Institution: University of St Andrews

Unit of Assessment: B10 – Mathematical Sciences

Title of case study: New statistical methods result in better marine environmental monitoring and impact assessment

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

Researchers at the University of St Andrews have changed the way environmental monitoring and impact assessment data are collected and analysed, particularly in the marine environment. We have developed new statistical models of wildlife population dynamics that, for example, form the basis for population assessment of most of the world's grey seals, allowing the UK and Canadian governments to implement effective management of the populations. Other research carried out by us has led to reformulation of the recommended standard statistical practice for impact assessment in the UK marine renewables industry, enabling marine regulators such as Marine Scotland to make better-informed licensing decisions concerning large-scale offshore renewable energy developments.

2. Underpinning research (indicative maximum 500 words)

At the University of St Andrews, the Centre for Research into Ecological and Environmental Modelling (CREEM) has been at the forefront of developing realistic "hidden process models" for animal population dynamics, which allow the major sources of uncertainty to be incorporated in inference (e.g.[1,2,3]). Work in this area started in 1993, when Prof ST Buckland was appointed. This resulted in deer management models, developed in collaboration with BioSS and the Macaulay Land Use Research Inst (now the James Hutton Inst), used to guide Scottish deer managers on culling levels. Dr KB Newman (Senior Lecturer, 2001-06, now US Fish and Wildlife Service) brought considerable expertise in this field, and at the same time, Dr L Thomas (Reader, appointed 1997) first became involved in modelling the dynamics of grey seal populations in work commissioned by Defra.

Prior to our work, realistic population models could be built, but not fitted to data in a rigorous manner; alternatively, models could be fitted to data, but they were necessarily too simple to be realistic. Our framework allows multiple diverse sources of information to be incorporated in a consistent manner, including expert opinion, which is vital when management decisions must be made about species for which little concrete information exists. The models (largely) use Bayesian inference; we have developed fitting methods based on Markov chain Monte Carlo[3] and on particle filtering[1,2], and have compared the two[2]. Key challenges that have been overcome, after the initial framework was developed, include developing general but reasonably fast fitting algorithms, extensions to allow model selection, and incorporating animal dispersal.

Since 2008, we have built a team to develop improved methods for assessing marine environmental impact. The key people in the team are Dr ML Mackenzie (Lecturer, appointed 2003), Dr EA Rexstad (Research Fellow, appointed 2005), Buckland and Thomas.

Assessment of environmental impact at marine renewable sites involves the analysis of survey data to look for evidence of either overall declines or redistribution of animals in the area (or both). Therefore, reliable quantification of any environmental impacts requires statistically-sound surface-fitting methods that accurately describe both the temporal magnitude and spatial range of impacts. Challenges include the requirement to account for missed animals during the surveying, small sample size, poor survey design, and the fact that sites designated for marine renewables (such as undersea turbines and wind farms) often have complex topography with abrupt local changes in animal density. Motivated by this and other applications, a research group led by Mackenzie developed during the REF period spatial smoothing methods[4] that respect complex study region boundaries, being based on geodesic ("as the animal swims") distance between points, rather than Euclidean distances. These methods allow the amount of smoothing to vary spatially, making them more flexible than standard approaches.

Until recently, the only reliable approach for collecting environmental impact assessment data was a visual shipboard or aerial survey along random transect lines – both of which are expensive to undertake. We have evaluated the use of digital survey methods, in which high-resolution digital

images are obtained from aircraft flying at higher altitude than is possible for visual surveys. These methods are now replacing visual survey methods for seabirds affected by offshore wind farm developments[5]. We have also explored the potential contribution of passive acoustics in these sites[6], which offer greater cost-effectiveness. This work has been led by Buckland and Thomas.

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

[1]Buckland, S.T., Newman, K.B., Fernández, C., Thomas, L. and Harwood, J. 2007. Embedding population dynamics models in inference. *Statistical Science* **22**, 44-58. DOI: 10.1214/088342306000000673.

This output was submitted to RAE2008 under UoA22, for which the unit scored 2.65 overall for publications, with 95% of outputs scored at 2* or greater.

[2]Newman, K.B., Fernández, C., Thomas, L. and Buckland, S.T. 2009. Monte Carlo inference for state-space models of wild animal populations. *Biometrics* **65**, 572-583. DOI: 10.1111/j.1541-0420.2008.01073.x

[3]King, R., Morgan, B.J.T., Gimenez, O. and Brooks, S.P. 2010. *Bayesian Analysis for Population Ecology*. CRC Press, Boca Raton. ISBN: 9781439811870. Available from the University library.

[4]Scott Hayward, L.A.S., MacKenzie, M.L., Donovan, C.R., Walker, C.G. and Ashe, E. 2013. Complex Region Spatial Smoother (CReSS). Journal of Computational and Graphical Statistics. DOI: 10.1080/10618600.2012.762920. Posted online 23 Jan 2013.

[5]Buckland, S.T., Burt, M.L., Rexstad, E.A., Mellor, M., Williams, A.E. and Woodward, R. 2012. Aerial surveys of seabirds: the advent of digital methods. *J. App. Ecol.* **49**, 960-967. DOI: 10.1111/j.1365-2664.2012.02150.x.

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

Outputs 2, 3 and 4 best indicate the quality of the research.

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

Population dynamics modelling

Our framework for modelling wildlife population dynamics, as detailed in section 2, has been applied to inform a range of real-world management scenarios involving multi-million pound industries, including red deer (UK), pacific salmon (USA) and the red grouse-hen harrier system (UK). Buckland was invited to participate in a Royal Society of Edinburgh inquiry into the future of the Scottish fishing industry; the resulting report[S3] made a number of recommendations, several of which have since been implemented. However, we focus on applications to grey seals, where our methods form the basis for management of most of the world's populations. In the UK, grey seals are a controversial conservation success story: they were the first mammal given statutory protection (in 1914) following historical over-harvesting; numbers have increased substantially and now support a large eco-tourism industry, but this has also brought conflict with both the fishing and the fish-farming industries. Management is led by an independent panel of scientists convened by NERC, the Special Committee on Seals. They meet annually and provide management recommendations, as well as answering specific questions posed by UK and Scottish government[S4]. Estimates of population size, trajectory and other management-relevant parameters come from a population dynamics model developed within CREEM, updated annually (including throughout 2008-2013) with new survey information. The other globally significant population occurs in Eastern Canada; there the methods developed for UK seals were adapted by members of CREEM to fit the different population dynamics and survey methods. These methods are used by the management agency (Canadian Department of Fisheries and Oceans) for population assessment, and also to determine sustainable levels of harvest, should a commercial harvest for this species be re-started.[S5]

The Deputy Chief Scientific Adviser and Head of Marine Evidence at Defra writes: "Under the 1970 Conservation of Seals Act, the Natural Environment Research Council has a statutory obligation to provide the UK government with '…scientific advice on matters related to the management of seal populations'. This advice is provided annually by a panel of experts – the Special Committee on Seals. A major component of the advice is up-to-date information on the size and distribution of UK seal populations – information provided each year by the University of St Andrews Sea Mammal Research Unit in collaboration with CREEM. The Bayesian state-space modelling methods developed by CREEM … are instrumental in providing an estimate of total

population size from annual survey data. They represent the state-of-the art in the field … Outputs from the models are viewed with confidence by all stakeholders and in our view are a unique and integral component of the advice to the Scottish Executive Environment and Rural Affairs Department (SEERAD) and the Department for Environment Food and Rural Affairs (Defra). Overall the advanced population dynamics modelling methods developed at CREEM have made a very considerable contribution to Defra's ability to determine the population status of UK grey seal populations, and to quantify uncertainty in these determinations. This has, in turn, contributed to assessing 'Favourable Conservation Status' for important seal populations – an EU requirement under the Habitats Directive." [S1]

State-space models are being used with increasing frequency to characterise the population dynamics of salmon, delta smelt, and other fish species in the western United States, and to provide guidance for assessing the effects of management actions. Methods developed at St Andrews have allowed more realistic, and hence more reliable, modelling to be conducted. The US Fish and Wildlife Service used our methods in 2008-2010 to develop improved life cycle models for Chinook salmon, and to assess the effects of management actions (particularly the effects of water exports, and reductions in these exports) on delta smelt populations[S6].

Monitoring the impact of renewable energy developments

Our spatial modelling (and associated) methods have had particular impact within the marine renewables industry. Offshore wind, tidal and wave energy is intended to produce 20% of UK electricity by 2020. However, the development and operation of energy installations has the potential to impact wild animal populations in the area, and developers are required to conduct environmental assessments as part of the permitting process, as well as ongoing monitoring. We have formulated UK-wide acceptable practice for survey design and analysis in this area based on work commissioned by Marine Scotland. We have also advised government regulators, advisory bodies, energy development companies and environmental consultants. We delivered a half-day workshop to representatives of the windfarm industry in London in November 2010, developed an EPSRC-funded 4-day workshop on impact assessment in offshore renewable energy development in June 2011, attended by 33 individuals, and offered a training workshop in St Andrews in September 2013, attended by 30 individuals. Attendees represent regulators (e.g. Marine Scotland, JNCC, SNH), conservation bodies (e.g. RSPB, BTO), consultancy companies and power companies.

The influence of our work on decisions of whether to license offshore renewable energy developments is indicated in a letter from the Marine Renewable Energy Programme Manager at Marine Scotland (Scottish Government body), which states[S2]: 'We scrutinise licence applications for evidence that energy developers … have provided robust estimates of abundance of seabirds and/or cetaceans. Marine Scotland commissioned CREEM to provide a guidance document on best practice for the design and analysis of baseline surveys of the distributions of birds and mammals and subsequent environmental impact assessments … of marine renewable energy developments. As a result, CREEM-based research outputs now form a central part of the recommended statistical analysis for impact assessment in the Scottish marine renewables sector. … We consider that the CREEM group is an authoritative source of advice on marine survey and data analysis in support of renewable energy developments …. Robust data analysis is providing sound foundations for both licensing decisions and for the definition of impact monitoring programmes.'

Two UK companies use methods, developed in collaboration with us during 2008-2010, for surveying seabirds using high-resolution imagery: HiDef (who use high-resolution video) and APEM (who use high-resolution stills). Both companies now routinely use the methods to quantify seabird abundance in areas proposed for large-scale offshore wind farms. Thaxter and Burton[S7] report on the Carmarthen Bay study, designed and analysed by us, and in which both companies participated, together with WWT Consulting, to compare and evaluate different survey methodologies.

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

[S1]Letter on file from the Deputy Chief Scientific Adviser to Defra.
[S2]Letter on file from the Marine Renewable Energy Programme Manager at Marine Scotland.
[S3]RSE press release. 2014. Independent inquiry makes key recommendations for the sustainable future of the Scottish fishing industry. See

http://www.royalsoced.org.uk/134_IndependentInquirymakeskeyrecommendationsfortheSustainableFutureoftheScottishFishingIndustry.html
This press release clarifies the importance of the inquiry recommendations for the future of the Scottish Fishing industry.

[S4] Special Committee on Seals. 2012. Scientific advice on matters related to the management of seal populations: 2012. See http://www.scotland.gov.uk/Topics/marine/marine-environment/species/19887/20814/22139 for information on SCOS and http://www.smru.st-andrews.ac.uk/documents/1199.pdf for the 2012 report.
Confirms contribution of our modelling in shaping advice to the UK and Scottish governments.

[S5] Department of Fisheries and Oceans. 2011. Stock assessment of Northwest Atlantic grey seals (*Halichoerus grypus*). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2010/091. See http://www.dfo-mpo.gc.ca/CSAS/Csas/publications/sar-as/2010/2010_091_e.pdf
Confirms contribution of our modelling in shaping advice to the Canadian government.

[S6] Maunder, M.N., and Deriso, R.B. 2011. A state-space multistage life cycle model to evaluate population impacts in the presence of density dependence: illustrated with application to delta smelt. *Can. J. Fish. Aquat. Sci.* **68**, 1285-1306. DOI: 10.1139/F2011-071.
Confirms use of our methods for assessing delta smout populations in California.

[S7] Thaxter, C.B. and Burton, N.H.K. 2009. High Definition Imagery for Surveying Seabirds and Marine Mammals: A Review of Recent Trials and Development of Protocols. COWRIE/BTO report, available at http://www.coastalkent.net/data/news/downloads/COWRIE%20High%20Definition%20Imagery%20Final%20Report%2020091130.pdf.
Confirms our input to methods adopted by HiDef and APEM.