Section A The fields in this section are mandatory.

Institution: Durham University

Unit of Assessment: 14 Geography and Environmental Studies

Title of case study: Vegetation analytics and management along power line corridors

Period when the underpinning research was undertaken: Between 2001 and 2017

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI**:
Professor Danny Donoghue	Professor of Physical Geography	January 1985 to present
Professor Nick Rosser	Professor of Physical Geography	October 2002 to present
Andrew Hewitt	KTP Associate (KTP 1)	January 2013 to September 2015
Sophie Davison	KTP Associate (KTP 2)	October 2015 to September 2017
Dr Nick Cox	Assistant Professor	October 1976 to present
Dr Peter Watt	Senior Research Associate	January 2002 to August 2005

Period when the claimed impact occurred: Between October 2015 and July 2020

Is this case study continued from a case study submitted in 2014? N

Section B

1. Summary of the impact

Durham University research on the use of airborne high-resolution laser remote sensing technology, known as light detection and ranging (LiDAR), has underpinned the development of bespoke commercial geospatial products for electricity network operators that need to manage vegetation along power line corridors. A Knowledge Transfer Partnership (2015-2017) between Durham and Network Mapping Group (NMG), a world-leading provider of power line engineering and utility management services, has enabled NMG to develop innovative vegetation modelling services and to gain a competitive edge in an emerging international market that includes the US, Australia, and the UK. As a direct result of the partnership, vegetation analytics now comprise 50% of NMG's business, worth an annual turnover of GBP3,000,000 in 2020. The collaboration with Durham has fundamentally transformed the company's business model, providing new access to the USD321,000,000 global market in vegetation management.

2. Underpinning research

Durham University research has established new ways of monitoring and modelling vegetation, allowing much better understanding of the risks that vegetation can pose to electrical power lines. These risks include growth and infringement of vegetation upon power lines, causing flashovers and potentially triggering wildfires, as well as direct damage to the lines by falling trees or limbs. Assessing these risks is complicated by difficulties in measuring the extent and structure of vegetation, as well as its anticipated growth and seasonal change, at the scale of an entire power line network. This case study is founded on innovative use of airborne light detection and ranging (LiDAR) data to identify vegetation that could cause damage to transmission and distribution lines at the whole-network scale. As part of a European Commission LIFE Programme-funded project entitled ForestSAFE, Durham researchers showed that airborne LiDAR intensity data could be used to distinguish between different tree species in mixed woodlands (reference **R1**). Prior research had documented the use of LiDAR for recovering tree height in single-species plantations, but the novelty of the Durham work was to relate statistics of the LiDAR data with the physical characteristics of different tree species. This, in turn, showed the promise of using LiDAR to characterise vegetation in natural forests with a wide range of species. Further research, funded in part by the Turkish Scientific and Technical Research Council, demonstrated that statistical analysis of airborne LiDAR data could recover not just height, but also forest structural diversity – that is, the distributions of both tree heights and diameters – in a natural forest stand (**R2**). This advance makes it possible to estimate forest growth patterns and rates, and thus anticipate infringement risks.

These methodological and technical advances led directly to a pair of Knowledge Transfer Partnerships (KTPs) between Durham University and Network Mapping Group (NMG). Durham research within KTP1 (2012-2015) combined data on the network structure of electrical circuits with environmental information, including LiDAR-derived tree cover, topography, and meteorological data, to model the transfer of electrical load and develop a network-level tool for determining capacity, visualising the network, and identifying risks. While we do not claim impact arising from KTP1 in this case study, the collaboration with Durham showed the potential benefits of this integrated network-level framework to NMG, while also indicating the shortcomings of existing vegetation management approaches. Working within that integrated framework, KTP2 (2015-2017) developed advanced LiDAR metrics of forest structural diversity (building directly on work reported in **R1** and **R2**) that could be combined with information on forest growth patterns and used by NMG to make realistic estimates of the risks of tree infringement within power line corridors. An important part of the research in KTP2 compared measures of structural diversity derived from LiDAR data collected at different times of year, under both leaf-on and leaf-off conditions, to understand the impact of data collection time on vegetation risk assessment (**R3**). The comparison showed that LiDAR data collected in any season can be reliably used to estimate structural diversity in natural mixed-species forests, but also that the combination of leaf-on and leaf-off data leads to more robust results than either data set in isolation (**R3**, **R4**). This is a critical advance because it demonstrates that (1) LiDAR is an effective tool for measuring tree canopy characteristics, and thus vegetation infringement, even in complex temperate forests, and (2) the precise timing of LiDAR surveys is not critical for determining those characteristics. KTP2 was awarded the highest grade of 'Outstanding' by the Innovate UK KTP Grading Panel for its achievement in meeting the KTP programme objectives.

3. References to the research

Note: underline indicates Durham employee during the research and/or at time of publication. Citation data are from Google Scholar, updated 1 September 2020.

R1: Donoghue, D.N.M., Watt, P.J., Cox, N.J., and Wilson, J. (2007) Remote sensing of species mixtures in conifer plantations using LiDAR height and intensity data. *Remote Sensing of Environment* 110, 509-522, doi:10.1016/j.rse.2007.02.032. *(242 citations)*

R2: Ozdemir, I., and Donoghue, D.N.M. (2013) Modelling tree size diversity from airborne laser scanning using canopy height models with image texture measures. *Forest Ecology and Management* 295, 28-37, doi:10.1016/j.foreco.2012.12.044. *(44 citations)*

R3: Davison, S.T. (2016) Analysis of the effect of leaf-on and leaf-off forest canopy conditions on LiDAR derived estimations of forest structural diversity. Master's thesis, Durham University, available at http://etheses.dur.ac.uk/12245/ *(2 citations)*.

R4: Davison, S.T., Donoghue, D.N.M., and Galiatsatos, N. (2020) The effect of leaf-on and leaf-off forest canopy conditions on LiDAR derived estimations of forest structural diversity. *International Journal of Applied Earth Observations and Geoinformation* 92, doi: 10.1016/j.jag.2020.102160. *(0 citations)*

4. Details of the impact

Overview

Vegetation management is a major challenge for power line operators worldwide. National energy regulators typically stipulate a minimum distance between vegetation and power lines, but there is no industry-wide best practice on how operators can comply with these requirements or efficiently identify and manage the trees that pose the greatest threat to their transmission and distribution networks. The aggregate costs can be substantial; the US has 450,000 km of transmission lines alone, and operators collectively spend approximately USD150,000,000 per year on vegetation management, while in Australia operators of the 45,000 km of transmission lines spend AUD25,000,000 per year (evidence source **E1**). While compliance costs for most individual operators are confidential, figures released by the Australian Energy Regulator show that compliance with updated vegetation regulations cost Evoenergy, a single distribution network

operator in the Australian Capital Territory with 200,000 subscribers, AUD2,400,000 in 2018-2019 compared with pre-tax revenues of AUD164,000,000.

In direct response to this issue, the collaboration with Durham has enabled NMG to be first-to-market with a network-scale power line risk assessment product that integrates multiple datasets to allow vegetation and line management, proof of compliance with clearance regulations, and assessment of risks from infringement and falling trees. The underpinning research provides both the technical basis for the product as well as enhanced credibility with current and potential customers. As a direct result of the collaboration, NMG has transformed its focus and business model and is part-way through an ambitious growth strategy designed to capture a larger share of an increasing international market. We describe the impacts on NMG below, in terms of both direct capacity building as well as a more structural shift in NMG's business model and relationship with its customers.

Direct impact on NMG

KTP1 resulted in new capacity within NMG to model the thermal behaviour and capacity of a power line network, but more importantly it led directly to the creation of an integrated framework for combining data on line geometry, electrical load, environmental conditions, and vegetation, and for visualising these data within a single flexible package. While many of these features were incorporated into NMG's bespoke 3D data management and visualisation software, Caydence, we do not claim impact arising from KTP1 because it spans across the REF2014 and REF2021 periods. That initial collaboration was a key element of the pathway to impact from KTP2, however, because it demonstrated to NMG that (1) the company lacked the fundamental understanding of forestry and vegetation data analysis that was required to bring a comprehensive vegetation management product to market, and (2) the KTP mechanism was an ideal way to address this gap (**E1**).

KTP2 has allowed NMG to define an emergent field of 'vegetation analytics' by providing a suite of tools and approaches to identify current and potential future vegetation risks to a power line network. LiDAR surveys can measure the structure of individual trees across an entire network, but those data alone are not sufficient to allow power line operators to pinpoint the areas of greatest risk or to prioritise their management actions. The core innovation in KTP2 was to combine Durham-developed approaches for deriving vegetation structure from LiDAR point cloud analysis with knowledge of forest growth patterns and other GIS data on canopy extent and health, all integrated within the Caydence software. This has resulted in a flexible toolbox rather than a single 'solution', enabling NMG to tailor vegetation risk models for power lines to specific national regulatory standards around the world (**E2**). As stated by the company, *'We utilise historical information and a suite of analysis tools to look at every tree and calculate its growth, its ability to hit the line and its likelihood of falling. Paired with risk criteria and cost information specific to the network operator, this allows for significantly improved targeting of tree inspections and the design of management programs for trimming/felling which optimise cost, risk or a balance of both'* (**E3**). In addition, NMG has used the Durham research on leaf-on and leaf-off conditions (**R4**) to justify the use of long-term LiDAR data series to understand, and analyse, changes in vegetation patterns over time. Thus, according to the business development manager of NMG Australia, *'rather than just telling the utilities where the trees are too close to the line, we're using existing LiDAR libraries to look at trends over time. So when you've got multiple year data sets you can start to look at how trees are behaving over time and we can start to predict growth rate. And using the predictive growth rate we can then take a proactive approach to a utilities' cutting programme'* (**E4**, 0:28 to 0:55).

Development of this predictive approach has led to direct impact on NMG through competitive advantage in the market and leadership within the field of vegetation management, leading to the acquisition of new contracts. In the KTP2 final report, NMG states that *'…the KTP contribution to the vegetation analytics played a part in the securing of three major contracts for fast turnaround vegetation clearance information on distribution networks: two in the UK and one in Australia. The contribution has primarily been around the thought leadership and the positioning of [NMG] as an innovator'* (**E2**). As a direct result of KTP2, vegetation analytics now makes up about 50% of NMG's business, compared to <10% in 2014 (the final year before the collaboration started; **E2**). Annual sales turnover resulting directly from KTP2 was GBP1,000,000 in 2017, rising to GBP3,000,000 in

2020 (**E2**). Annual exports that can be directly attributed to KTP2 rose from GBP500,000 in 2017 to more than GBP2,000,000 in 2020, while attributable pre-tax profits were nil in 2017 but exceeded GBP500,000 in 2020 (**E2**, **E5**, 00:44 to 2:28).

Shift in business model

More fundamentally, the toolbox developed in KTP2 has enabled a major shift in NMG's business model away from data acquisition and toward data analysis. In the KTP2 final report, NMG states that *'…market changes and improved commercial efforts, combined with an improved understanding of vegetation management techniques and technologies, has significantly expanded the scoping and audit side of the business, particularly with regards to distribution (as opposed to transmission). As such, the KTP has enhanced and supported a meaningful shift in business mix by provisioning tools, techniques and examples that have enabled us to capitalise on these new opportunities'* (**E2**). NMG's technical director has stated that *'…we're looking at new concepts around managing a data pipeline, an analytics pipeline. So you're thinking about a flow of data and information at different points. And how do you plug different input, outputs into that. Which is real paradigm shift in terms of how we look at serving the market. So it just generates new ways of thinking and looking at it which are all a consequence [of the KTP]… we have started to increase what the potential market is because you're starting to do new bits of the market ... And getting on to the next point about business models, that starts to really free us from the need to acquire data… And so it starts to mean that we're more scalable because you're working on what information exists and applying tools to that workflow cycle'* (**E5**, 05:21 to 06:45). NMG have estimated that the total addressable market worldwide for vegetation management is USD321,000,000, but that this is highly fragmented between different service providers. NMG has 2% market share at present, but is aiming for 10% on the back of the advances in KTP2 (**E5**, 6:48 to 8:58). It is important to note that this change will take time and that NMG's plans are significant given the nature of the industry; the NMG technical director argues that *'It's probably worth noting on that story that our customers [i.e., power line operators] are extremely conservative. Really risk averse, really conservative. And change is a matter of either them changing policy – which is really hard – or … the safety and the economic regulators making changes which influence behaviour. And that's probably where more impact happens. So to actually change things it's a long, hard slog; so big impact but it's slow'* (**E5**, 08:59 to 09:35).

Applications

Three examples illustrate the impact of the research in KTP2 on NMG and its engagement with major customers in diverse electricity markets worldwide:

- Endeavour Energy, Australia: Endeavour is a distribution network operator for greater western Sydney and part of New South Wales, serving 2.4 million people. Like other network operators in Australia, Endeavour is under significant regulatory pressure to reduce operational expenditure to lower consumer electricity prices while at the same time improving vegetation management practices. Compliance with new vegetation management regulations cost Endeavour more than AUD10,000,000 annually over the 2014-2019 regulatory period (**E6**). Endeavour began working with NMG in 2018 to utilise multi-year LiDAR data to predict vegetation risk at a network scale. The vegetation manager at Endeavour Energy has said that *'having Network Mapping Group's data and analytics means that we can go to the right spans at the right times before the bushfire season… Reputational risk is one of the great things that we manage at EE especially from a vegetation perspective. And this is a new, exciting chapter in data science. So it's brains like [NMG technical director] and [KTP associate] ... she's the person who built the algorithm around what we're doing here at Endeavour Energy. And together with our incredibly innovative teams what we're doing now is starting to look at how we take this to the next level'* (**E7**, 01:04 to 01:12 and 13:40 to 14:07).

- UK Power Networks (UKPN), UK: UKPN is a distribution network operator for south-eastern England, serving 8 million people and distributing 27% of the UK's electricity supply. Prior to working with NMG, UKPN relied on foot patrols of its entire network to assess vegetation risk, even in areas with low or negligible risk. NMG has now been awarded a multi-year contract for vegetation analytics across the entire UKPN network. The senior asset engineer at UKPN has

said that *'the inclusion of 3D visualisation technology enables us to better judge the damage risk to our network from trees and other vegetation, and help us to manage our contractors more effectively. This will assist in realising significant cost savings and further improve the reliability of power supplies for our customers'* (**E8**).

- Florida Power and Light, USA: Florida Power and Light is the largest retail electricity provider in the US, serving more than 10 million people. The company has engaged NMG in a three-year contract for vegetation analytics and management covering its 4,000 miles of high-voltage transmission lines. Florida Power and Light is responsible for LiDAR data collection while NMG has designed the workflow and analysis. This agreement has enabled Florida Power and Light to eliminate repeat ground patrols and to carry out rapid assessment of vegetation conditions, reducing the risk of both outages and regulatory violations. The operations leader at Florida Power and Light has estimated that the collaboration with NMG saves USD100,000 per year, and means that *'…our team is the first to perform a LiDAR capture 'in house' on such a large scale (4,000 miles) and have been able to do so at a fraction of the cost of the rest of the industry (based on recent industry benchmarking indicators)'* (**E9**).

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

E1: Knowledge Transfer Partnership Application, 4 February 2015.

E2: Partners Final Report, Knowledge Transfer Partnership KTP010013 (2017).

E3: Network Mapping Group website, https://nmgroup.com/en-gb/services/vegetation-analytics, accessed 31 January 2020.

E4: Video presentation by the business development manager, NMG Australia, at EECON 2019, 26-27 November 2019, Sydney, Australia.

E5: Audio interview with the technical director, NMG, 22 January 2020.

E6: Endeavour Energy (2018) Regulatory Proposal, 1 July 2019 to 30 June 2024, available at https://www.aer.gov.au/system/files/Endeavour%20Energy%20-%200.01%20Regulatory%20Proposal%20-%20April%202018%20-%20Public.pdf.

E7: Video interview and presentation by the vegetation manager, Endeavour Energy, at EECON 2019, 26-27 November 2019, Sydney, Australia.

E8: NMG (2019) Efficient vegetation management: A UK Power Networks case study, available at https://nmgroup.com/en-gb/resources/casestudies?category=case-studies-vegetation-management.

E9: Presentation slides by the operations leader (transmission/substations), Florida Power and Light, at Trees and Utilities 2019, 10-12 September 2019, Cincinnati, Ohio.