Institution: Liverpool John Moores University (LJMU)		
Unit of Assessment: 9		
Title of case study: Astro-Ecology: Tackling biodiversity loss using thermal imaging, machine learning and drone technology		
Period when the underpinning research was undertaken: 2015 – December 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:**
Steven Longmore	Professor of Astrophysics	01/03/2013 to date
Serge Wich	Professor of Ecology	01/08/2012 to date
Paul Fergus	Reader in Machine Learning	20/08/2003 to date
Carl Chalmers	Senior lecturer of Machine Learning	08/12/2008 to date
Period when the claimed impact occurred: 2015 – December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Using techniques developed in astronomy, ecology, and machine learning, we have developed drones with thermal cameras combined with automated animal detection system to tackle biodiversity loss. Working with global stakeholders we have demonstrated the system makes it up to 100x quicker to conduct animal surveys than existing methods, saving NGOs many thousands of pounds per project per year. This has a transformative effect on NGOs' abilities to tackle biodiversity loss and is affecting change in national governmental policy on the uptake of drones.

2. Underpinning research

The research is based on adapting innovations originally developed for use in astronomy, to tackle major ecological challenges. Specifically, we build upon the instrumentation, data reduction, source detection, and analysis software expertise that astrophysicists use to extract the maximum science from thermal-infrared astronomy data. Through a series of published research papers, we have demonstrated that these astrophysics techniques are ideally suited to interpreting data taken with thermal cameras on drones for conservation purposes. The project is effectively doing astrophysics, but rather than pointing into space, we are turning our "telescopes" back towards Earth to solve ecological challenges.

The project started in 2015 when we bought a drone and thermal camera and conducted a series of flights over humans and animals in the Liverpool area. These proof-of-concept experiments demonstrated it was possible to successfully detect animals/humans using COTS thermal cameras on drones. In 2016 we expanded the drone flight experiments to quantify the identification accuracy in a variety of environments and conditions. The tests proved very successful, and in 2017 we published our first paper demonstrating that astronomical source detection software is well suited to detecting animals and humans in thermal drone images [UR1].

Building on this success, in 2017 we were awarded £50k from the UK Government's Science and Technology Facilities Council (STFC) [grant ST/P003273/1] to hire a postdoc to begin systematically adapting astrophysics techniques to work in real, field-site conditions. We subsequently published two papers at the start of 2018 describing how to adapt thermal-infrared technology and astronomical techniques to overcome environmental and atmospheric challenges to capture high precision thermal data for use in conservation biology [UR2 & UR3].

Having successfully demonstrated the adaption of astrophysics techniques to work in real field conditions, later in 2018 we were awarded £412k of STFC funding (grant ST/R002673/1) to (i) begin helping conservation agencies around the globe to monitor different endangered animal

species and (ii) build a website with integrated machine learning analysis tools that can automatically find animals in conservation images and videos. We have subsequently published multiple papers as a result of this work, for example, demonstrating that thermal imaging from drones offers a major advance for surveys to find and identify spider monkeys [UR5] and orangutans [UR6] in the wild.

Based on the success of these STFC Global Challenge Research Fund (GCRF) grants, in 2019 our project was selected as one of a small number of GCRF projects across all UKRI Research Councils to receive a "Global Challenges Translation Award" (grant EP/T015403/1). We were awarded £574k to substantially scale-up our previous efforts to a national level in Madagascar – a "Least Developed" DAC list country with the greatest natural biodiversity. By building the country's first Drone Research Lab and training Madagascans to build/fly drones, we are simultaneously helping ensure the long-term protection of Madagascar's biodiversity – a cornerstone of the country's economy – while initiating Madagascar's industrial drone sector.

3. References to the research

All journal papers have been through a rigorous peer review process prior to publication.

UR1. **Longmore, SN**, Collins, RP, Pfeifer, S, Fox, SE, Mulero-Pazmany, M, Bezombes, F, Goodwin, A, de Juan Ovelar, M, Knapen, JH and **Wich, SA** (2017) ***Adapting astronomical source detection software to help detect animals in thermal images obtained by unmanned aerial systems***. International Journal of Remote Sensing, 38 (8-10). pp. 2623-2638. ISSN 0143-1161. Link: http://researchonline.ljmu.ac.uk/id/eprint/5173/

UR2. Burke, C, Rashman, M, McAree, O, Hambrecht, L, **Longmore, SN**, Piel, AK and **Wich, SA** (2018) ***Addressing environmental and atmospheric challenges for capturing high-precision thermal infrared data in the field of astro-ecology***. In: Proceedings of SPIE. (SPIE. Astronomical Telescopes and Instrumentation, 10th-15th June 2018, Austin, Texas, USA). Link: http://researchonline.ljmu.ac.uk/id/eprint/8925/

UR3. Burke, C, Rashman, M, **Wich, SA**, Symons, A, Theron, C and **Longmore, SN** (2019) ***Optimising observing strategies for monitoring animals using drone-mounted thermal infrared cameras***. International Journal of Remote Sensing, 40 (2). pp. 439-467. ISSN 0143-1161. Link: http://researchonline.ljmu.ac.uk/id/eprint/9872/

UR4. Burke, C, **Wich, SA**, Kusin, K, McAree, O, Harrison, M, Ripoll, B, Ermiasi, Y, Mulero-Pazmany, M and **Longmore, SN** (2019) ***Thermal-Drones as a Safe and Reliable Method for Detecting Subterranean Peat Fires***. Drones, 3 (1). ISSN 2504-446X.
Link: http://researchonline.ljmu.ac.uk/id/eprint/10221/

UR5. Spaan, D, Burke, C, McAree, O, Aureli, F, Rangel-Rivera, C, Hutschenreiter, A, **Longmore, SN**, McWhirter, PR and **Wich, SA** (2019) ***Thermal Infrared Imaging from Drones Offers a Major Advance for Spider Monkey Surveys***. Drones, 3 (2). ISSN 2504-446X.
Link: http://researchonline.ljmu.ac.uk/id/eprint/10539/

UR6. Burke, C, Rashman, MF, **Longmore, SN**, McAree, O, Glover-Kapfer, P, Ancrenaz, M and **Wich, SA** (2019) ***Successful observation of orangutans in the wild with thermal-equipped drones***. Journal of Unmanned Vehicle Systems. ISSN 2291-3467
Link: http://researchonline.ljmu.ac.uk/id/eprint/10675/

Total funding received for this research was **£1.2M** between 2014-2021, as follows:

1. USFWS (US Fishing and Wildlife Services), $25,536 (2014) [£19,152]
2. USFWS $36,461 (2014) [£27,345]
3. Chester Zoo $27,232 (2014) [£20,424]
4. NGS (National Geographic Society) $16,792 (2015) [£12,594]
5. ISTAT (International Society of Transport Aircraft Trading) Foundation, $4,000 (2016) [£3000]
6. STFC (Science and Technology Facilities Council) ST/P003273/1 £50,405 (May - Jan 2018)
7. STFC ST/R002673/1, £411,988, Jan 2018-Dec 2019
8. Leverhulme VP1-2017-031. £18,420 July 2018-July 2019
9. STFC, ODA Institutional Award, £70k (2018-19)
10. UKRI EP/T015403/1 "Using drones to protect biodiversity and spur economic growth in Madagascar" £574,039, Oct 2019- Mar 2021

4. Details of the impact

150 to 200 species of life on our planet become extinct every day[1]. This rate of "biological annihilation" means a sixth mass extinction in Earth's history is under way[2], with catastrophic consequences for those ecosystems, the world economy, and planet as a whole. Indeed, biodiversity loss and consequent ecosystem collapse are one of the 5 foremost dangers facing humanity[3]. There is a fundamental need to routinely monitor animal populations over much of the globe so that conservation strategies can be optimized with such information.

The critical units of tracking change in animal populations are Animal Distributions and Densities (ADDs). However, most ADD surveys are conducted manually, which is extremely labour-intensive, inherently slow and costly. Since project initiation (2015), we are now (12/2020) working with 10 leading conservation agencies on 4 continents to overcome this problem. To assess the impact our thermal drone and artificial intelligence animal detection system has had on tackling biodiversity loss, we invited our partner conservation agencies to provide feedback on what impact, if any, the system has had on their organisation, from individual project level to national/global strategy. Corroborating Sources (CS) 1 – 5 provide examples of the letters we received. Below we summarise the reported impacts, grouped into 6 themes commonly covered by the organisations. References to feedback from specific organisations are shown as [CS#], where # = organisation number.

Impact 1 – Up to factor 100x improvement in ADD survey efficiency: Our system provides a step-change in ADD survey efficiency through a combination of (i) drones being able to cover large areas much more quickly than traditional ground surveys, (ii) thermal cameras being able to easily pick out animal's heat signatures, and (iii) machine learning being able to automate identification of animals in footage that would traditionally have been done by eye.

[1] World Wildlife Fund for Nature (WWF): https://wwf.panda.org/knowledge_hub/endangered_species/

[2] Ceballos et al., **Biological annihilation via the ongoing sixth mass extinction signaled by vertebrate population losses and declines**, Proceedings of the National Academy of Sciences, 2017, 114, 30

[3] World Economic Forum Global Risk Report: https://www.weforum.org/reports/the-global-risks-report-2020

Dr Hudson, Head of Research, Durrell Wildlife Conservation Trust: *"… the team then flew the system over key areas of marsh that have been inaccessible to previous surveys. In 3 x 20-minute flights, the drone system reproduced lemur densities estimated from previous surveys requiring 24 person-weeks of effort. Scaling-up this programme to cover the entire lake represents an approximately 100 times increase in survey efficiency. … The adoption of this research technology will revolutionise the scale and frequency with which DWCT and our partners in Madagascar, including the Madagascar National Parks Service, can conduct surveys."* [CS3]
Dr Spaan, Population Monitoring Coordinator of the Mexican Conservation NGO, 'ConMonoMaya': *"… the drone allows for much faster coverage of an area than the [traditional] ground method does."* [CS4]

Impact 2 – Up to factor ~15x improvement in processing ADD survey data: Increased survey efficiency is an important first step in animal monitoring. However, the inability to extract ADDs from the exponentially growing volumes of data is an ever-growing bottleneck for conservation agencies and a key limiting factor to implementing biodiversity-loss mitigation strategies. To overcome this problem, in 2017 we created a secure online research environment which uses machine learning to automatically find and identify animals/poachers in photo and video footage. Approved users from conservation agencies anywhere in the world can upload conservation images/videos to the website (www.conservationai.co.uk) and almost immediately receive a robust list of the species in the footage. As of 21/9/20 we are supporting 61 users from 8 conservation projects across 4 different ecosystem types. The website has processed >35k images and detected over 100k objects.

Dr Theron, Head of Drylands Conservation Program at the Endangered Wildlife Trust: *"… manually sorting images will take 10 to 15 times the amount of time required to simply upload the images to the machine learning pipeline."* [CS1]
Dr Piel, Director of the Greater Mahale Ecosystem Research and Conservation Project: *"… drones coupled with machine learning can detect poachers 17x faster than when images are examined manually."* [CS2]

Impact 3 – Substantial savings in operating costs: Conservation agencies are typically charities operating to maximise ecosystem health on very tight budgets. Increased efficiency from Impact 1 & 2 translates directly into savings in operating and staff costs. Our conservation partners estimate the implementation of our technological solution saves them thousands of pounds per project per year.

Dr Hudson: our drone system represents *"…a saving of £8,000, annually. In the field of conservation where funding for 'routine' actions such as monitoring is hard won, this saving is a fantastic achievement and will help to guarantee the sustainability of our field programmes, long-term."* [CS3]
Dr Theron: the increased detection efficiency, *"… represents a significant amount of skilled resources that can be redirected to more productive conservation activities. The direct cost saving amounts to approximately £ 1500 per large camera trap survey (80 or more cameras) or more than 20 working days in one team members time."* [CS1]

Impact 4 – Transformative effect on biodiversity-loss mitigation strategies: The time and money saved can instead be invested in implementing optimal conservation strategies, which has a direct impact on halting biodiversity loss.

Dr Theron: *"In summary, the collaboration with Prof. Longmore and Wich, has made our animal survey methods more cost-effective which allows us to focus more on other aspects of our work and will have a direct impact on our effectiveness."* [CS1]
Dr Hudson: *"This new system has the potential to not only produce a step-change in the accuracy, frequency, robustness and geographic coverage of conservation data, but provide statistics of lemurs group numbers, and potentially even an individual's size, weight, etc., revolutionising the potential for ecosystem management and tracking the efficacy of different restoration measures."* [CS3]

Impact 5 – Shaping global animal monitoring strategies: As a direct result of our research, leading conservation agencies around the world, such as the World Wildlife Fund for Nature (WWF), are reviewing their animal monitoring strategies to consider the systematic adoption of thermal-drone technology.

Nicola Loweth, Regional Manager, World Wildlife Fund for Nature*: "In 2017, WWF approached Prof Longmore and Prof Wich … seeking assistance in resolving some of these challenge and stems from their research using (thermal) drones and machine learning to help conservation efforts. In particular we were interested to explore using these methods for our Bornean orangutan conservation work in Sabah (Malaysia) with an eye to potentially expanding these methods into other areas and species where WWF works around the globe."* [CS5]

Impact 6 – Shaping policy and legislation at a national level: With our collaborators in Madagascar we are advising the Madagascan Government's Civil Aviation Authority as they implement a National Drone Policy document and build a national framework and regulations for operating drones. Dr Hudson: *"… we expect this project to have long-term impacts at the highest national level."* [CS3]

Our research regularly appears in leading international media outlets (New York Times, BBC, Le Monde, National Geographic, etc.,) and has featured in 2 BBC Nature documentaries, reaching an estimated world-wide audience of 60 million in the last 2 years. This demonstrates the public reach and interest in the project, and has directly led researchers in conservation agencies around the world to contact us about collaborating to use our system.

5. Sources to corroborate the impact

CS1: Letter from Dr. Cobus Theron, Head of Drylands Conservation Program at the Endangered Wildlife Trust
CS2: Letter from Dr. Alex Piel, Director of the Greater Mahale Ecosystem Research and Conservation Project
CS3: Letter from Dr. Mike Hudson, Head of Research, Durrell Wildlife Conservation Trust
CS4: Letter from Dr Denise Spaan, Population Monitoring Coordinator of the Mexican Conservation NGO, 'ConMonoMaya'
CS5: Letter from Nicola Loweth, Regional Manager, World Wildlife Fund for Nature (UK)