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.

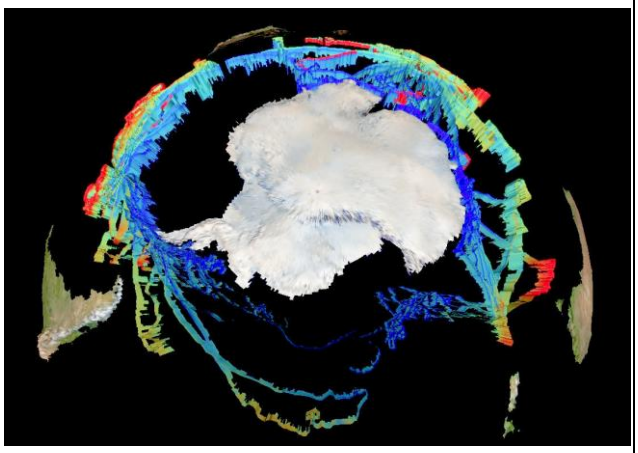

Figure 1. Elephant Seals have provided temperature profiles from the southern ocean (image generated using MAMVIS)

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