Institution:
Aberystwyth University

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

Title of case study:
Development and provision of resources to improve professional practice in satellite-based observation for mapping land cover and forest structure

1. Summary of the impact

The mapping and monitoring of land cover, habitats and forest structure through satellite-based observation by government and commercial organisations around the world has been enhanced by data analysis techniques and tools developed by the Earth Observation and Ecosystem Dynamics (EOED) Laboratory at Aberystwyth University (AU). This has allowed new commercial services to be provided and has change professional working practices. The key impacts include (i) improved knowledge and information about land cover and environmental change in forest and brigalow ecosystems in Australia, supporting effective management strategies; (ii) the completion of a comprehensive digital map of habitats in Wales to inform policy-making; and (iii) the increased capacity of the global remote sensing community in forest characterisation using open source software developed by AU.

2. Underpinning research

The overarching aim of research in EOED since 1999 has been the application of Earth Observation (EO) technology for large-scale mapping over broad areas using automated techniques for environmental monitoring. Research has particularly focused on a) furthering the field of remote and automated land-cover mapping, b) developing methods for extracting bio-physical parameters (e.g., above-ground biomass (AGB)), c) ecosystem dynamics including detecting and understanding the processes of change, and d) developing new technologies and research impact through the design and open release of software. EOED staff, led by Lucas (1999-2013) and Bunting (2007-11 & 2012-) have worked closely and collaboratively with many partners around the world, including academic, government and industry organizations, producing world-class research, as summarised below:

(i) **Land-cover and -use mapping**. EOED led research from 2003 demonstrating the benefits of an object-orientated rule-based approach to classifying habitats from optical satellite imagery, which has been applied subsequently to Wales to update the previous ground-based Phase I habitat mapping[3.1]. More recently EOED have developed a new generic approach to mapping land covers and habitats and changes in these in and around protected sites in Europe as part of the FP7 BIOSOS project (2010-13)[3.2].

(ii) **Extraction of biophysical parameters**. Over the period since 1999, EOED have worked at multiple scales to develop methods for retrieving AGB from EO data. For Australia, EOED established the requirements for using ALOS PALSAR data acquired under conditions of minimal surface moisture to provide more reliable retrieval of AGB and detection of vegetation change[3.3]. To support retrieval from PALSAR data, EOED collated significant forest inventory datasets (over 2500 plots and several million trees) ranging from sparse woodlands to dense tropical forests to establish a biomass library for Queensland, which is being extended to Australia thereby supporting national mapping and monitoring through a combination of PALSAR, Landsat and ICESAT data. An element of building the biomass library has been to include estimates obtained by scaling field-based measures using high resolution airborne (e.g., LIDAR) data[3.4].

(iii) **Ecosystem Dynamics**. EOED have actively participated in the collaborative Injune Landscape Collaborative Project (ILCP) since 2000, and have used its research area in central Queensland as a supersite allowing development of new algorithms[3.5,3.6] for retrieving biophysical attributes and detecting change (e.g., in biomass, structure) through continued acquisition of airborne and spaceborne sensors operating in different modes and supporting on-ground measurements at the tree and stand level. These data continue to provide an unprecedented opportunity to improve understanding of ecosystem response to change but also unique opportunities for calibration and validation of biomass and biomass-change maps derived from spaceborne data. Work undertaken in the Brigalow Belt Bioregion of southeast Queensland has resulted in the development of a new approach for differentiating and mapping different forest growth stages of the endangered brigalow ecosystems that integrates both ALOS PALSAR and

Landsat-derived Foliage Projected Cover (FPC) data and avoids the requirement for use of dense time-series for mapping regrowth forests[3.7]. Knowledge from the ILCP has also contributed to developing understanding of microwave[3.8] and LiDAR interaction with forest canopies through parameterisation simulation models[3.9].

(iv) **New technologies and Software**. To support the research being undertaken within EOED several new algorithms and techniques have been developed. These include innovative image and lidar processing software tools and data storage formats within the RSGISLib,[3.10] SPDLib[3.11,3.12] and KEA libraries[3.13]. These packages have allowed for consistent and rapid processing of airborne and spaceborne SAR, optical and LiDAR data at regional and national scales, while providing support for high performance computing (HPC) systems.

3. References to the research

Land-cover and use mapping

3.1 Journal Article: Lucas, R.M. *et al*., (2011). Updating the Phase 1 habitat map of Wales, UK, using satellite sensor data. *ISPRS Journal of Photogrammetry and Remote Sensing* 66, pp 81–102. DOI: 10.1016/j.isprsjprs.2010.09.004

3.2 Research Grant: BIOdiversity multi-SOurce monitoring System: from Space to Species (BioSOS). Lucas, R.M., and Bunting, P. EU FP7. €101,340 of €247,6363. 01.12.2010 – 30.11.2014.

Extraction of biophysical parameters

3.3 Journal Article: Lucas, R.M. *et al*., (2010). An evaluation of the ALOS PALSAR L-band backscatter – Above ground biomass relationship Queensland, Australia: Impacts of surface moisture condition and vegetation structure. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 3, 576–593. DOI: 10.1109/JSTARS.2010.2086436

3.4 Journal Article: Lucas, R.M. *et al*., (2008). Retrieving forest biomass through integration of CASI and LiDAR data. *International Journal of Remote Sensing* 29(5), 1553–1577. DOI: 10.1080/01431160701736497

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3.5 Journal Article: Lucas, R.M. *et al*., (2008). Classification of Australian forest communities using aerial photography, CASI and HyMap data. *Remote Sensing of Environment* 112(5), 2088–2103. DOI: 10.1016/j.rse.2007.10.011

3.6 Journal Article: Bunting, P. *et al*., (2010). Characterisation and mapping of forest communities by clustering individual tree crowns. *Remote Sensing of Environment* 114, 2536–2547. DOI: 10.1016/j.rse.2010.05.030

3.7 Journal Article: Clewley, D. *et al*., (2012). An Approach to Mapping Forest Growth Stages in Queensland, Australia through Integration of ALOS PALSAR and Landsat Sensor Data. *Remote Sensing* 4(8), 2236–2255. DOI: 10.3390/rs4082236

3.8 Journal Article: Burgin, M. *et al*., (2011). A generalized radar backscattering model based on wave theory for multilayer multispecies vegetation. *IEEE Transactions on Geoscience and Remote Sensing* 49(12), 4832–4845. DOI: 10.1109/TGRS.2011.2172949

3.9 Journal Article: Armston J. *et al*. (2013). Direct retrieval of canopy gap probability using airborne waveform lidar. *Remote Sensing Of Environment* 134, 24–38. DOI: 10.1016/j.rse.2013.02.021

New technologies and Software

3.10 Journal Article: Bunting P. *et al*., (2013) The Remote Sensing and GIS Software Library. *Computers and Geosciences*, Available early-online. DOI: 10.1016/j.cageo.2013.08.007

3.11 Journal Article: Bunting, P. *et al*., (2013). Sorted pulse data (SPD) library. Part I: A generic file format for LiDAR data from pulsed laser systems in terrestrial environments. *Computers and Geosciences* 56, 197–206. DOI: 10.1016/j.cageo.2013.01.019

3.12 Journal Article: Bunting, P. *et al*., (2013). Sorted pulse data (SPD) library. Part II: A processing framework for LiDAR data from pulsed laser systems in terrestrial environments. *Computers and Geosciences* 56, 207–215. DOI: 10.1016/j.cageo.2013.01.010

3.13 Journal Article: Bunting, P. & Gillingham, S., (2013). The KEA image file format. *Computers and Geosciences* 57, 54–58. DOI: 10.1016/j.cageo.2013.03.025

4. Details of the impact

Research by the EOED has had a direct impact on the professional practice of individuals and organisations involved in monitoring vegetation change and developing and implementing conservation policies, from government, industry and agency scientists engaged in collating and interpreting data, to field conservationists. Due to the collaborative nature of the research undertaken within EOED, which has involved staff visits for extended periods (in both directions) and regular interchange of ideas, software and datasets, the outputs and methodologies developed through this research have been incorporated into their collaborators' everyday working practices. By improving the information available to agencies involved in monitoring environmental change and making conservation decisions, the research has also had a secondary, indirect impact on the environment, supporting measures to protect endangered habitats in Australia and Europe.

Three key impacts of the research can be highlighted:

i) Improved knowledge and information about land cover and environmental change in forest and brigalow ecosystems in Australia, supporting effective management strategies.

Research by EOED has developed of new techniques for the use of ALOS PALSAR data and Landsat-derived Foliage Projected Cover (FPC) data in quantifying and mapping vegetation cover, structure and biomass. This has been applied to improving knowledge about forests and specifically the brigalow ecosystems in Queensland, Australia[5.1]. As the Assistant Director-General for Science Delivery in the Queensland Government Department of Environment and Resource Management has confirmed, the application of AU research in the period since 2008 has generated new policy options for managing vulnerable ecosystems:

> "The partnership with Aberystwyth has significantly added to the global knowledge of how the information content of radar and optical data can be integrated for discriminating and mapping the growth stage of vegetation communities. In a study of the entire Brigalow Belt Bioregion in southeast Queensland, an area of over 36.5 million ha was mapped using a combination of ALOS PALSAR and Landsat sensor data to derive four stages of growth: cleared areas, regrowth, mature and remnant of Brigalow dominated communities. Such information has contributed to knowledge of the distribution of carbon and biodiversity and provided options for management of these vulnerable ecosystems"[5.2].

Data processing and methodological innovation by AU has further enabled the Queensland Government to strengthen its own technical capacity to use satellite-based observation data in its operational programmes:

> "Targeted research at the Injune study area (established in 2000 by Professor Lucas and colleagues in Queensland) using airborne hyperspectral imagery and LiDAR has resulted in methods for mapping regrowth stages, individual tree species, tree death and changes in tree cover over the reporting period. As a result of this research, the Queensland Government has improved validation of several core products, including Foliage Projective Cover (from Landsat sensor and LiDAR data), and is in a much better position to take advantage of future radar, LiDAR and hyperspectral satellites for operational programs."[5.2]

Additionally, the Queensland Government has benefited from the development of its researchers' skills and knowledge base through staff exchanges and cooperation with AU, such that "the work with Aberystwyth University provided an important link to extend our base knowledge for mapping at the Statewide and continental level"[5.2].

Methods and data products developed by AU have also been used in the expansion of biomass mapping from Queensland to the rest of Australia, with a woody biomass map of Australia due for completion in late 2013[5.1,5.3]. The Queensland Governments notes the critical contribution of Lucas and the EOED in facilitating this project:

> "Professor Richard Lucas has been the key collaborator and responsible for establishing and maintaining the links with the Japanese Aerospace Exploration Agency (JAXA) which have resulted in cost-free access to ALOS PALSAR imagery for Australia"[5.4].

ii) The completion of a comprehensive digital map of habitats in Wales to inform policy-making.

An object-orientated rule-based approach to classifying habitats developed by the EOED has been applied since 2010 to the production of the Habitat Inventory for Wales, in collaboration with

Natural Resources Wales (NRW)[5.5] and commercial partner Environment Systems Ltd[5.6]. The inventory updated the previous Phase I habitat map[5.7], which had been produced from field observations, and made Wales the first country in Europe to have a national habitat map produced from satellite-based observation data[5.8]. The map was identified as available evidence for natural resource management by the Welsh Government consultation on its *Sustaining a Living Wales* Green Paper in 2012 ("We have a complete survey of our terrestrial habitats, now being repeated using remote sensing"[5.9]), which informed the development of a new integrated approach to natural resource management in Wales. Furthermore, the development of the Earth Observation Dynamic Habitat Mapping (EODHAM) system, a generic technique based on the Food and Agriculture (FAO) Land Cover Classification Scheme (LCCS) for generating classifications of land covers and translating these to General Habitat Categories (GHCs). The EODHAM system is now being used within number of collaborative projects with NRW through which field ecologists are being trained in EO and the use of EO imagery alongside some automated is now becoming an accepted method of working within NRW, a significant change in work practices[5.5].

This research that led to the new Phase I map for Wales has also formed "a foundation enabling Environment Systems to developed a wider commercial service using remote sensing that is now highly regarded across the UK and overseas"[5.6]. The research from EOED has therefore directly led to the expansion of the services Environment Systems are offering, with the service having been applied within "England, Scotland, Republic of Ireland, Canada, Anguilla and Georgia"[5.6].

iii) *The increased capacity of the global remote sensing community in forest characterisation using open source software developed by EOED*.

Open-source software developed by Bunting within EOED has been adopted for use in forest and land-cover characterisation, mapping and monitoring by public agencies and commercial organizations worldwide. Remote Sensing and GIS Software Library (RSGISLib) software has been downloaded 1659 times since January 2009, and Sorted Pulse Data Software Library (SPDLib) software downloaded 1412 times over the same period (data captured 20/10/13[5.10]). Software in the KEA file format has been installed and is in use by a number of institutions including the Queensland State Government (Australia) and has been downloaded >112 times since August 2012[5.10]. Additionally, the python scripting training materials made available by EOED has been download 321 times since February 2013[5.10]. The benefits from using this software have been described by the Manager of the Remote Sensing Centre in the Queensland Government Department of Environment and Resource Management:

> "Open source software tools developed by Peter Bunting and colleagues, in particular RSGISLib and SPDLib, have enabled more efficient storage and operational analysis of remotely sensed datasets including LiDAR and high resolution optical data. These software tools are used daily by up to 35 scientists within the Remote Sensing Centre, Queensland Government"[5.2].

5. Sources to corroborate the impact

5.1 Letter from Director of the Terrestrial Ecosystem Research Network (TERN), University of Queensland.
5.2 Letter from Assistant Director General - Science Delivery, Queensland Government, Australia.
5.3 Letter from Japanese Exploration Agency (JAXA).
5.4 Queensland Government Remote Sensing Centre website, http://www.nrm.qld.gov.au/science/remote-sensing/partnerships.html
5.5 Letter from Conservation Monitoring Advisor, NRW.
5.6 Letter from Director of Environment Systems Ltd.
5.7 'Habitat Inventory for Wales', http://www.gwylio.org.uk
5.8 'Satellite wildlife map of Wales could be EU "first"', BBC News website, 2 November 2010, http://www.bbc.co.uk/news/uk-wales-11672184
5.9 Welsh Government (2012) *Consultation Document: Sustaining a Living Wales, A Green Paper on a new approach to natural resource management in Wales*, WG13943, page 23, http://wales.gov.uk/docs/desh/consultation/120210nefgreenpaperen.pdf
5.10 Download data from sourceforge.net and bitbucket.org, where the files and source code are hosted.