Section A

Institution: University of St Andrews

Unit of Assessment: UoA 10: Mathematical Sciences

Title of case study: Statistical methods for wildlife monitoring and conservation in the digital age

Period when the underpinning research was undertaken: 2008 - 2014

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by HEI:
David Borchers	Professor	01 December 1993 - present
[text removed for publication]	[text removed for publication]	[text removed for publication]
Len Thomas	Professor	01 April 1997 - present

Period when the claimed impact occurred: 01 August 2013 - 31 December 2020

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

Section B

1. Summary of the impact

Prof. D. Borchers and colleagues have developed new statistical methods for digitally monitoring wildlife using GPS tags, camera traps and hydrophones, extending the reach of surveys into areas where human surveyors cannot gather data, and surveying for longer periods than humans could sustain. Their research has (i) [text removed for publication]; (ii) formed the basis for the Global Snow Leopard Ecosystem Protection Programme's use of camera traps deployed for months in hostile high-altitude environments to progress its aim of conserving snow leopards worldwide; and (iii) changed conservation policy in the Baltic, by using underwater digital-listening devices to survey harbour porpoises, finding a previously unknown Baltic harbour porpoise breeding site south of Gotland, Sweden and leading to the creation of a new Marine Protected Area covering over 1,000,000ha, to conserve this critically endangered population.

At the same time, the research team have built capacity in Namibia, India, Kyrgystan, Mongolia, Nepal and Bhutan by training more than 120 people (staff) at the [text removed for publication], the Snow Leopard Trust, the Snow Leopard Foundation and government conservation agencies from India, Kytrystan Mongolia, Nepal, Bhutan and other snow leopard range countries, over the course of approximately 4 years in the use of statistical methods for wildlife assessment and conservation, and developing associated training materials.

2. Underpinning research (indicative maximum 500 words)

The Centre for Research into Ecological and Environmental Modelling (CREEM) at the University of St Andrews specialises in the development of innovative statistical methods to address problems in ecology. All research mentioned here is of this sort – the development of new statistical methods to address ecological problems.

Survey devices such as GPS tags, camera traps and hydrophones, gather wildlife survey data in different ways, but all involve digitally sampling parts of survey regions and drawing inferences from this about wildlife in unsampled regions. In all cases, this involves modelling the number of animals missed and their distribution across a large region, from observations in a small fraction of the region.

The research challenge was how to turn limited digital evidence, such as [text removed for publication], images of snow leopard fur patterns, or sounds of harbour porpoise, obtained at a

few locations covering only a fraction of the area of interest, into estimates of the abundance and distribution of the species over a much larger area.

[text removed for publication]

Snow leopard fur patterns are their "fingerprints". Although they are notoriously elusive animals, snow leopards can now be surveyed by placing camera traps in the mountains for long periods of time. Identifying individuals from their fur patterns allows capture-recapture methods to be used for assessment. The "spatially explicit capture-recapture" ("SECR", or "SCR") methods developed by Borchers [R3] allow snow leopard abundance, distribution and space use to be modelled from the times and locations at which snow leopards were photographed, as well as how this changes over time and in response to environmental or anthropogenic impacts. This seminal paper developed a suite of methods that integrate spatial modelling and capture-recapture methods and established the first statistically rigorous basis for spatial modelling of wildlife distributions using capture-recapture data. Subsequent research [R4] extended SCR methods to use the times of photographs to learn about animal activity patterns within a day, a week, or longer periods.

Like snow leopards, Baltic porpoises are rare and elusive and can be detected much more effectively by digital devices than by humans. Unlike snow leopards, they are heard rather than seen by the devices, and this requires different analysis methods. Underwater acoustic methods are being used increasingly to monitor populations of whales and dolphins that vocalise, for communication or echolocation. CREEM is a leading developer of such methods. We developed statistical methods for animal density estimation from passive acoustic data [R5] that are appropriate in this context. In the Baltic Sea, we designed the world's largest passive acoustic survey (300 locations over 2 years) as part of an EU Life project [R6].

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

All papers below are in internationally recognised peer-reviewed journals and conference proceedings.

[R1] [text removed for publication]

[R2] [text removed for publication]

[[R3] **Borchers, D.L.** and Efford, M. 2008. Spatially explicit maximum likelihood methods for capture-recapture studies. *Biometrics* **64**: 377-385. DOI: 10.1111/j.1541-0420.2007.00927.x.

[R4] **Borchers, D.L.**, Distiller, G., Foster, R., Harmsen, B. and Milazzo, L. 2014. Continuous-time spatially explicit capture-recapture models, with an application to a jaguar camera-trap survey. *Methods in Ecology and Evolution* **5**: 656-665. DOI: 10.1111/2041-210X.12196.

[R5] Marques, T.A, **Thomas, L.**, Martin, S.W., Mellinger, D.K., Ward, J.A., Moretti, D.J., Harris, D. and Tyack, P.L. 2013. Estimating animal population density using passive acoustics. Biological Reviews 88: 287-309. DOI: 10.1111/brv.12001.

[R6] Carlén, I., **Thomas, L**, Carlström, J, Amundin, M, Teilmann, J., Tregenza, N., Tougaard, J., Koblitz, J.C., Sveegaard, S., Wennerberg, D., Loisa, O., Dähne, M., Brundiers, K., Kosecka, M., Kyhne, L.A., Ljungqvist, C.T., Pawliczka, I., Koza, R., Arciszewski, B., Galatius, A., Jabbusch, M., Laaksonlaita, J. , Niemi, J., Lyytinen, S., Gallus, A., Benke, H., Blankett, P., Skóra, K.E., Acevedo-Gutiérrez, A.. 2018. Basin-scale description of the spatial and seasonal distribution of harbour porpoises in the Baltic Sea provides basis for effective conservation actions. Biological Conservation **226**: 42-53. DOI: 10.1016/j.biocon.2018.06.031.

4. Details of the impact

The CREEM research group have developed new statistical methods for digitally monitoring wildlife using GPS tags, camera traps and hydrophones, extending the reach of surveys into areas where human surveyors cannot gather data, and surveying for longer periods than humans could sustain. As a result of the research into new statistical methods for digitally monitoring wildlife described in Section 2, statisticians at St Andrews, since August 2013, have (i) [text removed for publication]; (ii) provided the statistical tools for the Global Snow Leopard Ecosystem Protection Programme's efforts to protect snow leopards across their 2,000,000km^2 range in Asia, using camera traps to survey them for months in hostile high-altitude

environments; and (iii) changed conservation policy in the Baltic Sea, by using underwater digital-listening devices to survey harbour porpoises, leading to the creation of a new Marine Protected Area.

[text removed for publication] In the case of snow leopards, the beneficiaries are the participants in the Global Snow Leopard and Ecosystem Protection Program, from the 12 snow leopard range countries. In the case of harbour porpoise, the beneficiaries are the EU member states bordering the Baltic.

[text removed for publication]

Conserving snow leopards

Software and methods [R3, R4] developed at St Andrews are being used by an alliance of the 12 snow leopard range countries that are partners in the Global Snow Leopard Ecosystem Protection Program (GSLEP), to do surveys in consultation with St Andrews, in Mongolia (between 2017 and 2020), Kyrgystan (between 2017 and 2020), India (2019), Nepal (2019) and Bhutan (2020). This forms part of the world's first global survey of snow leopards: the "Population Assessment of the World's Snow Leopards" (PAWS). We provide analysis support and training (including co-authoring, with GSLEP partners, design and analysis manuals for PAWS), and have together produced new estimates of snow leopard distribution and abundance in these regions, which now form part of GSLEP's Population Assessment of the World's snow Leopards. The GSLEP International Coordinator and Senior Research Ecologist for the Snow Leopard Trust (our key contact for GSLEP) stated, "*Borchers' input has been crucial for design and analysis of at least 18 on-going and completed PAWS surveys to date*" [S2].

The snow leopard is listed as globally Vulnerable on the IUCN Red List and the species is listed (as *Uncia uncia*) on Appendix I of CITES (Convention on International Trade in Endangered Species of Fauna and Flora), which prohibits international trade in the animal and its parts and products except under exceptional, non-commercial circumstances. All snow leopard range countries except Tajikistan are parties to CITES but the process for Tajikistan to join is under way. Conservation actions and IUCN Red List status is based on estimates of snow leopard distribution and abundance, but snow leopards are famously elusive and difficult to survey. No survey of their vast range (2,000,000km^2) has ever been attempted, and in the absence of hard range-wide evidence, their IUCN conservation status is controversial. Camera traps left in the mountains for months can detect enough animals to make a range-wide survey feasible for the first time, with a suitable survey design [S2]. The GSLEP PAWS initiative is using methods developed in St Andrews for camera trap surveys to progress GSLEP's interim goal to "*secure at least 20 healthy populations of snow leopards across the cat's range by 2020*" and ultimate goal of "*ensuring that healthy snow leopard populations remain the icon of the mountains of Asia for generations to come*." [S3].

Borchers became involved in GSLEP PAWS after the GSLEP Secretariat approached him, because of his central role in developing these methods, for advice on the spatial capture-recapture (SCR) methods [R3] that PAWS planned to use. He was asked to advise on the survey methods at the International Snow Leopard and Ecosystem Forum in Kyrgystan in 2017– where the PAWS survey was initiated. After presenting a talk and short workshop on SCR methods to snow leopard range country ecologists at the Forum, he was invited to co-chair the PAWS Scientific Advisory Panel.

Protecting harbour porpoise through a new MPA in Sweden

A new survey using statistical methods developed entirely by St Andrews has located a previously unknown Baltic Sea harbour porpoise breeding site south of Gotland in Sweden; this finding led to the area being designated as the Baltic Sea's largest marine protected area (MPA, a Natura 2000 site), covering over 1,000,000ha [S4]. Three more sites are being designated, and two others enlarged [S5]. The survey was undertaken by an international consortium of governmental and non-governmental organisations from all EU Baltic states, the Static Acoustic Monitoring of Baltic Harbour porpoise (SAMBAH) project. CREEM undertook the statistical

method development and design and led on the analyses [S4]. The Baltic Sea harbour porpoise population is classified as Critically Endangered by the International Union for Conservation of Nature (IUCN). Marine protected areas (MPAs) are important instruments in the protection of marine mammals and this MPA is large enough to provide effective protection when combined with an effective management plan. Although a full management plan for the new site is still in preparation, this MPA has already been referred to by the relevant country administrations when turning down applications for large marine construction projects within it [S4].

Effective conservation requires knowledge of distribution and abundance, but until our work [R6] this information was lacking. Harbour porpoise are difficult to survey because of their small size and the fact that they spend most of their lives submerged. The Baltic population is particularly difficult because of its very low density. An alternative to visual surveys is to use underwater microphones (hydrophones) that can be deployed in large numbers for months at a time and in all weather conditions to listen for porpoise echolocation clicks. We pioneered the development of statistical methods to estimate animal density from acoustic surveys [R5]. Because of this, we were approached in 2008 by the SAMBAH team to participate in a EUR4,200,000 EU Life survey proposal. The SAMBAH project leader described our role as "*key to the success of the project*" and that the St Andrews team "*combine[d] the required statistical skills with a deep understanding of the specialized methods used for passive acoustic density estimation and the ability to work across disciplines and explain what [was] required to other project members including biologists, acousticians and engineers*" [S4]. The survey constituted the largest passive acoustic survey ever undertaken and received extensive publicity within Baltic countries; results were distributed to stakeholders from local and national governments, NGOs and industries (e.g. fisheries, shipping and marine construction) at an end-of-project conference in 2014, as a set of press releases and a final report to the EU [S6], with academic papers following [e.g. R6], coordinated by the SAMBAH project leader.

Capacity building and training of conservationists on wildlife monitoring methods

We have developed training material and trained more than 40 people (conservationists) in statistical methods for monitoring wildlife workshops; these were developed by St Andrews [text removed for publication].

We have developed training material and trained more than 90 people (conservationists) in design and analysis methods for camera trap surveys of snow leopards, at training workshops in Kygystan (2017, 2018), China (2018), India (2019), Mongolia (2019), and Nepal (2019), all coordinated by GSLEP's international coordinator [S2].

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

[text removed for publication]

[S1] [text removed for publication]

[S2] Letter from the GSLEP International Coordinator and Senior Research Ecologist, Snow Leopard Trust.

[S3] GSLEP goals: https://globalsnowleopard.org/what-is-gslep/gslep-goals/20by2020/

[S4] Letter from the SAMBAH project leader.

[S5] News article from Coalition Clean Baltic web portal https://tinyurl.com/y4p7ovmk

[S6] SAMBAH project description and outputs at EU Life web portal https://tinyurl.com/y35klkck