Institution: Durham University

Unit of Assessment: 17B

Title of case study: Remote-sensing tools for rapid and cost-effective forest management

1. Summary of the impact

DU researchers have developed new algorithms and statistical models with which to make precise quantitative assessments of forest cover and forest attributes over small or large areas using satellite remote-sensing data, either alone or in combination with airborne or ground-based laser scanning. This research underpins the use of remote sensing as a cost-effective tool for aspects of forest resource management, planning, and policy compliance in many countries. Users include government agencies in the UK, Sweden, New Zealand and Guyana, and international forestry consultancy companies based in Finland with regional branches in New Zealand. DU researchers have also used these methods to help verify the Guyana government's entitlement to $250m under a UN initiative for avoidance of CO_2 emissions.

2. Underpinning research

Forests cover 27% of Earth's land area, constitute one of the largest stores in the global carbon cycle, and yield a timber harvest worth about $90 bn/yr (www.fao.org/forestry/fra/62219/eng/). Their management and planning requires quantitative assessment of several attributes of forest cover and structure, and also of how these attributes change over time as trees grow, are planted or felled, or are lost to burning or wind throw. The attributes that are most frequently required are forest area (often subdivided by forest type and/or degree of degradation) and timber volume (traditionally estimated on the ground by manual measurements of tree spacing, height, and diameter at breast height). These assessments are required both by land owners and by public agencies, at all scales from individual landholdings or plantations upwards, and there is inevitably a desire for assessment methods that are both accurate and cost-effective. Following the Kyoto Protocol, national-scale assessments of timber volume expressed as carbon stock are needed as part of the UN-led REDD+ (Reducing Emissions from Deforestation and forest Degradation in developing countries) initiative, in which maintaining or increasing forest carbon stocks gains a financial reward.

Research at DU by Donoghue (DU staff 1985-), Cox (1976-), Watt (PhD and PGRA 2001-5), and Dunford (PhD 2002-5, PGRA 2005-8) made pioneering contributions to the practical and cost-effective use of remote sensing for such purposes. Early work (References 1 & 2) helped to establish the potential of Landsat TM satellite imagery for estimating changes over time in the characteristics of conifer plantations. Although this optical imagery has only medium spatial resolution (its pixels are about 30 m x 30 m on the ground) the research showed that it could be used to measure changes in tree height over time in single-species plantations, and confirmed the accuracy of the algorithms by comparison with GPS-located ground measurements in UK forests. The research used remotely sensed reflectance values from trees to derive modelled estimates of parameters of direct interest to foresters (height, diameter, basal area, species), while incorporating robust methods for radiometrically normalising, georegistering, segmenting and mosaicking image data. These techniques informed later work with higher spatial resolution imagery.

In 2001-5 DU was the main scientific partner in a European project to develop and promote remote-sensing methods for the benefit of management and environmental protection in the state-owned and commercial forest sectors. This ForestSAFE project (Reference 3) was funded by the EU's LIFE programme, which supports environmental policy, and also involved the Swedish Agricultural University and two major users: the UK Forestry Commission, including Forest Research and Forest Enterprise (responsible for managing 45% of British woodland), and Skogsstyrelsen, the Swedish Forest Agency (responsible for all forestry policy and practice in

Sweden). DU researchers developed methods for estimating key forest attributes and change over time to a higher precision than previously possible by taking advantage of three novel types of primary data:

- newly-available multispectral optical satellite imagery with higher spatial resolution than Landsat (e.g. IKONOS, with a 4 x 4 m footprint)
- airborne laser scanning (usually called LiDAR in the UK, but ALS in some countries), which has pinpoint spatial resolution but covers much smaller areas at one time; and
- ground-based 3-D laser scanning.

Image-processing algorithms were devised to make use of these new sources, statistical models were used to relate manually-estimated attributes to the new remotely-derived indices, and rigorous statistical intercomparisons were made between estimates derived from different remote sensing methods to establish which methods (or combinations) were most effective for different purposes and in different types of forest (References 4-6). High-resolution satellite imagery was shown to be much more versatile than Landsat, and airborne LiDAR was shown to be particularly good for assessing timber volume and carbon stock.

3. References to the research

(Bold denotes author was a DU researcher at time of research; underline denotes PhD student at time. Journal impact factors and citation counts are from ISI Web of Science as of 31/7/2013.)

1. **Puhr** CB, **Donoghue** DNM (2000) Remote sensing of upland conifer plantations using Landsat TM data: a case study from Galloway, south-west Scotland. *International Journal of Remote Sensing*, 21:4, 633-646. (JIF 1.14, 33 citations)
2. **Donoghue** DNM, **Watt** PJ, **Cox** NJ, Dunford R, Wilson J, Stables S, Smith S (2004) An evaluation of the use of satellite data for monitoring early development of young Sitka spruce plantation forest growth. *Forestry*, 77(5), 383-396. (JIF 1.68, 8 citations)
3. André, P. **et al.** (2006) Final Report of EU LIFE-ENVIRONMENT project FORESTSAFE: Forestry applications of remote sensing. Joint report by Durham University, UK Forestry Commission, Skogsstyrelsen.
4. **Donoghue** DNM, **Watt** PJ, Wilson J, **Cox** NJ (2007) Remote sensing of species mixtures in conifer plantations using LiDAR height and intensity data. *Remote Sensing of Environment*, 110(4), 509-522. (JIF 5.10, 60 citations)
5. **Donoghue** DNM, **Watt** PJ (2005) Using LiDAR to compare forest height estimates from IKONOS and Landsat ETM+ data in Sitka spruce plantation forests. *International Journal of Remote Sensing*, 27(11), 2161-2175. (JIF 1.14, 24 citations)
6. **Watt** PJ, **Donoghue** DNM (2005). Measuring forest structure with terrestrial laser scanning. *International Journal of Remote Sensing*, 26(7), 1437-1446. (JIF 1.14, 41 citations)

4. Details of the impact

Remote sensing methods developed by DU during and after the ForestSAFE project have had direct impact on forest management and planning in the UK and Sweden, and indirect impact in New Zealand through adoption by international consultancies. They also underpin DU's ongoing contribution to Guyana's engagement in the UN REDD+ scheme.

UK and Sweden: change-estimation algorithms developed by DU during ForestSAFE have been incorporated into web-based forest management systems which are used operationally by forest authorities and private landowners. Uptake was fostered initially by a large international seminar for forest professionals (ForestSAT). This became the first of a biennial series which subsequently has disseminated remote sensing developments to many hundreds of users worldwide.

In the UK, a ForestChange web tool was developed by DU for the Forestry Commission (FC) and Forest Authority. Pilot projects with Kielder and Galloway Forest Districts in 2005-7, building on research published in References 1, 4 and 5, demonstrated the potential benefits to the FC of using optical satellite imagery. DU also trained 40-50 FC staff in the methods involved. A senior officer in the FC's North England (formerly Kielder) District, which contains Britain's largest

productive forest, confirms that

> "In my role as Harvesting and Marketing Manager I have continued to use and buy satellite imagery and techniques developed by Durham in situations where I have not been able to acquire aerial photography …Given the ever increasing demands on resource, both financial and human, the need for useful tools from innovative technologies like remote sensing is a must for the Forestry Commission as a whole" (Source 1).

According to the Chief Regional Forester at the Swedish Forestry Agency, the ForestSAFE collaboration with DU

> "allowed experts from the UK and Sweden to work closely together … to develop … joint prototypes, algorithms and technical solutions…. [We] have used these developments to improve our service in a number of ways…..We use satellite imagery for routine analysis of felling across the whole of Sweden, we have tools to assess the environmental status of our forests and these data are now incorporated into our web GIS system" (Source 2).

The web GIS system was derived from joint prototype development by DU and the Swedish Forest Agency and went live at the end of 2008. By replacing the previous paper-based system of national monitoring of forest changes it is estimated to have saved owners and government 200m kroner (£20m) in administrative costs (Source 2).

New Zealand: Dr Peter Watt, who worked in DU on the ForestSAFE project, subsequently joined the New Zealand branch of Pöyry Ltd., a large Finnish-based international forestry consultancy company (2005-2011). In August 2011 he moved to become head of resource mapping in the NZ-based Asia Pacific branch of another large Finnish consultancy, Indufor. In these positions he has been instrumental in the operational application of the DU tools for forest remote sensing. His expertise helped Pöyry win a contract from the NZ Ministry for Environment to use airborne LiDAR to quantify tree height and density in sample areas and extrapolate the results to obtain a first estimate of New Zealand's above-ground forest carbon stock for the first assessment period of the Kyoto protocol. The methods proposed by Pöyry were based on DU research detailed in References 4 and 5 and were endorsed by experts from the Canadian Forest Service and CSIRO before detailed work commenced in 2007. This was the first time airborne laser scanning was used for a national carbon stock assessment. Since 2011 the estimates have been refined by Indufor, again using DU methods, after the Ministry decided to fly LiDAR transects over the whole country. A letter from Indufor Asia Pacific's managing director states:

> "Indufor Asia Pacific is a forestry consulting company and has since 2011 adopted much of the research conducted at Durham University during the ForestSAFE project. The direct benefits are very apparent across both the commercial sector and at a Government level. Commercially, the work has led to development of a range of remote sensing-based methods that assist foresters in making informed decisions. These methods use either satellite images to detect change across the forest which may be due to poor survival, wind damage or fire, or airborne laser scanning (ALS) to provide spatial estimates of key forestry parameters such as height or wood volume" (Source 3).

The letter goes on to explain that the two largest private forest companies in New Zealand (Kaingaroa Timberlands and Rayonnier NZ) are investing in ALS and satellite imagery for operational purposes using GIS-based software developed by Indufor on the basis of DU methods.

Guyana: 85% of Guyana is forested, mainly with intact natural rain forest. The nation has a Low Carbon Development Strategy, part of which involves engagement in the United Nations Collaborative Programme on Reducing Emissions from Deforestation and forest Degradation programme (REDD+). Guyana established a REDD+ partnership with Norway through which Guyana stands to gain $US 250m in payments for conserving forest stocks and thereby avoiding CO_2 emissions. The rules of these partnerships require Guyana to establish a system to monitor, report and verify forest resources and carbon stock changes and require Norway to procure an independent verification of these assessments before making any payments. The Guyana Forestry Commission contracted Pöyry to assess nationwide forest cover and forest degradation in year 1 of the scheme (2010-11) and Indufor Asia Pacific to make similar assessments in year 2. Both companies used optical satellite imagery and methods based on the DU research described

above. To quote Source 3 again,

> "Since 2011 Indufor [is] also assisting Guyana in South America to monitor and report annual forest change. The foundations of much of the forest change and accuracy assessment methods are based on earlier research that was conducted during ForestSAFE. … From an Industries perspective projects like this are invaluable. Essentially, ForestSAFE has provided focussed research that has assisted in making operational improvement in commercial forestry and provided forest monitoring methods that have supported REDD+ policy development in Guyana".

DU has also been directly involved in Guyana's REDD+ programme since 2011 when it was contracted to check the reliability of the numbers produced by Indufor and to attach confidence limits to them. According to the head of the Guyana Forestry Commission, DU

> "won the tender based on their scientific publications and track record in forest change assessment using satellite imagery" (Source 4).

The 'Independent accuracy assessments' carried out by DU in 2011 and 2012 involved estimating Guyana's forest cover in 1990, 2009, 2010 and 2011 using a two-stage sampling strategy with special attention to those randomly-selected 10 x 10 km blocks in which the 2010 and 2011 surveys suggested change had occurred. In those blocks, high spatial resolution satellite imagery combined with low altitude photography and field visits were used to quantify the levels of deforestation and forest degradation. The assessment confirmed that the Indufor survey was accurate to within a fraction of one per cent.

The Norwegian Government commissioned Det Norske Veritas (DNV; an NGO originally modelled on Lloyd's Register) to carry out an independent audit of Indufor's survey and Durham's accuracy assessment. DNV's report confirms that Indofor's survey was carried out using "methodology in accordance with internationally accepted good practice" and that "the results of the independent accuracy assessment [by DU] … were verified" (Source 5, page ii). The Guyana Forestry Commission has testified that

> "the independent accuracy assessment is a critical part of the [monitoring, reporting, and verification] process …. The GFC has welcomed Durham's involvement and expertise in conducting the accuracy assessment as without it Norway would not release REDD+ payments to Guyana. These payments will be of the order of $250 million by 2015" (Source 4).

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

Source 1: Letter dated 12/6/13 from Harvesting and Marketing Manager, Forestry Commission, North England Forest District [Reporter participant]

Source 2: Letter dated 29/713 from Chief Regional Forester (North) in the Swedish Forest Agency [Reporter participant]

Source 3: Letter dated 22/7/13 from the Managing Director of Indufor Asia Pacific Ltd, Auckland, New Zealand [Reporter]

Source 4: Letter dated 7/6/13 from the Commissioner of Forests, Guyana Forestry Commission [Reporter]

Source 5: Det Norske Veritas/DNV (2012) Verification of interim REDD+ Performance indicators under the Guyana-Norway REDD+ Partnership, for monitoring period 2010-2011; Year 2. (pdf document) [Independent reporter]