of DNA fragmentation [3.3]. Because the majority of DNA fragmentation happens shortly after deposition, age is largely irrelevant. This meant that although the primary purpose of the research had been to inform studies on archaeological ancient DNA, this technology could also be used to extract and analyse DNA from extant environmental samples with unprecedented accuracy, and could therefore be

applied to ecological forensics to identify species of bat, mustelid, rodent, canid and felid from evidence such as guano, scat or fur found in the field.

In 2009 Allaby and his team began exploring DNA retrieval from environmental samples of bat guano, in collaboration with a local ecological consultancy, Ecolocation, drawing upon the research group's ancient DNA expertise to infer information about bat ecology. This research was later developed into a UKRI-funded PhD studentship (2012-2015) [G5]. Morphological information, or morphometrics (shape, texture and colour), has often been used to identify bat species. PhD student Roselyn Ware discovered that many areas of the morphometric space were occupied by numerous bat species, so the assignation of species based on morphometric data was little better than random [3.5]. However, the morphometrics were found to be useful for identifying the species that had been consumed by the bats: guano morphologies are distinct based in part on whether they are largely made up of lepidopteran (butterflies or moths), coleopteran (beetles) or dipteran (flies) remains. This offered a new field-craft technique for ecologists to rapidly assess information about the ecology of an area. As well as establishing an alternative value for the morphometrics, the studentship laid the foundations for a new generation of ecological forensics services in supplying scientific interpretation back to the user community, building on Allaby's Ecological Forensics Service offering DNA genotyping established in 2009. Most building and renovation works require ecological assessments to identify the presence of bats: the results help formulate mitigation strategies, making them of considerable environmental and economic importance.

In 2017 research based on new data sets gathered through an iterative cycle of information exchange between industry and academia identified anomalies that had hitherto been invisible to the ecological sector. Some guano that appeared in shape, size and consistency to be derived from bats were in fact derived from shrews. This was met with disbelief, because this guano appeared in habitat spaces such as roof voids, not associated with shrews. Further work in the laboratory confirmed that roof voids represent a previously unidentified niche space for shrews, information which was shared with stakeholders and supported adaptation and expansion of the service [3.6].

3. References to the research (indicative maximum of six references)

Nucleic acid survival in the environment:
[3.1] **Smith, O, Clapham, AJ**., Rose, P, Liu, Y, Wang, J and **Allaby, RG**. (2014) *A complete ancient RNA genome: identification, reconstruction and evolutionary history of archaeological Barley Stripe Mosaic Virus.* Scientific Reports, Volume 4. Article number 4003. doi:10.1038/srep04003
[3.2] **Smith O,** Momber G, Bates R, Garwood P, Fitch S, **Pallen M**, Gaffney V, **Allaby RG** (2015) Sedimentary DNA from a submerged site reveals wheat in the British Isles 8000 years ago. *Science* 347: 998-1001. doi:10.1126/science.1261278
[3.3] **Kistler, L, Ware**, **R, Smith, O,** Collins, M and **Allaby, RG** (2017) A new model for ancient DNA decay based on paleogenomic meta-analysis. *Nucleic Acids Research* 45 (11): 6310-6320 doi:10.1093/nar/gkx361
[3.4] **Kistler, L**, Maezumi, SY, de Souza, JG, Przelomska, NAS., Costa, FM, Smith, O, Loiselle, H, Ramos-Madrigal, J, Wales, N, Ribeiro, E, **Morrison, RR**. , Grimaldo, C, Prous, AP., Arriaza, B, Gilbert, MTP., de Oliveira Freitas, F and **Allaby, RG.** (2018) *Multi-proxy evidence highlights a complex evolutionary legacy of maize in South America.* Science, 362 (6420). pp. 1309-1313. doi:10.1126/science.aav0207

Application of DNA analysis of guano:
[3.5] **Ware RL, Garrod B, Macdonald H**, **Allaby RG** (2020) Guano Morphology reflects ecological information in British bats. PLoS One 15(4):e0230865. doi.org/10.1371/journal.pone.0230865.
[3.6] **Ware RL, Booker A, Allaby RF**, **Allaby RG** (2020) Habitat selection drives dietary specialization in Sorex minutus. *BioRxiv* doi.org/10.1101/2020.02.03.932913 (submitted to PLoS One).

Key underpinning research grants:
[G1] PI **Allaby, RG**, Origins and evolution of ancient Egyptian cotton tracked by palaeogenomics, NERC, Nov 2007 - Jan 2009, GBP 43,947
[G2] PI **Allaby, RG**, Was barley locally adapted to drought conditions in ancient Nubia?, NERC, May 2009 - Jul 2012, GBP 338,358
[G3] PI Eric Holub, CoI **Allaby, RG** (Supervisor), Small RNA-mediated regulation, adaptation and stress response in barley archaeogenome, PhD studentship, BBSRC Environment Change DTP, Oct 2009 – Sept 2013, GBP 223,230
[G4] PI **Allaby, RG**, Archaeogenomics of Sorghum domestication and adaptation, NERC, Mar 2014 – Mar 2017, GBP 636,149
[G5] PI **Allaby, RG** (Supervisor) Niche partitioning in Great British bats through dietary specialisation PhD studentship (NERC Doctoral Training Grant (DTG) Quota 2012-2015)

4. Details of the impact (indicative maximum 750 words)

Establishment of bat genotyping service at Warwick
Professor Allaby's genotyping service, using DNA forensic analysis, is now used by 63% of ecological consultancies, as well as private individuals. The sustained growth of Warwick-based Ecological Forensics Service [5.1] in the absence of any form of commercial advertising has demonstrated a need in the sector as well as a reputation for effective, reliable on-demand services, leading to an average growth of 33% each year over 2014-2017, and 41% in 2018. Up to 31 December 2020 the service has dealt with over 16,100 samples and 686 companies, with 284 of those since January 2019 [5.1]. These companies represent the equivalent of one company for every 17 miles across the entire UK, demonstrating reach within the sector. Since 2011, the service has adapted and expanded and is now used not only to identify bats but also increasingly rare species such as dormice, pine martens, and the occasional otter. The annual turnover of the business (excluding VAT) in 2019 was GBP 85,366, and has been at this level since 2016, demonstrating the scale of the operation. In 2020, the operation adapted to the covid-19 pandemic and continued to support their client base through lockdown [5.1].

Adoption of genotyping services by other ecology services organisations in the UK
Since the creation of Professor Allaby's genotyping service using DNA forensic analysis, establishing this market, private businesses in the UK have started offered bat genotyping services. It is estimated the overall market is worth approximately GBP 135,000. Companies include ADAS, Nicholls Colton Group, SureScreen Scientifics, Swift Ecology, and Applied Genomics, some of which pay to use Allaby's service and some who have created an independent service [5.2].

Influence on best practice guidelines for bat surveys
Local planning authorities are legally obligated to consider all protected species when they assess planning applications, and ecological surveys must be undertaken to identify significant ecological impacts of proposed developments. As a result of Allaby's work, the use of DNA analysis has become accepted as best practice for detecting and identifying bats, particularly when other methods are not possible or appropriate. The 3rd edition of the 'Bat Surveys for Professional Ecologists Best Practice Guidelines (2016)', published by the Bat Conservation Trust (BCT), recommends the use of DNA analysis of guano for species identification which has consequently become standard practice [5.3]. DNA analysis is also recommended when assessing underground sites as winter roosts, where visits during hibernation should be minimised or where ecologists are unable to see diagnostic features. The Head of Biodiversity for the Bat Conservation Trust states: *'The availability of a DNA analysis service to identify bats to species level from their droppings has been highly valuable to those working in bat conservation. Alternative methods for reliable identification are constrained. … DNA analysis allows identification at any time of year regardless of what the bats themselves are doing. This technique is being applied at a larger scale to identify roosts of rarer species and to catalogue all of the species roosting in buildings within a given landholding'* [5.4]. As a result of the increased

awareness and change in best practice guidelines, the practice of validating bat identity using DNA genotyping has become widespread, as evidenced by the extraordinary annual growth in the Ecological Forensic Service business.

Effective protection of roost sites: regulations for planning applications

Planning permission for many building works and civil engineering projects, for which more than 100,000 applications are made each year in the UK, is contingent on the results of ecological surveys. As a result of analyses by the Ecological Forensic Service there have been numerous cases of changes to the planning process: accurate species identification and, therefore, accurate advice to clients on bat conservation and building regulations helps conserve bat populations and saves clients time and money. Taunton, Somerset-based Geckoella Ltd, specialist consultants for ecology, geology and heritage whose clients range from American engineering giant Aecom (HS2 Rail Project) to the Somerset West Heritage Trust, use Professor Allaby's service around four times a year. They say: *'Our advice to clients based on the results enabled them to complete their project without adversely affecting the conservation of bats, working within the legal obligations and saving them time and money in the process'* [5.5]. Similarly, Quants Environmental in North Yorkshire states: '*I would consider the overall key benefit to us and our client is that it provides certainty to our results (similar to when you find a bat in-situ), which in turn increases the robustness of our surveys/reports and increases the likelihood of the Local Planning Authority and Natural England agreeing with our methods, reports or licences*' [5.6].

TMA Consultants in Essex, whose clients include local government, land managers, developers for small, medium and large infrastructure, have used the Ecological Forensics Service on around 30 occasions since 2014. They say that the service *'can provide information that could otherwise only be obtained by costly and seasonally restricted bat 'emergence' surveys, or by disturbing or invasive capture and inspection of bats from their roosts. For larger development projects, avoiding a delay of up to 9 months to get this kind of information through summer surveys could save tens of thousands of pounds'* [5.7].

Identification of rare and 'visitor' species: shifts in bat populations in the UK

There are numerous reports of the Ecological Forensics Service validating the discovery of various species of bats for the first time in variety of locations, representing either changing distributions, possibly as a result of climate change, or a more finessed understanding of their biogeography. Warwick's services have helped identify complex roosts made up of multiple species previously missed. Poole-based KP Ecology reports: '*The results of DNA analysis have enabled species to be identified in new areas of Dorset and has enabled building projects to conduct good mitigation/compensation specific to particular species of bats'* [5.8]. Furthermore TMA Consultants cited a 'significant' example from a project undertaken in 2016 in a Hampshire school: '*A comprehensive set of night-time surveys recorded a variety of common bat species roosting at the site, including brown long-eared bat and common and soprano pipistrelle bat. However, the DNA analysis also revealed the presence of Brandt's bat roosting in one of the roof voids – a much scarcer species. Apart from creating an important record of this species, it meant that all of the species present were accounted for in the licensing and mitigation strategy*' [5.7].

In 2017, the discovery through DNA analysis of a rare grey long-eared bat, with a population of less than 3,000 in the UK, in East Devon, was featured in local newspaper *Sidmouth Express*. Senior ecologist at Acorn Ecology said in the article: *'The roost is also being used by other confirmed bat species including serotine and brown long-eared. Because of the difficulty in distinguishing the two species of long-eared bat, and their habits of sharing roosts, it's easy to miss the rarer species. This is why DNA analysis is so important'* [5.9]. He added that Devon, with low levels of light pollution and a diverse foraging habitat, is a haven for grey long-eared bats. In addition, since 2015, the Ecological Forensic Service have confirmed 3 positive test results of Myotis alcathoe, an occasional continental 'visitor' species, suggesting a transition into becoming a resident UK species [5.1].

Avoiding misidentification of other (non-bat) species

Before Allaby's precision techniques were applied across the ecological consultancy services sector, the inaccurate identification of bat species often led to the misidentification of the other species occupying traditional bat roosts. In particular, on numerous occasions shrews have been found in loft spaces, a niche which had not previously been associated with these small mammals. For example, in 2017 a pygmy shrew was discovered in the loft space of a two-storey pub called The Monkey, causing the consultant receiving the results, surprise and confusion about how they would survive in this space and what they were eating [5.10]. Without DNA analysis this would have been falsely identified as a bat, and advice given to clients and recorded on the ecological survey would have been inaccurate having a large impact on building works. These instances are also an example of a widening scope of the business to address the needs of clients.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[5.1] Ecological Forensics Service contact for corroboration - Forensic Ecologist - claims to corroborate: details annual growth, number of samples and clients, annual turnover, the 3 positive test results of Myotis alcathoe plus website: https://warwick.ac.uk/fac/sci/lifesci/research/archaeobotany/ecological_forensics/
[5.2] Since Allaby's operations started, several other companies have started to operate in this sector demonstrating that we have been actively building a viable part of the UK economy. Examples include: ADAS https://www.adas.uk/service/Bat-Speciation-DNA-Analysis-order, Nichols Colton Group http://nicholls-colton.co.uk/bat-genotyping-service/, Surescreen Scientifics https://www.surescreenscientifics.com/edna/batid/, Swift Ecology https://www.swiftecology.co.uk/dna.php, Applied Genomics https://appliedgenomics.co.uk/bats
[5.3] As a consequence of Allaby's Ecological Forensics Service, bat guano genotyping has become standard practice. The Bat Surveys for Professional Ecologists: Good Practice Guidelines (3rd edition) 2016 (http://www.bats.org.uk/pages/batsurveyguide.html).
[5.4] Published by the Bat Conservation Trust has changing ecological surveying practice nationally, as evidenced by a written statement from the author of the guidelines
[5.5] Written statement from Geckoella Ltd
[5.6] Written statement from Quants Environmental
[5.7] Written statement from TMA Consultants
[5.8] Written statement from KP Ecology
[5.9] News article confirming GLE bats in East Devon
https://www.sidmouthherald.co.uk/news/second-discovery-of-rare-bat-in-east-devon-1-4943201
[5.10] Confirmation of positive Pygmy Shrew result