Institution: University of St Andrews

Unit of Assessment: 10 - Mathematical Sciences

Title of case study: Distance sampling surveys: enabling better decision-making by wildlife managers

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

Reliable estimates of the size of natural populations are required by national and regional governments for management and conservation, by international commissions that manage natural resources, and by NGOs. Distance sampling, in which distances of animals from a line or point are sampled, is the most widely-applicable technique for obtaining such estimates. Statisticians at St Andrews are the acknowledged world-leaders in the development and dissemination of distance sampling survey methods. Their software *Distance* is the industry standard and has over 30,000 registered users from around 115 countries. The methodological developments and associated software have allowed better-informed decisions to be made in the management and conservation of populations as diverse as whales, seals, fish, elephants, apes, deer, birds, ants, trees and flowering plants.

2. Underpinning research (indicative maximum 500 words)

Distance sampling is a suite of techniques for estimating the size and/or spatial density of animal and plant populations from transect surveys. In the early 1990s, a 'Distance team' was established, comprising Prof ST Buckland (then at BioSS in Aberdeen), Anderson, Burnham and Laake (Colorado), to develop software and establish good practice. After Buckland's move to St Andrews in October 1993, Dr DL Borchers (Reader) and Dr L Thomas (Reader) were added to the team in December 1993 and April 1997, respectively, with Thomas taking responsibility for software development[1]. Since 2001, with the exception of ongoing contributions by Laake (mostly in the area of double-platform methods) and Fewster (Auckland, but a PhD student at St Andrews 1995-98), the active members of the team have all been at St Andrews. The key researchers are Borchers, Buckland, Thomas and Dr EA Rexstad (Research Fellow since 2005).

We have actively extended the applicability of distance sampling so that populations that violate the standard assumptions (perfect detection on the transect, no movement, distances measured without error, lines placed independently or animal locations), or are prohibitively expensive to survey by standard methods, can be reliably assessed. Since 2001, we have published methodological advances in 2 OUP books and in a wide range of statistical and biological journals: 1 paper in JASA, 7 in Biometrics, 4 in JABES, 4 in J Appl Ecol, 4 in J Acoustical Soc of America, and 1 each in Applied Statistics and J Ornith. We pick out a few highlights here.

Buckland recruited 3 research students (1 in 1995 and 2 in 1996) to develop 3 aspects of distance sampling: multiple-covariate distance sampling, spatial distance sampling and automated survey design. In parallel with their work, an introductory distance sampling book was prepared, and was published by OUP in 2001. It set out standards for conventional distance sampling, based on research conducted in the 1980s and 1990s. Subsequent developments of the team appeared in an advanced book in 2004[2]. The work on spatial distance sampling methods[3] has sparked much interest, and several groups have published papers developing the approach further. The methods allow density of animals to be related to geographical covariates that quantify habitat, topography, management practices, etc. Meanwhile, Borchers developed in a series of papers methods for when animals (such as whales) on the transect line are not certain to be detected, culminating in a comprehensive methodological framework for mark-recapture distance sampling[4]. The concept of 'point independence', covered in detail in that paper, was extended to that of 'limiting independence' subsequently[5]. Borchers' work was further extended to accommodate stochastic animal availability by embedding a Markov-modulated Poisson process model for availability into the distance sampling detection process model[6].

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

[1]Thomas, L., Buckland, S.T., Rexstad, E.A., Laake, J.L., Strindberg, S., Hedley, S.L., Bishop, J.R.B., Marques, T.A. and Burnham, K.P. 2010. *Distance* software: design and analysis of distance sampling surveys for estimating population size. *J. App. Ecol*. **47**, 5-14.
378 citations in Google Scholar (August 2013). DOI: 10.1111/j.1365-2664.2009.01737.x

[2]Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. and Thomas, L. (eds) 2004. *Advanced Distance Sampling.* Oxford University Press, Oxford. 419 citations in Google Scholar (August 2013); the 2001 introductory book had 2323 citations.

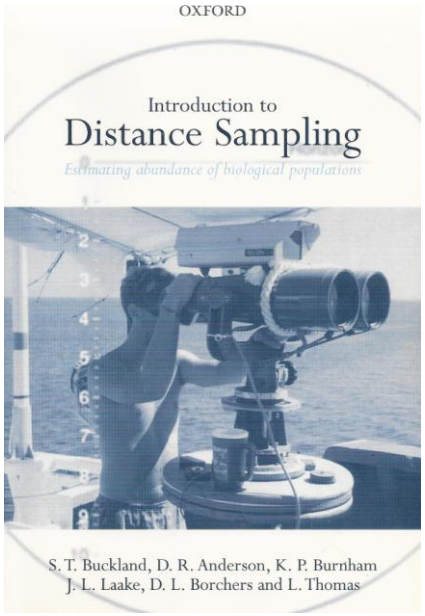
[3]Hedley, S.L. and Buckland, S.T. 2004. Spatial models for line transect sampling. *Journal of Agricultural, Biological and Environmental Statistics* **9**, 181-199. DOI: 10.1198/1085711043578
Selected as best JABES paper, 2004-05.

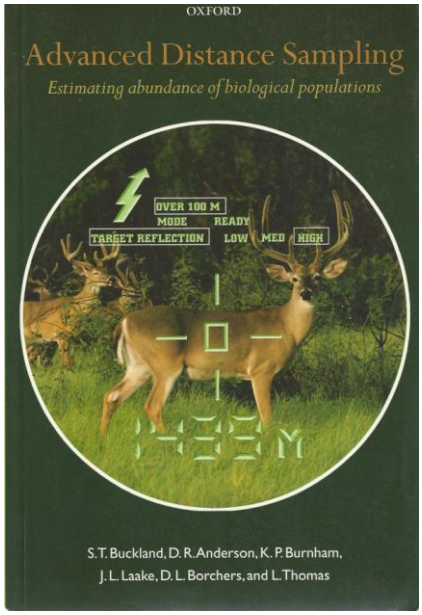
[4]Borchers, D.L., Laake, J.L., Southwell, C. and Paxton, C.G.M. 2006. Accommodating unmodeled heterogeneity in double-observer distance sampling surveys. *Biometrics* **62**, 372-378. DOI: 10.1111/j.1541-0420.2005.00493.x

[5]Buckland, S.T., Laake, J.L. and Borchers, D.L. 2010. Double-observer line transect methods: levels of independence. *Biometrics* **66**, 169-177. DOI: 10.1111/j.1541-0420.2009.01239.x

[6]Langrock, R., Borchers, D.L. and Skaug, H. Markov-modulated nonhomogeneous Poisson processes for modeling detections in surveys of marine mammal abundance. 2013. *Journal of the American Statistical Association.* DOI: 10.1080/01621459.2013.797356

Outputs 2, 3 and 4 were submitted to RAE2008 under UoA22, for which the unit scored 2.65 overall for publications, with 95% of outputs scored at 2* or greater. Outputs 3, 4 and 6 best indicate the quality of the underpinning research.





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

The distance sampling methods developed at the University of St Andrews are widely used for managing the catch or cull of natural resources (e.g. fisheries, deer), for monitoring the status of populations of conservation concern (e.g. elephants, apes, whales, polar bears), and for routine, often statutory, monitoring (e.g. UK Breeding Bird Survey, which feeds into the Wild Bird Indicator, one of 15 headline Quality of Life Indicators adopted by Defra). Organisations that have sponsored the development of our software *Distance* include the US Navy (US$455K during 2008-

13), and, prior to 2008, the US Office of Naval Research, US National Park Service, Fisheries and Oceans Canada, and the Wildlife Conservation Society. *Distance* is the global industry standard with over 30,000 registered users from around 115 countries.[S6]

The Distance team at St Andrews has disseminated its work through a multi-pronged strategy: 1. Publish methodological developments in top journals. 2. Publish introductory and advanced texts. 3. Provide user-friendly software *Distance*. 4. Provide training workshops (42 workshops during 1999-2012, attended by 833 participants – mostly non-academic – from 73 countries). 5. Publish papers in ecology and taxon-specific journals, targeting wildlife managers, that promote best practice, e.g. for dung and nest surveys (primarily used to assess deer and ape populations respectively, two papers in J App Ecol), primate surveys (two papers in Int J Primatology), bird surveys (two papers in The Auk and one in Bird Conservation International), whale surveys in geographically-complex regions (J Cetacean Res & Mgt), aerial surveys of seabirds (J App Ecol), and acoustic surveys (Biological Reviews).

As a result of this extensive dissemination, our *Distance* software and distance sampling methods are used for a wide range of surveys. In an editorial in J Appl Ecol[S7], the large number of citations to the paper describing *Distance* software (Thomas et al., 2010) is noted, and the editors state: "This academic impact is likely to translate into improved assessment of population densities by scientists worldwide and thence to better management decision-making." Here, we list just a few surveys that use our methods and software. For cetaceans, these include ongoing cetacean surveys conducted by NOAA in North America (e.g.[S8]) and under the auspices of the International Whaling Commission. Examples of surveys of endangered populations, for which abundance estimates are needed both to assess the risk of extinction and to monitor the success or otherwise of management action, and for which we developed tailor-made methods, include cotton-top tamarins (first large-scale surveys, results published in *Nature Communications* in 2010); passive acoustic surveys of North Pacific right whales (published in *Endangered Species Research* in 2011); and Key Largo woodrat surveys (published in *Methods in Ecology and Evolution* in 2012). Large-scale terrestrial surveys include the Pan Africa Great Ape Program (launched in 2010) and the ongoing Monitoring the Illegal Killing of Elephants Project. In the UK, the ongoing national Breeding Bird Survey (http://www.bto.org/volunteer-surveys/bbs) is analysed using our methods[S9].

Acoustic distance sampling methods are beginning to see wide use – e.g. the US$1.5m DECAF project (completed 2011) was jointly funded by the US government environmental regulation agency NOAA and by the International Association of Oil and Gas Industries, as the methods are needed for monitoring seismic exploration and oil production fields. Our methods also form the basis of the €4.2 million EU-Life funded SAMBAH project (started 2010), which aims to use a grid of 300 static acoustic monitoring devices to estimate, for the first time, density and distribution of the endangered Baltic harbour porpoise population.

The US Office of Naval Research has sponsored the *Distance* software, and continues to fund the development of acoustic survey methods. The Head, Marine Science Branch, Energy and Environmental Readiness Division, US Navy[S1] comments: "The CREEM group's work on survey design and analysis has found widespread application in addressing important research and environmental stewardship issues by several US federal Government agencies, including the Navy … a sign of the strength and merit of *Distance* is the adaptability of distance methods to the assessment of environmental risk from a wide range of human activities, including naval training and exercise. … The CREEM group's clever and innovative adaptations of distance methods to passive acoustic sensing has opened an entirely new and highly exciting field of research and environmental monitoring that will pay huge dividends for decades to come. … Thank you for this opportunity to document the tremendous impacts that distance methods and the combined expertise of the CREEM group have had on the way the US Navy, and many others, now address their environmental stewardship responsibilities …"

The Chief Science Advisor and Director of Scientific Programs at the US National Marine Fisheries Service (NOAA)[S2] confirms the importance of our work in enabling them to complete mandatory assessments: "Under the US Marine Mammal Protection Act, NOAA Fisheries is mandated to

maintain marine mammal populations … You … have had a profound impact on our ability to fulfil our mandates through your research, software development and support, and training. The software *Distance* is used throughout our organization … Your research on acoustic applications of distance sampling and double-observer surveys has been particularly important …"

The Head of Science, International Whaling Commission[S3], confirms the impact of our work on the conservation and management of cetacean populations: "Key developments by CREEM scientists, together with incorporation of these developments into later versions of your software, have ensured that abundance estimation for most stocks is now relatively uncontroversial. … the work of CREEM on matters related to cetacean abundance estimation using distance sampling techniques has been of immeasurable value to our work and cetacean conservation. The theoretical and practical developments that have arisen from CREEM scientists represent a remarkable degree of innovation from a single group. In my opinion this is unrivalled by any other group working in the field. The impact on the conservation and management has been profound and I look forward to continued collaboration between us in the future."

The Director, Conservation Support at the Wildlife Conservation Society[S4], notes that they use our methods and software to assess diverse populations, including elephants, great apes and other species at risk of poaching in Central Africa, primates, ungulates and cranes in Asia, and cetaceans in Africa and Asia. He concludes: "We pride ourselves in using rigorous science to inform our conservation work. The continuously improving wildlife estimation techniques and associated software that results from the research done by you and your colleagues at St Andrews helps us to do this well."

The Scientific Secretary, North Atlantic Marine Mammal Commission[S5], comments: "… work carried out at CREEM has had a significant impact on the efficiency of stock management within the NAMMCO countries. Reliable and improved methods for providing estimates of abundance … form the essential tool using which NAMMCO scientists provide management advice on the stocks under NAMMCO jurisdiction."

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

[S1]Letter on file from Head, Marine Science Branch, Energy and Environmental Readiness Division, US Navy, Pentagon.
[S2]Letter on file from Chief Science Advisor and Director of Scientific Programs at the US National Marine Fisheries Service (NOAA).
[S3]Letter on file from Head of Science, International Whaling Commission.
[S4]Letter on file from Director, Conservation Support at the Wildlife Conservation Society.
[S5]Letter on file from Scientific Secretary, North Atlantic Marine Mammal Commission.
[S6]*Distance* home page. http://www.ruwpa.st-and.ac.uk/distance/. Confirms number of registered users as over 30,000. See http://www.ruwpa.st-and.ac.uk/distance/distanceusers.html for a summary of use and http://www.ruwpa.st-and.ac.uk/distance/distancelist.html for the distance sampling listserver, with over 800 members.
[S7]Milner-Gulland, E.J., Barlow, J., Cadotte, M.W., Hulme, P.E., Kerby, G. and Whittingham, M.J. (2012) Ensuring applied ecology has impact. *Journal of Applied Ecology* 49, 1-5. DOI: 10.1111/j.1365-2664.2011.02102.x Confirms that our methods lead to better decision-making in the management of wild animal populations.
[S8]Gerrodette, T., Taylor, B.L., Swift, R., Rankin, S., Jaramillo-Legorreta, A.M. and Rojas-Bracho, L. (2011) A combined visual and acoustic estimate of 2008 abundance, and change in abundance since 1997, for the vaquita, *Phocoena sinus*. *Marine Mammal Science* 27, E79-E100. DOI: 10.1111/j.1748-7692.2010.00438.x Confirms use of our methods in NOAA surveys to help manage marine mammal populations.
[S9]Newson, S.E., Evans, K.L., Noble, D.G., Greenwood, J.J.D. and Gaston, K.J. (2008) Use of distance sampling to improve estimates of national population sizes for common and widespread breeding birds in the UK. *Journal of Applied Ecology* 45, 1330–1338. DOI: 10.1111/j.1365-2664.2008.01480.x Confirms use of our methods in the UK Breeding Bird Survey.