Institution: University of St Andrews

Unit of Assessment: 5 – Biological Sciences

Title of case study: Animal-borne telemetry tags for conservation and weather forecasting

1. Summary of the impact

The Sea Mammal Research Unit (SMRU) in St Andrews designs, builds and supplies instrumentation and software essential for marine mammal tracking. Specific impacts are:

- Direct economic benefit arising from the production of around 400 telemetry tags per annum, employing 8 highly skilled staff with turnover of £5.6M since 2008.
- Companies in UK and USA supplying tag components have received over £2M since 2008.
- Tags on Monk seals and Steller Sea Lions have enabled conservation of these endangered species whilst minimising economic hardship to fishermen.
- Tags on elephant seals in the southern oceans have improved Global Ocean circulation models significantly, leading to better weather forecasting and consequent economic benefits to shipping, oil and gas companies.

2. Underpinning research

The impact has been derived from fundamental research by **Lovell** (in post since 1997), **McConnell** (in post since 1996), **Fedak** (in post since 1996), **Boehme** (lecturer since 2012) and co-workers at the Sea Mammal Research Unit (SMRU) at the University of St Andrews in the use of space by marine mammals, especially seals. The at-sea behaviour of seals is challenging to study. Many species spend up to 90% of their lives underwater, often at great distances from land. Thus there is a need to develop technology and software to provide data that resolves the movement of animals in three dimensions from any location on the planet. This required sufficient accuracy of location and a capacity to transmit the data from the animal itself because in most cases there is no possibility of recovering information from an archive tag by re-capturing the animals. Consequently the Sea Mammal Research Unit at St Andrews has been developing instruments with this capability and these began to produce research results in the late 1990s **[1].**

The technical challenges of building an instrument that would perform appropriately were substantial. These can be summarised as follows: instruments had to (a) be robust enough to survive the physical abuse from being attached to large marine mammals for periods of months to years; (b) withstand near-constant immersion in seawater; (c) be resistant to hydrostatic pressures down to that found at 2000 metres depth and to cope with pressure changes from 1-200 atmospheres 10-20 times per day; (d) carry a power supply (and power management system) sufficient to collect data and then transmit the data to an orbiting satellite over periods of months to years; (e) carry and power enough environmental and movement sensors to sufficiently characterise the behaviour of the animal, its location and its environment; (f) be sufficiently small to not be a significant burden to the study animal.

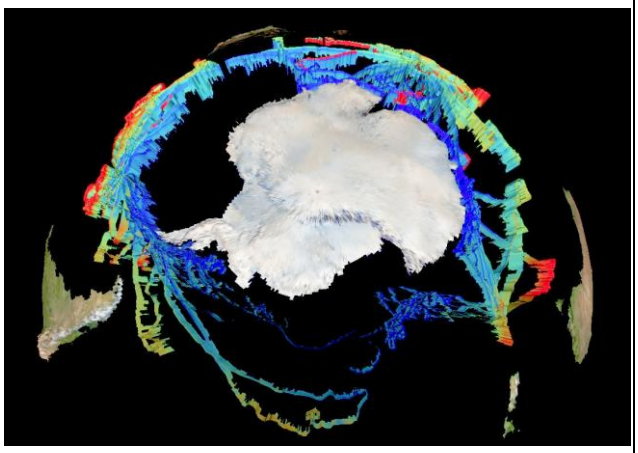


Figure 1. Elephant Seals have provided temperature profiles from the southern ocean (image generated using MAMVIS)

The innovations within the instruments developed to support SMRU's research represent some of the key underpinning research of this project. This included the need to develop dedicated software to allow visualisation of data, addressed by the MAMVIS software in 1996, which is freely available for researchers (http://www.smru.st-andrews.ac.uk/Instrumentation/DataProcessing/#mamvis). In 2001-02, novel algorithms to

compress data were developed, reducing power drain on batteries, which allowed smaller or longer-lived tags to be deployed **[2]**. This research activity also allowed the locational errors inherent in the ARGOS satellite system to be measured, to the benefit of many other research groups around the world **[3]**. The instruments have also been used imaginatively to develop a proxy measurement of deep ocean productivity by measuring relative changes in the feeding success of deep-diving seals using buoyancy changes resolved from the vectors of force in the vertical movement of seals in the water column. In work published in 2003 the detection of 'drift dives' and thus changes in buoyancy (=blubber stores) in southern elephant seals permitted the identification of their Antarctic foraging grounds with clear implications for conservation **[4]**. The development of novel sensors within the tags, especially to allow the long-term measurement of conductivity, allowed the deployment of animal-borne oceanographic sensors that provide real-time environmental data from some of the most inaccessible parts of the globe such as the Southern Ocean **[5]** (Figure 1). In parallel with the technical advances, SMRU has developed new statistical analysis tools and methods that maximise the derived information content of the telemetry data **[6]**.

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

St Andrews contributors in BOLD. Employment dates in St Andrews: Biuw 2000-2007; Boehme 2007-present; Fedak 1996-present; Hammond 1996-present; Hunter 1992-2003; Lovell 1997-present; Matthioupoulos 1997-2012; McConnell 1996-present

SMRU in St Andrews has published 546 papers in this area in the period 1996-2013, with over 10,000 citations, of which the following are a representative cross-section with application to this case study. These are all published in international, peer reviewed journals.

[1] McConnell, BJ, Fedak, MA, Lovell, P, Hammond, PS (1999) Movements and foraging areas of grey seals in the North Sea. J. Appl. Ecol. 36: 573-590 DOI: 10.1046/j.1365-2664.1999.00429.x. (88 citations).

[2] Fedak, MA, Lovell, P, McConnell, B, Hunter, C (2002) Overcoming the constraints of long range radio telemetry from animals: Getting more useful data from smaller packages. Int. Comp. Biol. 42: 3-10 DOI: 10.1093/icb/42.1.3. (61 citations).

[3] Vincent C, **McConnell BJ,** Ridoux V, **Fedak MA** (2002) Assessment of Argos location accuracy from satellite tags deployed on captive gray seals Marine Mammal Science 18, 156-166. DOI: 10.1111/j.1748-7692.2002.tb01025.x (119 citations).

[4] Biuw, **M, McConnell**, **B**, Bradshaw, CJA., Burton, H & **Fedak**, **MA** Blubber and buoyancy: monitoring the body condition of free-ranging seals using simple dive characteristics. *J. Exp. Biol.* **206**, 3405-3423 (2003). DOI: 10.1242/jeb.00583 (58 citations).

[5] Biuw, M., Boehme, L., Guinet, C., Hindell, M., Costa, D.; Charrasin, J.-B., Roquet, F., Bailleul, F., Meredith, M., Thorpe, S., Tremblay, Y., McDonald, B., Park, Y.-H., Rintoul, S.R., Bindoff, N., Goebel, M., Crocker, D., **Lovell, P.**, Nicholson, J., **Monks, F.**, **Fedak, M.A.** (2007) Variations in behaviour and condition of a Southern Ocean top predator in relation to *in situ* oceanographic conditions. Proc Natl Acad Sci USA, 104 (34). 13705-13710. DOI: 10.1073/pnas.0701121104 (112 citations).

[6] Aarts, G, MacKenzie, M, **McConnell, B, Fedak, MA, Matthioupoulos, J** (2008). Estimating space-use and habitat preference from wildlife telemetry data. Ecography 31: 140-160 DOI: 10.1111/j.2007.0906-7590.05236.x (64 citations).

4. Details of the impact

The development of marine telemetry technology and associated underpinning research by the SMRU in St Andrews has resulted in 3 main areas of impact in the REF period:

a) Direct economic impact from turnover totalling £5.6 million.

b) Conservation of endangered species such as the Monk Seal and Steller Sea Lion.

c) Improvements in operational oceanography contributing to weather forecasting and ocean prediction with consequent economic benefits.

a) Direct economic impact from tag production

SMRU builds 300-400 telemetry tags per year and has generated a financial turnover of £5.6M in the REF period. This sustains 8 technical staff and engineers and funds new development work to maintain the instruments at the leading edge of the fast-moving field of technology **[S2]**. Companies in the UK and USA have benefited by developing and supplying specialised components for the tags made in St Andrews, with sales totalling £2.03M in the period 2008-13 **[S3]**.

b) Conservation of species, marine spatial planning and species management

The instruments have been used by a total of 44 institutions from 15 countries world-wide (Fig 2) **[S4]**. The instruments are used by national agencies to build their knowledge of endangered or threatened species, especially the habitat they need to sustain themselves. This allows judgements to be made about the regulation of offshore industrial developments, including fisheries. Specific examples include:

Figure 2. Global distribution of SMRU CTD tag customers.

Hawaiian monk seal: In 2010-11, the instruments enabled the compliance monitoring for the US Navy in its offshore ranges in the Hawaiian Islands **[S5]**. It is a legal requirement that the US Navy shows that it is not disturbing the highly endangered Hawaiian monk seal and the instruments have been used to track monk seals to determine the extent to which there is overlap between the range over which seals forage and the regions in which US Naval exercises take place. By avoiding areas frequented by monk seals, the Navy was able to pursue offshore exercises without harming the species.

Steller Sea Lion: The instruments have been used to determine the "critical habitat" for Steller sea lions in the Aleutian Islands to provide the information necessary to reduce the probability of negative effects of fishing on the food supply for this endangered species. It is a legal requirement under the US Endangered Species Act to define critical habitat for species classified as endangered. This work was carried out by the US National Marine Fisheries Service (NMFS) using SMRU tags. The resulting Steller sea lion protection measures were set out in a draft environmental impact statement by the NMFS in 2013 **[S6]**.

Columbia River Inter Tribal Commission: SMRU tags were used to track California sea lion movements to prevent damage to tribal fishing gear and stealing fish from tribal nets (2013) (www.critfc.org)

Oregon Dept of Fish and Wildlife: SMRU tags were used to track movements of Steller sea lions to assess impact on fishery stocks in multiple states along the Columbia River (2010) (www.dfw.state.or.us)

Pacific States Marine Fisheries Commission: SMRU tags were used to assess the impact of seal populations on the fisheries industry (2010) (www.psmfc.org)

Pendoley Environmental Marine Conservation Environmental Services: SMRU tags were used to track offshore turtles to aid conservation efforts (2011) (www.penv.com.au)

Zoological Society London: SMRU tags were used to monitor the health of Thames Harbour seals to gain insight into their diet (2012) (www.zsl.org)

c) Operational oceanography contributing to weather forecasting and ocean prediction:

Seal-borne instruments that measure conductivity and temperature during the ascent and descent portions of an animal's dive can provide information equivalent to that of ARGO floats or ships. In

some circumstances – especially in polar regions where ice cover often precludes measurement of oceanographic profiles using conventional methods, seal-borne data are input to the Global Ocean Observing System (GOOS). GOOS is an international backbone for oceanographic products and services and is the principle focus for international cooperation in operational oceanography.

Data from seal-borne instruments are automatically relayed to the World Meteorological Organization's Global Telecommunication System (GTS). Since 2008, over 300,000 CTD profiles from seals tagged with SMRU instruments have been incorporated into the World Ocean Database providing 56% of all oceanographic CTD profiles available for the Southern Ocean south of 60 °S **[S7]**. According to an independent oceanographic expert in this area, quantification of the impact of SMRU CTD tag data on the ECCO ocean model (one of the main global ocean circulation models) was significant:

> "*the use of seal data improved significantly (by up to 30%) the representation of ocean circulation south of the Antarctic Circumpolar Current in the seasonally ice covered subpolar zone, increasing the consistency of the modelled sea-ice distribution*" **[S1]**.

Figure 3. CTD tag on Southern elephant seal.

These models are utilised by a variety of marine industries and services, including shipping (fuel savings through optimal routing), oil and gas industries– in addition to meteorological forecasting. The combined impact of improved weather forecasting on these activities is naturally very difficult to quantify. However, in Australia alone, the commercial value of Global Ocean Observing Systems to such industries and services was estimated in 2006 as over A$ 600 million annually **[S8]**.

5. Sources to corroborate the impact

[S1] Letter from an independent oceanographic expert at the Department of Meteorology, Stockholm University. Corroborates improvement in weather forecasting due to SMRU-designed animal-borne tags.

[S2] Audited statement of SMRU instrumentation group turnover and production in the REF period 2008-13.

[S3] Audited list of invoices for SMRU instrumentation group.

[S4] List of institutions supplied with tags by SMRU instrumentation group 2008-13.

[S5] Habitat Use and Behavioral Monitoring of Hawaiian Monk Seals in Proximity to the Navy Hawaii Range Complex. Report Period: August 2010 - July 2011. Department of the Navy, 2011 Annual Range Complex Monitoring Report for Hawaii and Southern California, Appendix M. See P 284. Corroborates Navy compliance policy.
http://www.navymarinespeciesmonitoring.us/files/2413/4749/5443/2011-HRC-SOCAL-annual-monitoring-report_HRC_appendix-m.pdf

[S6] Steller Sea Lion Protection Measures Environmental Impact Statement (EIS). Corroborates proposed protection measures for Steller sea lions in fisheries off Alaska.
http://alaskafisheries.noaa.gov/sustainablefisheries/sslpm/eis/

[S7] Corroborates number of animal-borne CTD profiles in Southern Ocean. extract APB profiles at http://www.nodc.noaa.gov/OC5/SELECT/dbsearch/dbsearch.html

[S8] Economics of Australia's sustained ocean observation system, benefits and rationale for public funding. Report by the Australian Academy of Technological Sciences and Engineering, (page 40). Corroborates financial value of the GOOS to the Austrailian economy.
http://imos.org.au/fileadmin/user_upload/shared/IMOS General/documents/external_reports/Economics_of_Australia_a_Sustained_Ocean_Observation_System_1_.pdf

Institution: University of St Andrews

Unit of Assessment: 5 – Biological Sciences

Title of case study: Mitigating environmental impacts of naval Sonar

1. Summary of the impact

Research by St Andrews scientists studying the effects of naval Sonar on marine mammals has had the following international impacts:

- **on the environment** by developing new ways to manage environmental risks of anthropogenic sound on marine mammals,
- **on public policy and defence** as research evidence changed US and European policy and criteria on impacts of Sonar on marine mammals, allowing US and European Navies to continue sonar training with reduced risk to whales,
- **on commerce** as a new product with a current sales value of £3.5 million has been commercialised to help navies to predict and manage risk to marine mammals.

2. Underpinning research

Marine mammals are difficult to study as they spend most of their lives underwater, often travel large distances in 3 dimensions and frequently have low population densities. St Andrews researchers at the Sea Mammal Research Unit (SMRU) including Professors **Ian Boyd**, **Phil Hammond**, **John Harwood** & **Peter Tyack** and Dr **Patrick Miller** have developed methods to overcome these difficulties, allowing research to evaluate the impact of threats such as anthropogenic sound on wildlife populations. They developed a theoretical approach to environmental risk assessment that involves identifying hazards, probability of exposure to the hazard, estimating the effects produced by different levels of exposure, and evaluating the benefits of different strategies to manage the risk **[1]**. The ability to estimate exposure to the hazard was enabled by the improvement at St Andrews of survey methods, generally involving visual identification, to estimate marine mammal population density and distribution **[2]**. A second crucial development in 2009 was the application of passive acoustic monitoring (PAM) to estimate the distribution and abundance of marine mammals **[3]**. This overcame the limitations of previous methods of visual identification for species that spend most of their lives underwater.

In 2004, St Andrews scientists articulated a new methodology designed to allow measurement of the effects of different levels of sound exposure on a marine mammal for the first time **[4]**, providing critical data to establish acoustic dose: behavioural response functions in the field. Using these methods, SMRU led major field experiments in 2007-08 to quantify effects of naval sonar on beaked whales. The major documented lethal effect of underwater sound on marine mammals has involved mass strandings of beaked whales during naval sonar exercises **[5]**. Therefore beaked whales formed a critical subject species for these experiments. Their cryptic deep-diving lifestyle necessitated the use of tags to record sound exposure and behavioural responses of individual animals throughout their dive cycle. Free-ranging beaked whales were exposed to simulated sonar sounds of US Navy anti-submarine sonars and the behaviour of the animals was measured against a carefully titrated dose of sound. Responses of beaked whales to simulated sonar were observed at exposure levels of about 140 dB re 1 µPa **[5]**.

These research methods have been extended to study the behavioural responses of other marine mammal species. **Miller** and **Tyack** are co-PIs of an experiment called 3S to determine the dose-response of several whale species in Norwegian waters to sonars deployed by the Dutch and Norwegian navies. This project used advanced physiological models to analyse dive responses of tagged whales of several species during controlled exposure experiments, allowing for the first time estimates of the risk of decompression sickness for whales exposed to sonar **[6]**.

3. References to the research

St Andrews contributors in BOLD. Employment dates in St Andrews: Professor Boyd 2001-present; Professor Hammond 1996-present; Professor Harwood 1996-present; Dr Marques 2007-present; Dr Thomas 1997-present; Dr Miller 2002-present; Dr Thompson 1996-present; Professor Tyack 2011-present

SMRU in St Andrews has published 546 papers in this area in the period 1996-2013, with over 10,000 citations (Scopus), of which the following are a representative cross-section with application to this impact. These are all published in international, peer-reviewed journals.

[1] Harwood, J. (2000) Risk assessment and decision analysis in conservation. *Biological Conservation* 95: 219-226 DOI: 10.1016/S0006-3207(00)00036-7. (46 citations).
[2] Hammond, PS, Berggren, P, Benke, H, Borchers, DL, Collet, A, Heide-Jørgensen, MP, Heimlich, S, Hiby, AR, Leopold, MF & Øien, N (2002). Abundance of harbour porpoises and other cetaceans in the North Sea and adjacent waters. *Journal of Applied Ecology* 39: 361-376. DOI: 10.1046/j.1365-2664.2002.00713.x (130 citations).
[3] Marques TA, Thomas L, Ward J, DiMarzio N, Tyack PL. (2009) Estimating cetacean population density using fixed passive acoustic sensors: An example with Blainville's beaked whales. *Journal of the Acoustical Society of America* 125:1982-1994. DOI: 10.1121/1.3089590 (48 citations).
[4] Tyack P**,** Gordon J, **Thompson D.** (2004) Controlled exposure experiments to determine the effects of noise on large marine mammals. *Marine Technology Society Journal* 37(4):41-53 DOI: 10.4031/002533203787537087 (10 citations).
[5] Tyack PL Zimmer WMX, Moretti D, Southall BL, Claridge DE, Durban JW, Clark CW, D'Amico A, DiMarzio N, Jarvis S, McCarthy E, Morrissey R, Ward J, **Boyd IL** (2011) Beaked Whales Respond to Simulated and Actual Navy Sonar. *PLOS ONE* 6: e17009 DOI: 10.1371/journal.pone.0017009 (30 citations).
[6] Kvadsheim PH, **Miller PJO, Tyack PL**, Sivle LD, Lam FPA, Fahlman A. (2012) Estimated tissue and blood N_2 levels and risk of in vivo bubble formation in deep-, intermediate- and shallow diving toothed whales during exposure to naval sonar. *Frontiers in Aquatic Physiology* 3(125):1-14. DOI: 10.3389/fphys.2012.00125 (3 citations).

4. Details of the impact

Impacts derived from the underpinning research include the removal of obstacles to naval training in anti-submarine warfare whilst reducing risk to whales and supporting development of a commercial product to manage risk of sounds from naval activities.

Enabling US Navy Sonar Operations whilst protecting marine mammals.
Evidence that Sonar can lead to lethal strandings of whales led to legislative and judicial restrictions on military sonar use. From 2001-2008, courts in the US repeatedly judged that the US Navy had not conducted adequate environmental reviews. The courts issued injunctions limiting the use of Sonar, which interfered with the navy's ability to train for anti-submarine warfare and to maintain readiness against submarine attacks **[S4]**.
In 2008 a court case involving naval Sonar training in Southern California waters was heard by the US Supreme Court **[S5]**. After these legal actions, the Navy committed to prepare Environmental Impact Statements (EIS) for Sonar use. The St Andrews research on the distribution of beaked whales and effects of exposure to anthropogenic noise made it possible to estimate the inherent risks. As the Deputy Assistant Secretary of the Navy (DASN) stated in 2013,

> "(St Andrews) *research assessing exposure and effects of sonar for beaked and other whales has provided the scientific bases for Environmental Impact Statements (EIS) for US Navy training and testing activities*" **[S1]**

These Environmental Impact Statements were approved by the regulator in the years following 2008, allowing the US Navy to operate naval sonars. Quoting DASN:

> "*The results of the research conducted by the St Andrews faculty and staff have played a vital role in the deliberations of the US Navy and the Navy's regulator, the National Marine Fisheries Service, to establish new behavioural risk criteria for anthropogenic sound exposure risk to beaked whales and other marine mammals*" **[S1]**

Beaked Whales Mass Stranded in the Canary Islands during a Naval Sonar Exercise in 2002 [credit: Vidal Martin]

Subsequent to the demonstration that beaked whales show strong responses to Sonar at levels of 140 dB re 1 µPa (reference 5 above), the US Navy modified its response criterion for beaked whales to this lower level to reduce the risks of exposure to harmful sound **[S6]**. In the period 2008-12 there have been no documented cases of mass strandings linked to US Navy Sonar **[S7]**.

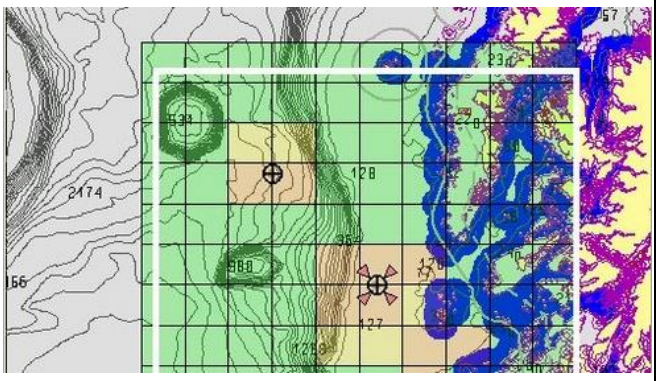
Mitigating the environmental harm caused by EU Navy Sonar

The St Andrews research has also had a direct impact on the operational practices of several European Navies. Uncertainty as to what exposures are risky, and lack of adequate monitoring and mitigation methods led the European Parliament to pass a resolution in 2004 calling for a moratorium on the use of intense naval sonar until this problem was resolved **(EU resolution 86-0089/2004).** The European Union Marine Strategy Framework Directive (MSFD), adopted in 2008, requires each member state to achieve good environmental status of their marine habitats, including the requirement that "*introduction of energy (including underwater noise) does not adversely affect the ecosystem*." **[S8]**. The Head of Marine Advice for the UK Joint Nature *Conservation* Committee states that:

> *"Particularly important St Andrews studies include those involving Patrick Miller, Ian Boyd and Peter Tyack demonstrated the reaction of whales to these underwater sounds … may lead to lethal physiological effects. This understanding has been crucial in the setting of policies by a number of Navies that will reduce the risk of further deaths. The research has also been important in gaining perspectives that have avoided over-regulation."* **[S2]**

SAFESIMM

A Navy cannot be effective without the use of Sonar. Since the operation of Sonar is an unavoidable activity, UK regulations require monitoring of marine mammals within a danger zone by Naval vessels. St Andrews research on marine mammal distribution allows predictions about animal densities in different areas around the globe to be made. This underpinning St Andrews science has led to the development of an established product: Statistical Algorithms for Estimating the Sonar Influence on Marine Megafauna (SAFESIMM) **[S9]**. SAFESIMM models marine mammal distribution and abundance, dive and movement behaviour, and sensitivity to sound and has been licensed to BAE Systems, which uses it as part of its Marine Environmental Risk Management Capability. SAFESIMM forms part of the 2117 sonar used by the Royal Navy for planning sonar exercises and used by commanders to judge the level of risk associated with planned



Safesimm screen capture from BAE systems website.

Sonar operations. If the risk is too high the tool presents a series of mitigation activities that can be used to reduce the level of risk and meet the requirements of UK and EU legislation. The Commercial Manager of Combat Systems for BAE Systems Maritime estimates the value of SAFESIMM on BAE sales to be "*of the order of £3.5 million based on the current contract value*". **[S3]**

In the words of the Head of Marine Advice for the UK Joint Nature Conservation Committee:

> *"St Andrews researchers have developed techniques for establishing the presence of marine mammals in an area using passive monitoring for underwater sounds made by the mammals. These techniques are now part of standard mitigation (…) during naval exercises in UK and some other EU waters."* **[S2]**

5. Sources to corroborate the impact

[S1] Letter from the Deputy Assistant Secretary of the US Navy (Environment). Corroborates impact of St Andrews research on Navy's ability to use Sonar.

[S2] Letter from Head of Marine Advice for the Joint Nature Conservation Committee. Corroborates impact of St Andrews research on standard mitigation during naval exercises internationally.

[S3] Email from the Commercial Manager, combat systems, BAE Systems Maritime – Naval Ships. Corroborates value of SAFESIMM contracts.

[S4] US Court injunction against the use of Sonar due to threats to marine mammals. http://cdn.ca9.uscourts.gov/datastore/opinions/2008/02/29/0855054o.pdf

[S5] US court case on naval Sonar in Californian waters. Winter v. Natural Resources Defense Council, 555 U.S. (2008). http://supreme.justia.com/cases/federal/us/555/07-1239

[S6] (2012) Criteria and Thresholds for U.S. Navy Acoustic and Explosive Effects Analysis. US NAVY SSC Pacific Technical Report. Corroborates change in Navy policy in response to known risk to marine mammal. http://www.dtic.mil/dtic/tr/fulltext/u2/a561707.pdf

[S7] Marine Mammal Strandings Associated with U.S. Navy Sonar Activities (2012). Corroborates no known strandings linked to naval Sonar in 2008-12. www.agriculturedefensecoalition.org/sites/default/files/file/us_navy/217_1_2012_U.S._Navy_Marine_Mammal_Strandings_Associated_With_U.S._Navy_Sonar_Activities_Website_April_2012_Draft_EIS_OEIS.pdf

[S8] Report from the Commission to the Council and the European Parliament. Contribution of the Marine Strategy Framework Directive (2008/56/EC) to the implementation of existing obligations, commitments and initiatives of the Member States or the EU at EU or international level in the sphere of environmental protection in marine waters. COM(2012) 662 final.

http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2012:0662:FIN:EN:PDF

[S9] SAFESIMM product described in http://www.baesystems.com/product/BAES_027473?_afrLoop=286444596923000

Institution: University of St Andrews

Unit of Assessment: 5 – Biological Sciences

Title of case study: Enabling Industry compliance with offshore regulation

1. Summary of the impact

Research on the distribution, abundance and sensitivity to disturbance of marine predators has been translated into environmental and economic benefits via a series of spin-out companies with a global presence. The research enabled the following impacts:

- PAMGuard software enables the oil and gas industry to conduct seismic surveys within legal environmental limits, saving the industry ~$100M per annum.
- The licensing of the world's first grid-connected tidal stream power station (SeaGen) in Strangford loch and offshore developments in the wind-power industry.
- The progress of major engineering projects, including bridges (Forth Crossing and Hong Kong to Macao) and port extensions (Vancouver).

Direct company earnings were ~£6 million turnover in the assessment period and this supported 24 employees two-thirds of whom are skilled specialists.

2. Underpinning research

The research conducted at the University of St Andrews by Professors **Boyd**, **Harwood**, **Hammond** and colleagues has focussed upon resolving the general hypothesis that marine predators can be used as indicators of the state of the marine ecosystems **[1]**. This is driven by the concept that system complexity limits predictive capacity and that, in exploited systems, there is a need for high-level indicators of system state which can then be managed within a risk-based, adaptive framework. The research was focused on solving the problems associated with the capture of high quality, predictive data on marine predator populations from a very challenging experimental system: the ocean. These challenges were overcome using a spectrum of advances in data gathering, data analysis and interpretation.

Research on the distribution and abundance of marine wildlife was developed using three approaches:

a) distance sampling, which is a statistical method developed in St Andrews that allows visual observation of marine mammals from ships or aircraft to be used to estimate abundance using a robust statistical procedure **[2].**

b) detailed tracking of individual animals using electronic tags developed in St Andrews **[3]**.

c) the development of passive acoustic methods for detection and classification of marine animals **[4]**.

Calculation of total animal populations from each of these methods has required the development of statistical methods that allow inference about their use of space **[3, 5]**. The development of these methods was driven in part to answer the question "*What is the abundance and distribution of marine mammals over the European continental shelf?*" In other words, the creation of a robust distribution map for the species (fig 1). Hammond led a Europe-wide project using greatly enhanced technology developed in St Andrews to survey whales, dolphins and porpoises in the European Continental Shelf (SCANS II in 2006; http://biology.st-andrews.ac.uk/scans2/).

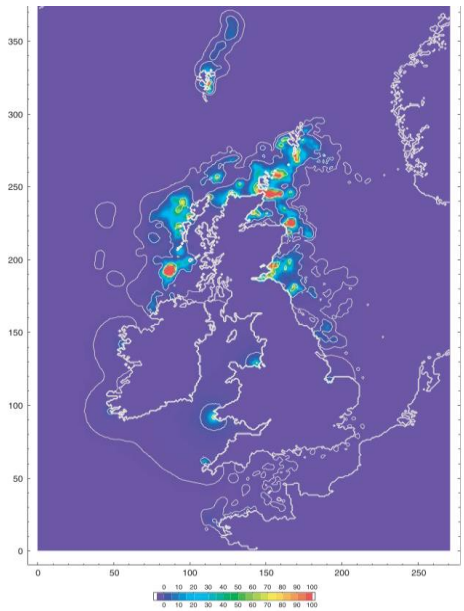


Figure 1. Grey seal population distribution at sea [3].

Building on this work, we tackled the question: "*How does species abundance and distribution change through time?*" Spatial information was gathered repeatedly to add a temporal component to better understand the dynamics of habitat use. The information has been used to improve the methods for defining areas with consistent high animal

abundance, which predicts high quality habitat **[3, 6]** (fig 1)**.** These habitats form the basis for suggestion of protected areas for animals or their food supplies **[6]**. In addition, this spatial information has provided the foundation data for risk assessment and risk management of marine offshore activities in the presence of high uncertainty **[7]**.

3. References to the research

St Andrews contributors in BOLD. Employment dates in St Andrews: Borchers 1993-present; Boyd 2001-present; Buckland 1993-present; Duck 1996-present; Fedak 1996-present; Hammond 1996-present; Harwood 1996-present; Hooker 2001-present; Matthiopoulos 1997-2012; McConnell 1996-present.

These are all published in international, peer-reviewed journals.

[1] Boyd IL & Murray AWA (2001) Monitoring a marine ecosystem using responses of upper trophic level predators. J. Animal Ecol. 70, 747-760. DOI: 10.1046/j.0021-8790.2001.00534.x (66 citations).

[2] Borchers DL, **Buckland ST**, Goedhart PW, Clarke ED and Hedley SL (1998) Horvitz-Thompson estimators for double-platform line transect surveys. Biometrics 54, 1221-37. DOI: 10.2307/2533652 (64 citations).

[3] Matthiopoulos, J., McConnell, B.J., Duck, C.D., Fedak, M.A. (2004) Using satellite telemetry and aerial counts to estimate space use by grey seals around the British Isles. J. Appl. Ecol. 41: 476-491 DOI: 10.1111/j.0021-8901.2004.00911.x (34 citations).

[4] Evans, P.G.H., **Hammond, P.S.** (2004) Monitoring cetaceans in European waters. Mammal Review 34: 131-156 DOI: 10.1046/j.0305-1838.2003.00027.x. (63 citations).

[5] Hammond, P.S.; Berggren, P.; Benke, H.; et al. (2002) Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. J. Appl. Ecology 39: 361-376 DOI: 10.1046/j.1365-2664.2002.00713.x. (141 citations).

[6] Hooker, S.K., Gerber, L.R. (2004) Marine reserves as a tool for ecosystem-based management: The potential importance of megafauna. Bioscience 54: 27-39 DOI: 10.1641/0006-3568(2004)054[0027:MRAATF]2.0.CO;2. (82 citations).

[7] Harwood, J. (2000) Risk assessment and decision analysis in conservation. Biological Conservation 95: 219-226 DOI: 10.1016/S0006-3207(00)00036-7. (46 citations).

4. Details of the impact

The underpinning research carried out by SMRU on the abundance, distribution and behaviour of marine mammals has been translated during the REF period to enable a wide range of commercial activity that impinges on the marine environment to take place. The benefits are both environmental and economic and the beneficiaries include marine wildlife, renewable energy companies, oil and gas companies and major engineering projects.

a) SOI Group Ltd: products and services

The main impact of the research has been delivered through the establishment of 6 spin-out companies (SOI Ltd, SMRU Ltd, Marine Instrumentation Ltd, SMRU Ltd (Canada), SMRU Ltd (USA) and SMRU Ltd (Hong Kong)) operating under the umbrella company SOI Group Ltd. These are the translational mechanism used to deliver products, in the form of bespoke instruments and software, and services, in the form of advice about environmental impacts or data analysis, to a broad range of customers including oil and gas companies, electrical utilities, and developers such as The Crown Estate in the UK. More than 70 industry customers have been serviced since 2008. Direct company sales totalled ~£6 million (2008-2012) with a compound annualised growth rate of 16% and this supported 24 employees (with 16 skilled specialists) **[S6]**. Products derived from the research include:

i) Environmental impact assessments **[S6]**; ii) data collection, management and analysis **[S6]**; iii) **PAMGuard** open access software for acoustic detection of marine mammals, recognised by the Technical Director of the International Association of Oil and Gas Producers as a "*highly successful product*" that is "*now widely used in the industry across the world*" **[S5]**. iv) **PAMBuoy** for the automated detection and transmission of data concerning underwater acoustic targets in the marine environment.

b) Managing risks of anthropogenic marine noise in EU waters

The European Union Marine Strategy Framework Directive (MSFD) of 2010 requires each

member state to achieve good environmental status of their marine habitats, including the requirement that "*introduction of energy (including underwater noise) does not adversely affect the ecosystem.*" **[S7]**

In some circumstances, intense sound generation is unavoidable. Regulations require these activities to desist when marine animals are present within a danger zone. The development of real-time passive acoustic monitoring (**PAMGuard**) allows detection of marine mammals in many circumstances where they cannot be sighted. In the words of the Head of Marine Advice for the UK Joint Nature Conservation Committee in 2013:

> *"St Andrews researchers have developed techniques for establishing the presence of marine mammals in an area using passive monitoring for underwater sounds made by the mammals. These techniques are now part of standard mitigation around seismic surveys (…) in UK and some other EU waters."* **[S4]**

Oil and Gas Industries

The beneficial impact of PAMGuard on both marine life and the operating costs of the offshore oil and gas industries has been clearly stated by the President of the International Association of Geophysical Contractors in 2013:

> "*it is usually a condition of operating licenses that operators mitigate potential negative effects of seismic surveys on marine mammals. This tool not only allows operators to comply with their licenses, but to also minimize potential negative effects on any marine mammals in the vicinity. The (PAMGuard) tool has evolved into a highly successful product that enables a wide range of operators in the global offshore oil and gas sector to conduct seismic surveys to the satisfaction of regulators.*
>
> *It can cost >$500k per day to operate our most complex and involved surveys. We have documented cases where PAMGuard has saved many days of downtime on such surveys. In such cases its use has resulted in millions of dollars in savings. While not all surveys are this elaborate and expensive, we conservatively estimate that on a global scale,* ***PAMGuard saves hundreds of days of down-time each year, resulting in downtime savings approaching $100 million per year****. This estimate does not include the cost that could be incurred if operating licences were withheld due to inability to effectively mitigate potential negative effects from our operations. Indeed there are some circumstances in which the industry would simply be unable to operate effectively without PAMGuard."* **[S3]**

Renewable energy

The underpinning research allows measurement of marine mammal location and abundance before, during and after commission of offshore energy installations. The translation of the research has enabled renewable energy operators to comply with the requirements of environmental regulations. The Crown Estate is charged with developing the marine estate (seabed) around the UK and as such is a "*major facilitator for the development of renewable energy from the marine environment*" **[S1]**. The Chef Scientist for The Crown Estate asserts that "*the long-term activities of SMRU, as a genuine world centre of excellence in the understanding of marine mammals, continue to be very important to the Crown Estate's business*" and that "*the on-going efforts at St Andrews to understand the population consequences of developments is particularly important at this time*" **[S1]**. SMRU Ltd (UK) has used this to supply environmental impact assessments and mitigation of potential impacts of the offshore wind industry and the emerging tidal power generation industry **[S2]**. Examples of impact include the delivery of pre-development assessments for the Aberdeen Wind Farm (*AOWDC Vattenfall*), Forth and Tay wind farms (*InchCape Offshore Ltd*), and the tidal arrays at Ramsey Sound (*Tidal Energy Ltd*), Sound of Islay (*SSE renewables*) and Anglesey, Kyle Rhea, and the Pentland Firth for *MCT Ltd* **[S6]**.

SeaGen – the world's largest operational tidal stream turbine.

Marine Current Turbines (MCT) developed the world's first commercial scale tidal-stream power station, which was installed in April 2008 in Strangford Lough, Northern Ireland (fig 2). As a new technology, perceived environmental risks could easily have halted the project. SMRU developed and implemented the environmental risk management for marine mammals. This included undertaking monitoring of the engineering activities during installation and operation using a novel active sonar to detect marine mammals and thus avoid collisions. An independent report by DTZ Consulting in 2011 stated that SMRU "*played a crucial role in reassuring the regulator that the risk to marine mammals from the installation of the turbine would be low, allowing the project to go*

ahead." **[S8]**. SMRU provided the evidence required for a successful defence of infraction proceedings (essentially prosecution of a member state for infringing European Law) initiated by the European Commission. This evidence was used "*to reassure the EC that environmental interests in the area are being respected*." **[S8]**. As a result the EC dropped the infraction.

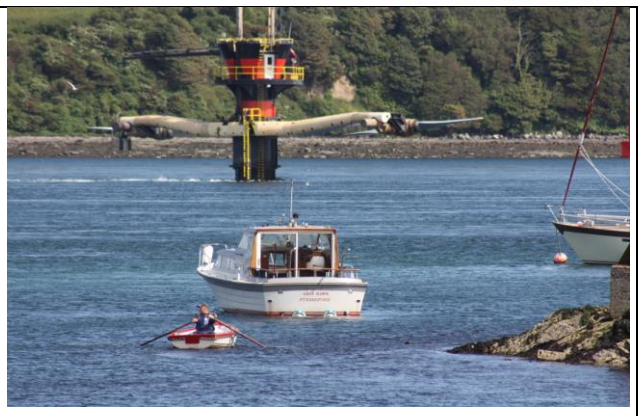


Figure 2. SeaGen installed at Strangford Lough

This project represents a "*huge step in de-risking SeaGen and making it a more attractive proposition for large-scale investors in the future*." **[S8]**. MCT has recently been bought by Siemens and now plans to deploy 500-1000 SeaGens in UK Waters by 2020. The MCT Business Development Director envisages "*a similar kind of support from SMRU for developments at Anglesey, Kyle Rhea and the Pentland Firth*" **[S2]**.

Current Major Engineering Projects [S6]

SOI Group Ltd is delivering environmental impact assessments, monitoring and risk management advice for a number of current major engineering projects. These inputs are an essential component of these construction projects, mandated by legislation from state authorities to minimise the environmental risks.

The Hong Kong – Macao Bridge. This 54 km bridge threatens the endangered population of Chinese White Dolphins. SOI Group has deployed PAMBuoy technology to provide assurance of minimal disturbance to dolphin populations.

The New Forth Road Bridge. This is currently under construction and one condition imposed by the Government is that underwater noise levels be controlled to protect salmon and lampreys. SOI Group have installed PAMBuoy technology to measure underwater noise levels in real-time on site, allowing engineers to act should the noise thresholds be breached.

Vancouver Metro Harbor. The extension of this harbour by 25% could threaten the resident population of Orca (Killer Whales). Construction beginning in summer 2013 utilises PAMBuoy technology to mitigate this danger.

5. Sources to corroborate the impact

[S1] Letter from the Chief Scientist of Crown Estates. Corroborates importance of SMRU research for offshore developments in REF period.

[S2] Letter from the Business Development Officer, Marine Current Turbines. Corroborates relationship with SMRU.

[S3] Letter from the President of the International Association of Geophysical Contractors, Houston, Texas. Corroborates importance of PAMGuard to offshore industry with value $100 million per year.

[S4] Letter from the Head of Marine Advice for the Joint Nature Conservation Committee. Corroborates role of SMRU in developing standard mitigation techniques for offshore developments.

[S5] Letter from the Technical Director of the International Association of Oil and Gas Producers. Corroborates reach and significance of PAMGuard software for offshore companies.

[S6] Statement from SOI (Group) Ltd reporting operational details, staff numbers etc.

[S7] Report from the Commission to the Council and the European Parliament. Contribution of the Marine Strategy Framework Directive (2008/56/EC) to the implementation of existing obligations, commitments and initiatives of the Member States at EU or international level in the sphere of environmental protection in marine waters. (p2, footnote 2 point 11). http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2012:0662:FIN:EN:PDF

[S8] Economic assessment by DTZ corroborating importance of SMRU research on successful deployment of SeaGen and in de-risking activities of Marine Current Turbines.

Institution: University of St Andrews

Unit of Assessment: 5 – Biological Sciences

Title of case study: Marine Mammal Conservation: from policy to bycatch reduction

1. Summary of the impact

The research resulted in primary legislation and provided government with the evidence used when implementing the measures set out within legislation. Specifically, this concerned:

- Enabling effective conservation of marine mammals in UK, EU and international waters
- Defining UK and EU policy objectives for marine mammal conservation
- Delivering UK obligations arising from EU legal instruments
- Reducing marine mammal bycatch by over 90% in key fisheries

This work, together with connected public outreach, was awarded the Queen's Anniversary Prize in 2011 for excellence in research supporting better governance of the ocean.

2. Underpinning research

The following research was undertaken at the University of St Andrews in the period 1996-2013 by Sea Mammal Research Unit (SMRU) researchers including Professors **Boyd** and **Hammond**; Dr's **Hall**, **Lonergan**, **McConnell**, **Northridge** and others (details in section 3).

This research has focussed on the accurate measurement of marine mammal populations and distributions in UK and EU waters. Marine mammals spend most of their lives under water and are typically highly mobile; they are thus inherently difficult to study. This has necessitated the development of new technologies, data collection and statistical analysis methodologies to ensure that estimates of population abundance and mortality rates are robust. This maximises the ability of end users such as Governments, NGOs and the fishing industry to enact policy and implement changes to achieve conservation aims.

Key research-led advances that were developed by St Andrews scientists have included the development of methods for "sparse data sampling" from boats or aircraft, to give robust estimates of marine mammal population density and distribution **[1]**. The development of new telemetry technology from the late 1990s has allowed individual animals to be tagged and their behaviour and movements logged and recovered via satellite **[2]** and more recently via mobile phone technology.

Some specific examples from St Andrews' research on marine mammals include:

Harbour seal decline

Using techniques for the collection and analysis of "sparse data sampling", SMRU scientists have accurately quantified the decline in populations of harbour seals in UK waters in the period 2000-07 **[3]**. This research demonstrated that populations were dropping significantly in diverse locations from Shetland to the Wash, but were stable or increasing in the Hebrides, with consequences for marine policy.

Rogue seals in the Moray Firth

In the Moray Firth seals have been shot due to the perception that they impact on salmon stocks and thus the local economy. Research in the period 2005-08 using photo sampling of seals combined with analysis of their diets suggested that only a small number of rogue seals specialising in river feeding were responsible **[4]**. Targeting individual seals in rivers is thus a more effective management option, whilst protecting seal populations.

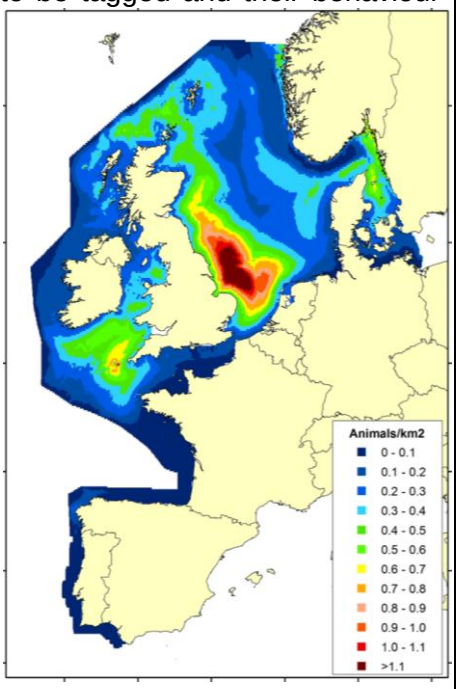


Figure 1. Predicted density of harbour porpoise in 2005.

Quantifying and assessing the importance of marine mammal bycatch
In 2006, a global analysis by SMRU scientists and collaborators highlighted the bycatch of marine mammals in fisheries as the main threat to their conservation status **[5]**. For policymakers to address this threat and take effective action, robust estimates of marine mammal abundance over relevant (large) spatial scales, coupled with estimates of bycatch mortality, are essential. In the period 2004-2009 SMRU led two major European projects (SCANS-II and CODA) that established the benchmark for collection and analysis of data to estimate the abundance of cetacean species (Figure 1) and to define associated safe limits to bycatch **[6]**.

3. References to the research

St Andrews contributors in bold. Employment dates in St Andrews: Borchers 1993-present; Boyd 2001-present; Burt 1996-present; Duck 1996-present; Fedak 1996-present; Gillespie 2005-present; Gordon 2000-present; Graham 2005-2010; Hammond 1996-present; Harwood 1996-present; Harris 1999-present; Hooker 2001-present; Lonergan 2001-present; Lovell 1997-present; Mackey 2005-2010; Macleod 2002-present; McConnell 1996-present; Northridge 1997-present; Paxton 2001-present; Swift 2005-present; Thompson 1996-present.

SMRU in St Andrews has published 546 papers in this area in the period 1996-2013, with over 10,000 citations, of which the following are a representative cross-section with application to this impact. These are all published in international, peer-reviewed journals.

[1] Hammond, PS, Berggren, P, Benke, H, **Borchers, DL**, Collet, A, Heide-Jørgensen, MP, Heimlich, S, Hiby, AR, Leopold, MF & Øien, N (2002) Abundance of harbour porpoises and other cetaceans in the North Sea and adjacent waters. Journal of Applied Ecology 39: 361-376. DOI: 10.1046/j.1365-2664.2002.00713.x (130 citations).

[2] McConnell, B.J., Fedak, M.A., Lovell, P., Hammond, P.S. (1999) Movements and foraging areas of grey seals in the North Sea. J. Appl. Ecol. 36: 573-590 DOI: 10.1046/j.1365-2664.1999.00429.x. (91 citations).

[3] Lonergan, M., Duck, C.D., Thompson, D., Mackey, B.L., Cunningham, L.**, Boyd, I.L.** (2007) Using sparse survey data to investigate the declining abundance of British harbour seals. J. Zoology 271: 261-269 DOI: 10.1111/j.1469-7998.2007.00311.x (25 citations).

[4] Graham, I.M., Harris, R.N., Matejusova, I. & Middlemas, S.J. (2011) Do rogue' seals exist? Implications for seal conservation in the UK. Animal Conservation 14: 587-598, DOI 10.1111/j.1469-1795.2011.00469.x. (7 citations).

[5] Read, A.J., Drinker, P. & **Northridge, S.P.** (2006) Bycatch of marine mammals in US and global fisheries. Conservation Biology. 20(1):163-169. DOI: 10.1111/j.1523-1739.2006.00338.x (106 citations).

[6] Hammond, P.S., **Macleod, K.**, Berggren, P.**, Borchers, D.L.**, **Burt, M.L.**, Cañadas, A., Desportes, G., Donovan, G.P., Gilles, A., **Gillespie, D.**, **Gordon, J.**, Hiby, L., Kuklik, I., Leaper, R., Lehnert, K., Leopold, M., **Lovell, P.**, Øien, N., **Paxton, C.G.M.**, Ridoux, V., Rogan, E., Samarra, F., Scheidat, M., Sequeira, M., Siebert, U., Skov, H., **Swift, R.**, Tasker, M.L., Teilmann, J., Van Canneyt, O. & Vázquez, J.A. (2013) Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation 164: 107-122. DOI: 10.1016/j.biocon.2013.04.010.

4. Details of the impact

This impact case study relates to important changes in marine policy at the local, national and international levels in the period 2008-13. Policy has been informed and underpinned by the research carried out by SMRU in St Andrews since 1996, which has allowed sea mammal behaviour, abundance and distribution to be understood to a robust degree. The main impact areas are:

- Enabling effective conservation of marine mammals in UK, EU and international waters
- Defining EU policy objectives for marine mammal conservation
- Delivering UK obligations arising from EU legal instruments
- Reducing marine mammal bycatch by over 90% in key fisheries

Conservation of Seals in UK Waters

SMRU has a critical role undertaking the research that underpins Government policy in relation to seals. The Scottish Government highlighted in 2012 the

> "*vital work undertaken by SMRU in support of the development of Scottish Government policy on seal management*" **[S1]**.

In the Moray Firth, conflicts arising between fishermen and seals led to widespread shooting of seals. SMRU research showed that specific 'rogue' seals were responsible, suggesting that a targeted response was crucial to the co-management of this seal-fishery conflict. The Scottish Government **[S1]** has recognised that research by SMRU was "*instrumental in the success*" of the **Moray Firth Seal Management Plan** (MFSMP) which was a landmark agreement forged between all interested parties. The result was a "*dramatic reduction* (~60%) *in seal shooting in the area*" **[S1]**. The success of the MFSMP led to the development, successful drafting and progression to legislation of the **Marine (Scotland) Act 2010 [S6],** which relied heavily on the seal research carried out by SMRU. It introduces a new system within Scotland for licensing of the removal and disturbance of seals and for placing protective measures on seals when that is deemed necessary. This licensing scheme has "*greatly improved the ability of Ministers to protect seals*" according to the principal marine advisor to Scottish Natural Heritage **[S2]**. The Scottish Government has acknowledged

> "*The research undertaken by SMRU has informed all these important policy developments*" **[S1]**.

Defining EU policy objectives for marine mammal conservation

SMRU's research has been instrumental in the development of policy on marine mammal conservation at an EU level, such as the **Marine Strategy Framework Directive (MSFD)** (2010) **[S7]**, as marine mammal population trajectories and bycatch levels are key targets and indicators for defining 'good environmental status' for the seas around our coastline. The Head of Marine Advice for the UK Joint Nature Conservation Committee stated in 2013:

> "*St Andrews research has been particularly effective and therefore influential on policy and policy implementation. I chaired EU level groups that examined the scientific evidence around these issues that has led to policy changes and in doing so was able to assess and draw upon St Andrews (and other) research. I thus feel in a good position to assess the relative importance of the St Andrews work*." And continued:
> "*The St Andrews work in particular helped to underpin EU Regulation 812/2004 and subsequent amendments. This regulation has undoubtedly helped to reduce small cetacean bycatch within EU waters. It has also allowed the setting of suitable targets to describe Good Environmental Status under the EU's Marine Strategy Framework Directive*." **[S3]**

Delivering obligations arising from UK and EU legal instruments

The EU Habitats Directive (1992) and MSFD (2010) place legal obligations on Member States to assess and report on the conservation status of their marine mammal populations. These directives form the basis of national marine environmental planning in the UK. The underpinning research required to meet these obligations is delivered by SMRU. In particular, the large-scale abundance surveys (SCANS, SCANS-II and CODA) developed robust methodology that has become the "gold standard" and has been widely emulated in surveys of the waters of other European countries. The large majority of the information on cetacean distribution and abundance used by the UK to report under Article 17 of the Habitats Directive **[S8]** was generated by these SMRU-led surveys. Other EU countries bordering the Atlantic Ocean have also made extensive use of this information.

A DEFRA spokesperson commented:

> "*Through its coordination of the Europe-wide SCANS and CODA surveys, SMRU has played a notable role in the subsequent determination of the conservation status of cetacean species to be determined for European Atlantic waters, which is a requirement for all relevant EU Member States under Article 17 of the Habitats Directive.*" **[S4]**

In 2013, Scottish Natural Heritage said:

> "*The joint objectives of maintaining 'favourable conservation status' and 'good environmental status' in the context of European directives is integral to the conservation objectives set out in the Scottish Marine Plan. The research done by SMRU sustains our ability to uphold those objectives for some of the most highly valued conservation assets.*" **[S2]**

Reducing bycatch

Under the EU Habitats Directive, MSFD, Council regulation 812/2004, the UK is required to reduce marine mammal bycatch to levels that are sustainable. To address these obligations, SMRU has implemented an observer scheme on UK fishing boats to quantify bycatch. Furthermore, SMRU has identified and helped to implement specific acoustic deterrent devices (Pingers) that have been effective in reducing cetacean bycatch by over 90% from over 400 animals in 2004/5 to just a handful in 2010-12 in the Pair-trawl bass fishery in the English Channel **[S4]**. SMRU research has also shown that Pingers deployed in the Cornish Offshore Gillnet fishery in the period 2009-12 can reduce porpoise bycatch by over 90%, and since July 2013 the UK Marine Management Organisation is enforcing this use of Pingers in this fishery. A DEFRA spokesperson stated in 2013:

> *"The new approaches developed by SMRU on bycatch limits for small cetaceans have been adopted as the de facto European standard for other Member States to achieve conservation goals."* **[S4]**

The Head of Marine Advice for the UK Joint Nature Conservation Committee states that:

> *"The St Andrews work led by Simon Northridge on bycatch of cetaceans in fisheries is world class. The UK is widely praised as having a state of the art bycatch observer scheme, that has worked well with the fishermen stakeholder community, and has also been influential in developing techniques for minimising that bycatch. When carrying out this sort of practical research, it is absolutely critical to be sensitive to the concerns and problems facing the fishermen, and the St Andrews team has been exemplary in this regard. This work has been published in papers and in reports, but the contributions through the ICES and EU Expert groups should not be overlooked as they are crucial to policy and policy development in the EU."* **[S3]**

Finally, the Head of Science at the International Whaling Commission stated in 2013:

> "*I would just like to state that the work of SMRU on matters related to cetacean conservation and management has been of immeasurable value to our work and to cetacean conservation. The theoretical and practical developments that have arisen from SMRU scientists represent a remarkable degree of innovation from a single group. The impact on the conservation and management has been profound"* **[S5].**

5. Sources to corroborate the impact

[S1] Letter from the Marine Environment officer of Scottish Government Oct 2012. Corroborates impact of SMRU research on Moray Firth Seal Management Plan, reduction of seal mortality and Marine Scotland act.

[S2] Letter from the principal marine advisor to Scottish Natural Heritage, 15-8-13.Corroborates impact of SMRU research on Scottish Government Policy relating to marine mammals.

[S3] Letter from the Head of Marine Advice, Joint Nature Conservation Committee. Corroborates impact of SMRU research on reduction in bycatch in fisheries, and on formulation of EU policy.

[S4] Letter from the Evidence and Analysis Deputy Director, Marine Directorate, DEFRA Corroborates impact of SMRU research on bycatch and policy.

[S5] Letter from the Head of Science, International Whaling Commission. Corroborates profound impact of SMRU research on cetacean conservation.

[S6] Marine (Scotland) Act 2010.
http://www.legislation.gov.uk/asp/2010/5/pdfs/asp_20100005_en.pdf

[S7] Report from the Commission to the Council and the European Parliament. Contribution of the Marine Strategy Framework Directive (2008/56/EC) to the implementation of existing obligations, commitments and initiatives of the Member States or the EU at EU or international level in the sphere of environmental protection in marine waters. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2012:0662:FIN:EN:PDF

[S8] UK report under Article 17 – http://jncc.defra.gov.uk/page-6387

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.

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.

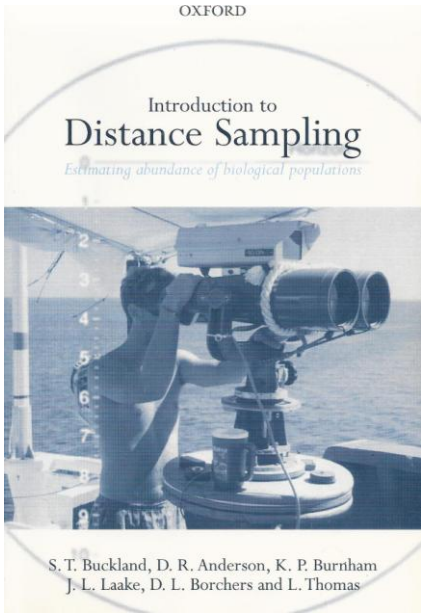
[3]Hedley, S.L. and Buckland, S.T. 2004. Spatial models for line transect sampling. *Journal of Agricultural, Biological and Environmental Statistics* **9**, 181-199. DOI: 10.1198/1085711043578
Selected as best JABES paper, 2004-05.

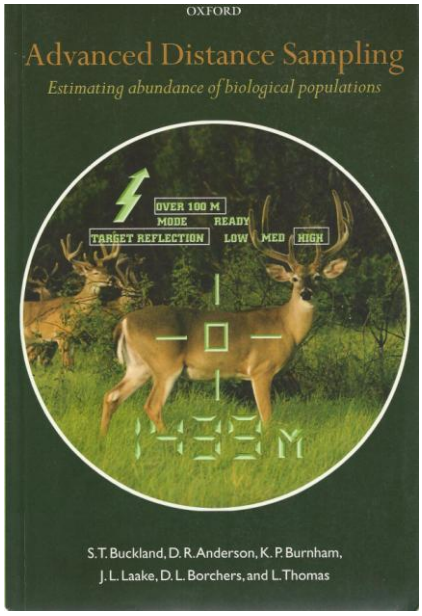
[4]Borchers, D.L., Laake, J.L., Southwell, C. and Paxton, C.G.M. 2006. Accommodating unmodeled heterogeneity in double-observer distance sampling surveys. *Biometrics* **62**, 372-378. DOI: 10.1111/j.1541-0420.2005.00493.x

[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.

Institution: University of St Andrews

Unit of Assessment: 17 – Geography, Environmental Studies and Archaeology

Title of case study: A sea-change in geophysical-marine surveying for protecting our Ocean's future

1. Summary of the impact

Safeguarding our seas through the establishment of marine Special Protection Areas and cultural heritage Seascapes is a fundamental aim of European Union Directives and the UK Marine and Coastal Access Act 2009. Over the past decade, sonar research development led by Dr Bates of the University of St Andrews has had widespread influence on international government and industry through accurate mapping of these assets, championing their importance and establishing new management strategies for their conservation. This work has been pivotal to the creation of 107 of the current legislated European Marine Special Areas of Conservation and Marine Special Protection Areas. The innovations in technology pioneered by this work also are providing critical findings on climate change impacts in the Earth's most sensitive and threatened environments with world media coverage on work in the Arctic including the award-winning TV series Operation Iceberg in 2012. Strong international media involvement has become one of the hallmarks of this work which simultaneously delivers research results as outputs of high quality across the globe. Furthermore, the technology has had economic impact in the form of three spin-out companies.

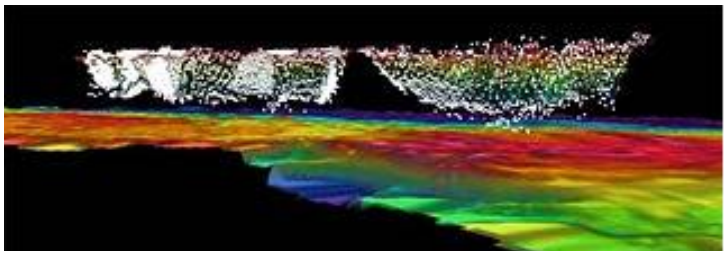
Public awareness of the world's threatened environments drives debate and action on climate change.

2. Underpinning research (indicative maximum 500 words)

Understanding complex systems on the Earth's surface requires a multi-disciplinary approach where information is needed that is both spatially and temporarily extensive. Over the past decade it has become increasingly clear that this coverage can only be made using remote sensing techniques such as provided by geophysical methods. In astronomy and petroleum exploration, for example, this has been achieved, but for other disciplines it has only relatively recently becoming possible. Seismic acoustic methods have been the mainstay of oil and gas exploration for over 40 years, but the last decade has seen important new technology developments based on multicomponent wave fields. Initial investigations on these techniques for characterising fractured gas reservoirs[1] in 2001 led Bates, a researcher at the University of St Andrews since 1996, to develop new methods for the application of acoustic techniques, in particular for multibeam sonar[2] that included imaging techniques, novel deployment and automated processing for very high resolution marine surveying thus producing 3D maps of seafloor and sub-seafloor fabrics, structures and environments. A number of publications ensued which demonstrated their application to multi-disciplinary fields spanning geology, biology, archaeology and environmental science which was used to capitalise publicity for the trial of the techniques for marine conservation management in the UK[2,3]. In subsequent research Bates obtained hitherto unavailable detail on seabed habitats from ship-based measurements across major marine European Special Areas of Conservation that were previously only available in limited diver-based surveys. The success of the methods led to further adaptations for investigation and classification of threatened and protected species sites for deep-water coral in the North Atlantic[3]. In 2008, interest in the research prompted the Smithsonian Tropical Research Institute to ask Bates to test the methodologies at key fishing Protection Zones in the Pacific Central Americas where traditional survey had failed to recognise key seabed habitats. These were successfully characterised using the new methods.

Parallel to the research for biological applications, a programme of investigation into advances in novel sonar technologies for submerged cultural heritage discovery, mapping and monitoring change began in 2002. New automated pattern recognition algorithms for sonar images based on Wavelet Analysis Techniques were developed and tested on artificial and internationally important wreck sites[4]. In addition to increasing the success of correctly identifying marine cultural heritage, the techniques delivered a step-change in resolution of seafloor images, thus forming the basis for defining new protocols for marine cultural heritage surveying as part of long-term site management and protection[5].

Recognition of the utility of sonar techniques for monitoring both short and long-term environmental changes has led in the last three years to experimentation with combining acoustic with laser measuring tools for climate impact studies of marine terminating glaciers in crucial locations such as northern Greenland. In particular for these studies, laser scanning and sonar techniques are simultaneously deployed from bespoke survey craft at extremely hazardous locations to measure rates of calving and melt. This multidisciplinary research led by Bates is finding wide-spread interest in academic studies of glacial retreat[6].



Sonar image: the seafloor is in colour shaded by depth and the icebergs are 'hanging' in the water column.

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

[1]Bates, C. R., Phillips, R., Grimm, R and Lynn, H. 2001. The Seismic Evaluation of a Naturally Fractured Tight Gas Sand Reservoir in the Wind River Basin, Wyoming. Petroleum Geosciences, v. 7, pp. 35-44. DOI: 10.1144/petgeo.7.1.35
Winner of the European Association of Geoscientist and Engineers Best Paper Award for 2001.

[2]Bates, C. R. and Byham, P. 2001. Bathymetric Sidescan Techniques for Near Shore Surveying. The Hydrographic Journal, v. 100, pp. 13-18.
Winner of the Hydrographic Society Best Paper Award.

[3]Roberts, J. M., Brown, C. J., Long, D. and Bates, C. R. 2005. Acoustic Mapping using a Multibeam Echosounder Reveals Cold-water Coral Reefs and Surrounding Habitats. Coral Reefs, v. 24, pp. 654-669. DOI: 10.1007/s00338-005-0049-6
Article was published in a specialist peer-reviewed journal and has 41 citations in WoS.

[4]Atallah, L., Probert Smith, P. and Bates, C. R. 2002. Wavelet analysis of bathymetric sidescan sonar data for the classification of seafloor sediments in Hopvågen Bay - Norway. Marine Geophysical Researches, v. 23, pp. 431-442. DOI: 10.1023/B:MARI.0000018239.07561.76
Article was published in an international peer-reviewed journal.

[5]Bates, C. R., Lawrence, M., Dean, M. & Robertson, P. 2011. Geophysical Methods for Wreck-Site Monitoring: the Rapid Archaeological Site Surveying and Evaluation (RASSE) programme. International Journal of Nautical Archaeology. v 40.2: 404–416. DOI: 10.1111/j.1095-9270.2010.00298.x
Article was published in an international peer-reviewed journal.

[6]Neal, M., Bates, C. R., Blanchard, T. Hubbard, A. and Woodward, J. 2012. A hardware proof of concept for a remote-controlled glacier-surveying boat. Journal of Field Robotics. v29, 6, pp.880-890. DOI: 10.1002/rob.21420
Article was published in a specialist peer-reviewed journal with an impact factor of 3.580.

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

The underpinning research was motivated by government, cross-industry and public need for better methods to monitor, manage, protect and publicise international marine assets, including sensitive habitats with endangered or threatened species, cultural heritage (in particular associated with World Heritage Sites) and critical climate-impacted environments. Sonar methodologies developed by Bates have provided a cornerstone to meeting the needs of government regulators while simultaneously providing the platform for furthering public understanding of the asset

importance of such sites and habitats through a global media effort. Specifically, the methods have been used (1) to define the existence, map the extent and establish the baseline habitat health of new Special Areas of Conservation and Marine Protection Areas (MPA) in Europe and Central America, (2) to provide the means to map, monitor and manage submerged heritage sites in European waters and (3) to record and broadcast to a global audience the changes in critical Arctic regions. In addition, (4) financial impact in the form of three spin-out companies ensuing from engagement efforts have resulted from the research.

Impact on Policy Directives for the Conservation of Sensitive Marine Habitats: The underpinning research conducted in the early 2000s by Bates resulted in commissioned conservation reports for government, for example on special areas of conservation, and through the development of new sonar technologies, the adoption of the technologies in mapping programmes. Following, Bates acted in an external consultant role for the definitive EU project for the mapping of European marine habitats – the MESH Project - "*Dr Bates' work has been instrumental in the adoption of sonar-based technologies for broadscale sea bed surveys into mainstream use…. demonstrating how these products may be applied to policy development and operational delivery ….has bridged that gap between 'standard research' and operational delivery*" [S1]. This ultimately culminated in the adoption of mandatory procedures developed by Bates and colleagues for benthic habitat survey based on the sonar methodologies which, in 2009, were adopted by all principal UK Conservation Organisations (e.g. Natural England, Joint Nature Conservancy Council, Scottish Natural Heritage) for conservation guidelines on habitat mapping that ultimately led to the establishment of over 107 internationally important sites of Special Areas of Conservation and Marine Special Protection Areas. "*These techniques have, and will continue to help in the implementation of the Habitats Directive, and more recently have been fundamental to the deliberations over MSPAs as required by the Marine (Scotland) Act and the delivery of commitments in the Marine Strategy Framework Directive*"[S2]. The sonar methods, which provide key data for the management and thus protection of key designated areas, are now an internationally adopted practice (e.g. fisheries protection research conducted for the Smithsonian Tropical Research Institute, Panama under the Darwin Initiative); they also provide the stunning visualisation widely used for public dissemination of the information, for example with internationally important deep-water coral sites.

Impact on Public Understanding of Marine Cultural Heritage: Since the early successes of the multibeam programme for habitat evaluation, a parallel research stream, as discussed in section 2, was developed for its use in marine cultural heritage sites (wrecks, structures and drowned palaeo-landscapes) appraisal, monitoring and management. This led to research contracts from English Heritage to develop new visualisations and the mandate to adopt specific protocols for monitoring important submerged cultural heritage such as the UK Designated and Protected Wrecks under the Protection of Wrecks Act (1973)[S3]. The site-specific investigations stimulated work on drowned landscapes on the European Shelf that are under increasing threat from climate impacts and development. Here, associated research on the submerged Neolithic remains around World Heritage sites in Orkney and Jersey revealed a lost world that not only caused widespread academic interest by uncovering new insights into early human expansion in Northern Europe but which also captured public imagination through a series of media events. Invited exhibits, included the Royal Society 2012 Summer Science Exhibition which saw over 11,000 visitors, made up of an audience of 15% educational, and 85% general public and media[S8], with Europe's Lost World web and Facebook pages receiving over 38,000 unique hits over the exhibit period. Follow-up related media interest included over 3,360 reporting websites, 477 blog sites and 1630 discussion sites worldwide through 31 July 2013[S9], interviews, as far afield as California and Russia, published articles and commentary. This led to the request for the work to be displayed in the UK's first dedicated Mesolithic to Neolithic hunter-gatherer permanent exhibit housed in an extension to the museum of Tomb of the Eagles, Orkney that receives over 10,000 visitors pa. Media interest has broadened with radio, TV and major articles published in, amongst others, BBC Focus Magazine (average UK circulation, 65k/month) and National Geographic (average US circulation, 5million/month).

Impact on Public Understanding of Critical (Climate) Environments: A complementary dimension that developed from the sonar mapping research was first realised in 2009 with a request from Greenpeace to join their expedition to northern Greenland to use Bates' techniques to

study the rapidly retreating, marine-terminating glaciers and areas of sea-ice melt which are habitats to some of our most threatened species, such as the polar bear. Significant public and governmental attention followed during the Copenhagen Summit, 2009, and with articles for National Geographic (US, Australia and China) and presentations to policy makers during the 2010 Arctic Frontiers conference. The interest in this work continued. In 2012 the BBC2 /Discovery Channel/ BBC Learning commissioned two programmes (BBC2 Operation Iceberg) dedicated to the research, specifically highlighting the sonar and laser scanning advances[S4]. The programmes were broadcast in the UK in Nov 2012, with an audience in excess of 3.5 million and viewing numbers at 50% above slot averages[S4]. Subsequently, it has been broadcast to international audiences through the Discovery Channel, an indication of the strong public interest in the research which also received acclaim by winning the 2012 Royal Television Society Best Science and Natural History Documentary[S4].

Economic Impact: Apart from the evident, yet difficult to account, economic impact resulting from public engagement events as listed above, the sonar research has been used in commercialisation with the establishment of the marine survey division of SOI Ltd, a company dedicated to marine habitat conservation based at the University of St Andrews (sales of over £800k since incorporation) [S7]. In 2008, the novel, high-fidelity acoustic technologies also resulted in the spin-out company, Advanced Underwater Surveys Ltd (ADUS). This company's success was demonstrated in 2013 when Deep Ocean UK, a marine industry leader with turnover in excess of £500Mpa, acquired a 50% stake in the company[S6]. Finally, the survey methodologies developed in early tests led one of Bates' students in mid-2011 to establish GeoSurv Ltd UK, an independent dedicated marine survey company that posted a first-year turnover of over £100k[S5].

The sonar developments and their adoption across a wide spectrum of applied marine spheres has had major national and international reach over the past 10 years, as manifest by increased widespread use of the methods, and has informed the attitude and awareness to significant global environmental and heritage issues by both government and the wider public. Further, the sonar developments have unlocked key information that is being used to reduce potential harm to environments and heritage sites with the establishment of Marine Protection Areas and Heritage Protection Sites, helping to preserve them for future generations.

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

Conservation – directly quoted in text

[S1]Head of Marine Protected Areas, JNCC
[S2]Principal Advisor (Marine), Scottish Natural Heritage

Submerged Cultural Heritage – direct use of research in the management of submerged heritage
[S3]Head of Maritime Archaeology, English Heritage

Climate Impact – Glacial Retreat
[S4]Executive Producer, BBC2 Operation Iceberg (http://www.bbc.co.uk/programmes/p00tvcnx) – Documentary Series statistics
[S5]GeoSurv Ltd UK (http://geosurvuk.com/) verification of spin-out company
[S6]Advanced Underwater Surveys Ltd, (ADUS - http://www.adus-uk.com/) verification of a spin-out company from the University of St Andrews with an economic benefit
[S7]SOI Ltd (http://www.soi.ltd.uk/how-we-work/) - verification of the economic impact of the independent start-up company at the University of St Andrews as a result of the underpinning research
[S8]Summer Science Exhibition Statistics sheet – corroborating audience make-up and numbers at exhibition
[S9]Internet public interest statistics from period following media publicity of Drowned Landscapes exhibition