Forest Research

Forest Research Impact Case Studies

November 2017

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The Research Agency of the Forestry Commission

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Forest Research is the Research Agency of the Forestry Commission and is the leading UK organisation engaged in forestry and tree related research. The Agency aims to support and enhance forestry and its role in sustainable development by providing innovative, high quality scientific research, technical support and consultancy services.

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Background

In 2015, Forest Research (FR) was commissioned by Corporate and Forestry Support (CFS) of the Forestry Commission (FC) to undertake a four-year research programme entitled 'Integrating research for policy and practice' (referred to here as 'CFS Programme 7'). The overall aim is to understand and demonstrate how the impact of research into trees, woods and forests can be enhanced through dialogue and collaboration between scientists, policy-makers, land managers and other stakeholders across the public and private sectors. The programme is led by social scientists from FR's Social and Economic Research Group (SERG).

A key activity of the programme is the coordination and development of 15 case studies. These will be used to analyse and demonstrate the impacts of a range of projects led by FR, the causes of impact, and lessons learned. This interim report presents our findings to date for the case studies in preparation for the FR External Review Group visit on 6-8 November 2017.

Case study selection and development

The 15 case studies were selected from responses to a research questionnaire completed by 70 FR and FC staff over the last 12 months. They were chosen to reflect the diversity of research, advisory work and training delivered by FR according to several criteria: science group & CFS programme, size of budget, policy agenda, types of users, types of outputs, degree of interdisciplinary working and co-production of knowledge, the dissemination strategy that was used, and the types of impact that were realised. The list is given in Table 1 below.

Case study leaders were asked to describe their research activities and outputs, the impacts and reasons for impact, and lessons learned, through reflective self-evaluation. SERG staff facilitated the writing process through a number of iterations, guided by a template (see Appendix), which included a typology of impacts developed by Laura Meagher and colleagues: a) instrumental impact, b) conceptual impact, c) capacity-building, d) enduring connectivity, and e) changes in attitude and culture towards knowledge exchange and research impact (Meagher et al. 2017). The template also included a generic list of factors influencing impact, which was developed by members of

SERG. To date, 11 of the 15 short-listed case studies have completed this first phase of the work; the remaining four (or similar alternatives) will be completed by early 2018.

Table 1. Impact case studies

	Project/topic	Lead Science Group	CFS Programme[1] (Work Package or Area)	FR lead
1	Long-term monitoring of carbon and greenhouse gas fluxes	Climate Change Research Group	P1 (WA5.1, 5.2, 5.3) P6 (WA5.3)	Matt Wilkinson and Ed Eaton
2	Ecological Site Classification	Climate Change Research Group	P1 (WA4.1) P3 (WA3.1)	Stephen Bathgate
3	Slowing the Flow at Pickering	Physical Environment	P1 (WA3.4) P4 (WA1.2)	Tom Nisbet
4	Sitka spruce breeding programme	Forest Resource and Product Assessment	P5 (WP3)	Steve Lee
5	Adaptive genetic diversity	Species, Genes and Habitat Conservation	P1 (WA2.1)	Joan Cottrell and Stuart A'Hara
6	Population monitoring and management of feral wild boar	Species, Genes and Habitat Conservation	P3 (WA4.3)	Robin Gill
7	The health and wellbeing benefits of trees, woods and forests	Social and Economic Research Group	P4 (WA1.1)	Liz O'Brien
8	Economic analysis helping underpin the Woodland Carbon Code	Social and Economic Research Group	P4 (WA3.2)	Gregory Valatin
9	WrEN: Woodland creation & ecological networks	Land Use and Ecosystem Services	P1 (WA2.5)	Louise Sing and Kevin Watts
10	i-Tree: quantifying and valuing urban forest benefits	Urban Forest Research Group	P1 (WA4.2) P3 (WA5.2) P4 (WA1.3)	Kieron Doick, Clare Hall, Kathryn Hand, Liz O'Brien & Susanne Raum
11	Forest carbon and biomass policy	Forest Mensuration, Modelling and Forecasting	P6 (WP5)	Robert Matthews
12	Hylobius Management Support System	Tree Health	P2 (WA4.5) P3 (WA4.5)	Roger Moore
13	Advice for Phytophthora ramorum	Tree Health	P2 (WA1.1, 3.3)	Joan Webber
14	Pesticide derogations	Forest Management	P3 (WA4.1)	Ian Willoughby
15	Forester GIS	Inventory, Forecasting & Operational Support	IFOS	Morag Hawkins

[1] In most case studies, the research was externally funded as well as core funded by CFS.

During a second phase, the core Programme 7 team is helping case study leaders to identify key stakeholders and ask them for feedback on similar questions covered in the template, i.e. what changed and why, and what lessons can be learned. To date, this phase has been completed by one case study (#10), which reports on a detailed evaluation of ‘i-Tree’ (a suite of software tools that assess the value of urban trees) that was commissioned independently of Programme 7. We plan to carry out phase two over the coming six months, possibly for a subset of the 15 cases.

Looking ahead to a third phase, interested researchers will be invited to work with the Programme 7 team, and communications teams in FR and other parts of the sector, to share their impact stories in engaging ways (e.g. through trade articles, webpages and social media). In some cases, the possibility of collaborations with artists and writers will also be explored.

In 2018, we will reflect on the value of the case study process in workshops with researchers, senior managers and other stakeholders, to help develop, test and deliver recommendations, guidance and tools. The cases will also be analysed to help identify general patterns, lessons and actions that can help the agency and sector make greater use of the expertise, enthusiasm, innovation and commitment of FR researchers, and their partners and stakeholders.

Initial findings

The case studies confirm that FR research activities are delivering across all five types of impact identified above. They provide several compelling examples of instrumental and conceptual impact on policymakers and practitioners, and insights into how we conduct our work and how this might be improved.

The reasons for impact are seen to be diverse and complex. Multiple factors often need to be in place, both within and beyond the influence of individual researchers. The case studies affirm the value of engagement with key stakeholders throughout the research process, creating opportunities to reflect on and if necessary revise the research questions and agenda, the assumptions that underpin the research, the ways in which its results and conclusions are communicated and interpreted, and the forms of financial and other support required to realise desired changes to knowledge, attitudes, decisions, behaviours and actions on the ground.

In terms of lessons for the future, the case studies suggest a need to move beyond a focus on the delivery of research outputs and work towards shared understandings of impact for any given research activity. This may require changes to how we understand our roles and responsibilities, our business processes and ways of working together, and the mechanisms through which we receive funding and support. In particular, the case studies are beginning to demonstrate the value of embedding some kind of reflective practice into the everyday activities of the agency.

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1. Long-term monitoring of carbon and greenhouse gas fluxes

Matthew Wilkinson and Edward Eaton

Climate Change Research Group

1.1. Introduction

Trees, woodlands and forests play a crucial role in helping to mitigate the harmful effects of anthropogenic climate change through their ability to sequester (remove or lock up) carbon dioxide from the atmosphere and therefore are being promoted as a climate change mitigation measure. In the late 1990s FR established one of the first 'flux' towers in the UK to continually measure in real time the exchange of carbon dioxide between the atmosphere and a plantation oak woodland in south-east England. As the climate has continued to change, these measurements have also been sustained and are providing a unique and powerful data set allowing FR scientists and collaborators to understand and model the complexity of the processes controlling carbon sequestration in deciduous broadleaved woodland ecosystems. Over the past 20 years the number of flux sites around the world making comparable measurements has increased rapidly, however very few other forest sites have a record of comparable length to that from Alice Holt. This case study focusses on the research activity of the Straits Flux site which forms part of a much wider forest and greenhouse gas research programme at Forest Research.

The overall objective of the project is to improve understanding of processes controlling the carbon exchange at the stand scale, including the impacts of climate, management and natural disturbance events (e.g. disease and defoliating insects). At the onset of the project, the original intended users were a niche scientific community and FC policy requirements. However, as our understanding of the power of these measurements developed, along with the increasing length of the data set, our intended audience changed. In parallel with this, the number of flux sites around the world also increased, with the results that the Alice Holt data has become part of an important international data set that is now being used to influence global policy on climate change mitigation. At a more local scale, these data are of value to a number of scientific disciplines: forest ecologists and physiologists have used the data to help improve understanding of carbon and water cycling processes; remote sensing scientists are reliant on these data to validate satellite observations; and the forest modelling community use data to parametrize and validate models. The long-term nature of the project and data set (>18 years) have been key to its success and impact.

The project receives FC core funding and forms part of Programme 1, WP5, WA 5.2; there are strong links to WA 5.3 soil C and 5.1 on environmental monitoring. The site is run by one PB4 researcher with support from a PB5 research assistant.

1.2. Description of research activity

This project which is located in the Straits Enclosure, Alice Holt Forest, Hampshire uses a technique called Eddy Covariance (EC) whereby the rapid turbulence in the air (or 'eddies') and the fluctuations in the carbon dioxide concentration are measured simultaneously to see how they 'co-vary' (vary together). Scientific instruments are mounted above the top of the forest canopy on a 26m walk-up scaffolding tower. Research, knowledge and data from the site are communicated and disseminated in a variety of traditional and novel methods.

Original scientific research from the site is regularly published in peer-reviewed scientific journals, and presented at national and international scientific conferences. The full eighteen years' worth of site data is freely available to the scientific community, through our participation in the European Flux Database project (http://www.europe-fluxdata.eu/) and the Defra open data project (http://environment.data.gov.uk/index.html).

The Straits Flux site has also been used for many years as a collaborative research facility. Several MSc and PhD students from a range of UK universities have based their research around the Straits flux site. Other UK and international research institutes have also carried out environmental research (e.g. water isotope monitoring led by Dan Nelson from the University of Basel) and monitoring (CEH-led COSMOS project (http://cosmos.ceh.ac.uk/)).

Communication during site visits. Individuals or groups who visit the Alice Holt Research Station regularly take the opportunity to visit the Straits Flux tower. Visitors have a diverse range of interests and backgrounds, and have ranged from local community groups to visiting international scientists and groups of students. These visits typically last between one and two hours, during which the visitors get a chance to see and discuss the research carried out at the site with one or more members of the project team. Over the course of this project, there have also been several high-profile visitors to the site including the Government Chief Scientific Advisor (Sir John Beddington), several FC Commissioners and Ministerial visits. Such high-profile visits enable the FR scientists to demonstrate the importance of their work and enhance the reputation of FR as a cutting edge and relevant institute.

Collaborative support. Because of the synergistic links between this project and other FR research in Alice Holt Forest, and due to the experience and knowledge of the project team, we regularly provide collaborative supportive and informal advice to both other internal FR science projects (e.g. the Alice Holt Environmental Change Network and the

Soil Sustainability research) and external groups (e.g. BIFoR, CEH JULES Team and the Met Office).

Participation in art project. In 2014 the high frequency raw data collected at the Straits Flux tower were used by the artists Semiconductor to produce a sculpture called 'Cosmos'; this was one of two commissions made through the Jerwood Open Forests in England. The Cosmos sculpture is now on permanent display in Alice Holt Forest Park. In the artists' own words:

"The spherical piece is based on one year's worth of measurements of the take up and loss of carbon dioxide from the forest trees collected from the top of a 28m high flux tower, located nearby in the research forest at Alice Holt. The artist's work considers scientific data as a means of understanding the environment, and explores the relationship between how science represents the physical world and how we experience it. Through a process of re-contextualising the data, it becomes abstract in form and meaning, taking on sculptural properties. The work will be open to the public for years to come"

International summer school. In the summer of 2016 the Straits research site hosted participants at an international summer school on measuring and modelling greenhouse gas balances. This was a component of the NERC-funded greenhouse gas programme. Twenty-five early career scientists from across Europe and further afield got hands-on experience of estimating tree biomass (including laser scanning techniques), measuring CO_2 exchanges from soil and whole forest stands, characterising soil carbon stocks, and assessing leaf area and modelling forest carbon uptake. The various activities led up to a consolidation session, 'putting the numbers together'. FR staff led the organisation of the visitors and co-ordinated the full programme which involved a number of FR staff and colleagues from Edinburgh University acting as tutors.

Social and new media. Working with FR's Communication team, the site manager and research assistant have embraced new platforms for communicating the science and interesting biological or meteorological events. Two online videos have been produced which are available on the FR Vimeo channel, and a series of tweets have also been produced which link to the Forest Research website.

1.3. Impacts

The research that has been carried and disseminated from the site has helped to improve the scientific knowledge not only of FR staff, but also of the wider global flux community, specifically in the fields of long-term inter-annual variation in carbon fluxes and the impacts of management thinning. This work has fed directly into a number of important research synthesis studies (e.g. Morison et al., 2012) since the site provides the only long-term data set of its type for oak woodland in the UK. There has also been a direct contribution to numerous peer reviewed scientific journal papers, both with FR first authors (e.g. Wilkinson et al., 2012, Wilkinson et al., 2016, Yamulki and Morison 2017) and as contributory authors (e.g. Ward et al., 2014, Xia et al., 2015).

Although it is difficult to quantify, there are several examples of scientific methods and techniques that have been adapted for use in temperate forests at the Strait Flux site which have subsequently being taken up and used by other scientific groups, (e.g. technical staff from the BIFoR FACE site at Mill Haft sought our assistance when they were considering starting stem CO_2 flux measurements at their site). The site was one of the first in the UK to use repeat digital photography as a near remote sensing application, a technique that has now become common at many monitoring sites both in the UK and around the world.

Through the Straits Flux site, FR has been able to develop stronger collaborative links with several UK Universities (e.g. Edinburgh, Swansea, Newcastle, Reading and RHUL) and Research Institutes (e.g. CEH & BiFOR). FR played a major role the recent NERC-funded project, greenhouse gas programme. One of the key aims of this project where the Straits data was used was to build accurate GHG inventories and improve the capabilities of two land surface models (LSMs) to estimate GHG emissions. The development of collaborative links with UK universities facilitated through this project has also led to the successful completion of several joint PhD and MSc studies. International research links have also been developed through collaborative projects carried out at the Straits e.g. the Phenological Eyes Network (PEN). This project, led by a Japanese scientist at the University of Tsukuba, has facilitated the sharing of ideas and techniques through the development of links with the Japanese scientific and remote sensing communities.

Whilst presentations at conferences both international and more local, are a more formal way in which the work at the Straits has impact, less formal interactions with groups and individuals can have impact too. The Greenhouse Gas Summer School in 2016 was particularly wellreceived by the participants, with one student from Italy commenting afterwards:

"I really enjoyed the summer school. It was my first one and I learnt a lot! And the two days in the forest were indeed really interesting, well organized, I learn new things and it was really enjoyable to talk to you guys!"

Engagement with local universities and students is an important aspect of the impact of the Straits. Staff took on a placement year student from the University of Reading, who assisted with various research projects at the Straits. His BSc dissertation, in collaboration with the team, won the prize for the best soil-related dissertation that year, and he gained a first-class degree. Inspired by the time he spent with the team, he subsequently went on to study for a PhD.

A visit by a group of students from the University of Reading, as part of a module on ecosystem services, was followed by the comments below from the tutors who accompanied them:

"I just wanted to say in writing what an excellent visit Matt and Ed gave the Reading students this morning. Despite the weather, the on-site presentations about the work were among the very best I can recall from many visits to the tower and the level II site. The questions and points raised indicate the interest engendered and how well the research meshed with the course module looking at ecosystem services."

"…this was greatly appreciated by the students. The visit has received an excellent feedback - the issues you were presenting fit very well with the theoretical approaches discussed in the classroom."

The education of younger scientists and students of science is something that the team believe in, and try to contribute to wherever possible. Work experience students from local schools are often taken on, with comments from two of them given below:

"Just to say thank you very much for showing me what goes on at the research centre during my work experience week. There was a good variety of things to do and gave me an understanding of the work that's involved at the centre." Year 9 student from Weydon School, 2014.

"I have gained so many valuable skills from it and I have enjoyed myself very much." Year 10 student from Hounsdown School, 2015.

Other impacts are not brought about by the team directly. The Cosmos sculpture, mentioned above, generated attention in a number of media outlets nationally and internationally, including Architects' Journal, ICF, Public Art Online, Artdependence magazine, a-n.co.uk, WorldNews Network, architetti.bticino.it, as well as being used as a case study in a Brazilian journal (Zanotello, L.G.F. Data aesthetics: a estéticas de dados e o papel da narração em artefatos generativos. **V!RUS**, São Carlos, n. 11, 2015. [online] Available from: http://www.nomads.usp.br/virus/virus11/?sec=4&item=3&lang=pt. Accessed: 28.7.2017).

There has also been some very positive feedback from members of the general public who have had their visitor experience at the Alice Holt Forest Park enhanced by the Cosmos sculpture (see for example https://tinboxtraveller.co.uk/2017/02/family-cycling-alice-holt-forest/. Accessed:19.9.2017 and http://www.rsgardendesign.co.uk/inspiration/2016/01/14/theres-something-in-the-forest/. Accessed:19.9.2017).

Furthermore, the commercial companies that were involved in the production of the sculpture have also capitalised on their involvement to enhance their websites and to showcase their technical and production capabilities (see for example http://wupdoodle.com/case-studies/. Accessed:19.9.2017).

1.4. Reasons for impact

One of the main reasons why impacts have been successfully generated from this project is due to the motivation of the small project team. All of the staff involved are keen to communicate their work and passionate about communicating their science, with the science group leader supporting this ethos and encouraging novel methods of communication. The team is good at spotting and developing opportunities to generate impact (e.g. winner of the 2016 CommBeBiz Bio Economy photo competition, with the photo subsequently being used as the cover image for Teagasc Research vol 11:1 and to illustrate an article on communicating the bioeconomy through images). Furthermore, the team is proactive in seeking out opportunities to create impact, especially though communication opportunities and knowledge exchange (e.g. we were able to rapidly produce a series of tweets and web pages demonstrating the impacts of the recent UK heat wave on carbon sequestration at the Straits).

The physical location of the Straits Flux tower, close to the Alice Holt Research Station, and the fact that we actually have 'something to show' has helped to keep the project visible. The team work hard to make sure that the Straits C Flux work is prominent in the awareness of other staff at Alice Holt, to keep the project as part of visits to Alice Holt, through internal seminars, posters and informal contact.

The concerns and scientific questions that the Straits was originally set up to address haven't gone away over the past twenty years: it is still relevant and timely. Due to the investment required, there is a lack of such research infrastructure in the UK to investigate these issues, and therefore the Straits Flux site is of national and international scientific importance.

1.5. Lessons learned

- Impact has to be pursued but some happens indirectly.
- Having a physical presence in the forest (i.e. a large tower) facilitates the dissemination of knowledge and improves understanding because it gives the visitors an experience from which they can 'hang' the science.
- We need to improve how we define and how we measure impact.
- We need to get better at planning impact rather than being opportunistic.
- Both formal and informal networking has led to important impact opportunities.

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2. Ecological Site Classification

Stephen Bathgate

Climate Change Research Group

2.1. Introduction

Ecological Site Classification (ESC) was developed in the 1990s to provide an objective system for tree species selection in support of sustainable forest management objectives. The tool was built around the principle that tree species growth could be viewed as a function of site climate and soil conditions. It was intended to complement previous systems, which were mainly in the form of published bulletins, and enable users to work directly with models and spatial data. It is one of only 11 such decision support tools available globally and one of the only tools available to support multi-criteria, multi-objective forest decision-making which takes account of the future climate.

The initial research included working with international partners who had developed similar systems as well as leveraging upon contemporary and historical works which provided a sound scientific basis for the techniques employed. As some of the information was derived from data collected for different purposes, the research programme included PhD research that provided evidence for the relationship between soil nutrients and indicator plant species.

Through the provision of ESC tools to the forestry sector it was anticipated that impacts would emerge across policy and practice, at scales ranging from national through to site level. In part the requirement for ESC emerged from the changing policy objectives, forest certification and the financial challenges facing restock programmes. The policy drivers were related to the increasing interest in native woodlands and less focus on production objectives, coupled with a desire to reduce the intensity of chemical inputs in forest establishment for environmental and financial reasons.

The research and development was primarily conducted within the Ecology branch of Forest Research, with input from experts in silviculture and wind risk to provide country-wide maps of exposure indices that were not available at the time from other sources. Initial work delivered case study outputs for Grampian followed by the New Forest and led to the publication of a software tool that operated at the level of individual forest stands in 2001, with Forest Research utilising a spatial version of the model in consultancy work. Following the release of version 1, subsequent iterations focussed on making the software tools and data more widely available and integrating those with the business processes of forestry stakeholders across the private and public sectors. In addition, outreach activities led to the inclusion of ESC tools within university courses and the development of dedicated training within the Forestry Commission. Research activities have also continued with work on climate change and extensions to ESC for ecosystem service appraisal and wider silvicultural guidance.

2.2. Description of research activity

The initial research activity was documented in an unpublished report by Pyatt *et al.* The work was a synthesis of activity both within Forest Research and the Forestry Commission (soil classification systems and exposure data), and external groups such as BADC (Climate data), CEH (indicator plants). Spatial climate data were developed in the late 1990s to provide national-scale coverage at high resolution, by applying downscaling processes on lower resolution data to account for topography. Some of the work included coordination with other research programmes to obtain exposure risk maps (which were being developed in parallel by Silviculture branch). ESC models of tree species potential were knowledge based, which required the use of Delphi exercises to generate much of the data from silvicultural specialists with good knowledge of species trials across GB.

Initial delivery of ESC to customers in 2001 was a Microsoft Windows application delivered on CD format accompanied by a user manual, with a nominal charge to cover handling costs and production. This version of the tool was intended for use at an individual site level by forest practitioners, but additional versions were created to handle spatial data at operational (forest block) or national scales. The latter tools were utilised in consultancy contracts and reports but could not be disseminated more widely because of their dependencies upon certain data and software to operate them effectively.

The first version of ESC was complemented at the time of release with the provision of ESC related training courses delivered by FR. The courses were run throughout GB but the delivery capacity was unsustainable alongside research activities and the courses were phased out once it was believed sufficient staff had been trained.

Around 2003 it was decided to develop a new version of ESC that could be maintained more easily and work also started in parallel on systems that integrate ESC to provide a range of silvicultural advice based upon site factors. Those activities shifted ESC from being a desktop tool to being a freely available web based system increasing the accessibility of the system to users. This was possible at the time because of the decision by FC to develop web based systems for handling grant payments for woodland creation. The web based ESC tools centralised the software and ensured that users were always accessing the latest available models and data removing the need to distribute software updates.

While the new version of ESC was well received by some users the absence of training led the FC to take the initiative with a new course on site recognition and species choice.

This placed emphasis on the field craft elements of the tool and was well supported. However there was still a need for tools that could be utilised beyond the site scale.

In 2009 as a proof of concept, ESC was integrated with soils data and the Forestry Commission sub-compartment database (a GIS map of detailed stand information for the whole Public Forest Estate). The potential of this version of the tool was obvious to the forest planning community and led to a programme of work to digitise existing soils data and more collaboration between forest planners and researchers. Shortly afterwards ESC data was provided to FES teams who started building their own decision tools on top of those and stimulated demand for an ESC tool in Forester (the GIS system used by FC to manage the public forest estate). This was built as a soils data capture tool which provides a means for running ESC on the best available data.

Further development of new climate data from research programmes and the opportunities afforded by new technology led to further releases of new versions of the ESC tool that included more spatial features and the outputs of additional research into tree species options. ESC is now embedded in a number of business processes such as grant schemes, woodland carbon code and forest planning.

2.3. Impacts

While the extent of ESC use has been varied across stakeholders, the dissemination of the tool has stimulated discussion and formed a consensus among the community that site appraisal prior to planting is an important and valuable step. It has informed policy development, since ESC use makes it possible to quantify the impact of land use changes and where they are likely to be most significant (e.g. peatland restoration). The business processes of some forestry businesses are now built around site appraisal and most often ESC is central to this, because it also allows users to explore future climates.

Training courses have delivered additional capacity although impact within the FC has been varied due to staff turnover. Also the use of external contractors for soil mapping has meant that some of the site surveyor roles envisaged have not materialised to the extent anticipated. Funding has occasionally been found as a result of the increased profile of ESC, though this is not necessarily directly due to FR. For example training is handled by FC Learning & Development, and some FC districts are sufficiently expert that in most cases they can now utilise tools directly themselves, and soils data capture and other work is often undertaken by external contractors. Income has been generated however, for example on case study work, by utilising ESC as part of EU projects and most recently to appraise the suitability of large private sector planting schemes according to site conditions now and in the future.

The development of ESC also stimulated discussion on cross-cutting topics, for example the need for high resolution soils data, which led to a programme of data collection and curation within Forest Enterprise (managed by FR). ESC approaches to site classification were utilised in additional areas such as restocking guidance, peatland restoration and as data within experimental analyses. Essentially ESC provided a common set of variables that could be used to describe a site.

Table 1. Key impacts associated with ESC research

Community	**Impact**
Researchers	Availability of models and data to appraise species potential in future climates. Climate data can be used to explore relationships between experimental observations and site data.
Policy Makers	Appraisal of national scale options (e.g. peatland restoration, productive broadleaves) (FCS, FS, NRW) Development of policy measures such as species diversification Development of publications (e.g. images)
Practitioners	Better, easier and faster landscape planning (FES, FEE, NRW) to take account of future suitability of species to site. Results can trigger and inform discussion. Site level assessment and planning (foresters)
Communities	General public - Grant applicants without forestry background can test options (i.e. test species suitability to a site, to the end of the century) Wider awareness of the projected future impact of climate change on forests and woodland and the need to adapt to the changing climate. Wider awareness of the options of how to adapt through species diversification.
Forest Owners / Agents / Foresters	Selected and planted species better suited to both their site and the future climate as a result of using the tool.

A key impact has been the development of relationships between the ESC development team and the forestry community (by which we mean academia, research, and public and private sector interests). Through working in partnership with stakeholders across those sectors it has been possible for researchers to understand business requirements more clearly and tailor outputs accordingly. It has also led to the joint development of some tools as partners have additional perspectives on how data and models might answer planning questions.

For example Galloway Forest District produces over 600k cubic metres of timber annually and was asked to sustain this alongside species diversification and native woodland restoration objectives. Using ESC at a stand level would have been time consuming, while strategic analyses using coarse soil data lacked spatial precision. What was needed was an ESC analysis at a regional scale using high quality digital soil data. We worked with Galloway FD to build a system that worked at district scale and included functions to address specific business rules (for example a bespoke hierarchy of species preferences). The result was a dataset that illustrated where species diversification was feasible and/or illustrated the sites where production could be maximised.

Note that some of the impact is facilitated by initiatives to create open data and open source software upon which to build, and disseminate ESC. Those range from Ordnance Survey open-data digital elevation models, BGS lithology and climatic data from research groups in the Met Office and elsewhere. Without these initiatives, ESC could have been very expensive to disseminate due to the need for licensing fees and usage constraints. Open source tools reduced some of the software development and dissemination costs and provided a means for a number of user communities to utilise spatial data without the expense of commercial software.

2.4. Reasons for impact

It was apparent during early presentations of ESC to user communities that there was no ‘one size fits all’ version that would meet the diverse range of user needs. Those operating at a site level, needed a tool that worked at that scale, but this was too time-consuming for landscape planning when large numbers of sites might need to be considered.

The move to a web based platform for the tool provided the opportunity to collect usage data and this was found to be much higher than other evidence had suggested. A survey circulated by spreadsheet indicated low levels (<25 per year) of use of the desktop tools, though those undoubtedly were skewed by nil returns. The metrics from the ESC tools suggested around 1000 per year in 2009 and now over 100,000 per year (though some of those ‘uses’ will be clicks on maps for the sake of curiosity).

However, there was a consensus developing around the release of ESC that not all first rotation sites could sustain the same yields in the second rotation without the input of fertilisers. Increasingly there was evidence that both production and restoration objectives could fail due to inappropriate species choice and/or silviculture on new or restock sites. As a consequence there was a rekindling of interest in site-species matching techniques and ESC was widely regarded as the most robust tool available.

Much of the initial drive to embed ESC into the FC came via the Establishment Management Information System (EMIS) project, which built extensively upon ESC and was the focus of presentations to the planning community mainly in the FC. Initially those efforts were driven solely from a research side but the integration with soil surveying teams that regularly engaged with practitioners seemed to reassure some elements of the community that initiatives were ultimately simple and effective measures that would ultimately save time and reduce pressure.

Discussions around ESC (and EMIS) elevated the profile of soils data, much of which was undigitised and at risk of being lost as offices closed and data was rehoused or discarded. The foresight of the instigators of the ESC work, and the planners who shared the vision, led to the digitisation and effective curation of the FC soils data. This at last provided a sound spatial input dataset that could be used in tactical and operational plans (national soil data is poor for forest planning at 1:250,000 whereas FC data is higher resolution, generally 1:10,000).

The development of a spatial version of ESC in partnership with the FES planning community catalysed usage. This arose through the close working relationship between FES and the FR soil survey team (Andy Kennedy and Bill Rayner), and the connection was reinforced when ESC developers (Stephen Bathgate and Duncan Ray) increased their visibility with the two groups. This accelerated because now development was effectively a partnership and the tools were being used at scale in real world scenarios, such that they could be further disseminated and demonstrated in internal (FES) best practice events. In addition, some groups (Galloway, and Moray and Aberdeenshire) chose to build their own regional models upon ESC that could analyse district wide strategies.

In conjunction with this, representations to communities involved in grant schemes led to ESC being adopted as a step within the approval process thereby increasing usage in the private sector. The Woodland Carbon Code similarly embedded ESC within its protocols. Champions for ESC also emerged both within and outside the FC, who helped promote ESC in other forums (e.g. sector events, universities), and their role in stimulating the uptake of stand level tools was probably significant.

A geographical bias is also present in ESC use; it is used more in Scotland, because the development team have generally had limited opportunities to engage elsewhere. Unfortunately the training aspect, being delivered externally to FR, has not provided the same integration as other forums with users (because it is a one-way discourse). In England uptake was strong in the private sector largely because the Forest Services teams chose to promote ESC strongly at events, but impact is variable within FEE; it is widely used in the Lake District but in many other situations policy constraints limit species options and/or the site types have fewer issues than their upland counterparts. However there is also limited capacity to undertake engagement should the occasion arise as all the staff involved in ESC related work do so among other commitments.

Probably a critical success factor was the persistence of the ESC project over time. Many of the success factors depended upon underpinning actions to happen, for example the creation of digital soil maps. Without the long term commitment to the project, in terms of the researchers, commissioning groups and users, it is likely that the ESC tool would have a different form and user base from what it has today.

To reiterate in terms of the impact factors:

Problem framing and management

- ESC was relevant to forestry community interests both at policy and practice level (e.g. climate change)
- The embedding of ESC within protocols relating to grants and forest practices mandated some usage.
- Failure of tree establishment schemes highlighted that problems were real and that ESC could provide a solution.
- With increased interest in species diversification at a policy level, practitioners needed tools to test the effectiveness of hitherto lesser known options on their sites.
- Research commissioners had foresight in anticipating many of the issues in such time that a tool could be developed in a robust way.
- There was some resistance in the community as the impact of the tool might be additional overheads (extra time to collect and process data).

Inputs

- Contributions external to research, both in terms of support to justify work and feedback to steer development. For example liaising with private sector companies or universities.
- The initiative of teams to leverage multiple funding streams to enable ESC development work to benefit the whole community, for example, data generated in EU projects being integrated into the GB ESC tools.
- Flexibility for the researchers to engage with the community and develop solutions without rigid constraints in terms of technical platform or process.

Outputs

- Appropriate to user context, e.g. stand level tool for small scale requirements, spatial tools for large scale analysis with generic options.
- Licence free, direct cost is not a barrier to use of the tool.

Engagement

- The adoption of a partnership/network style to engagement and development rather than a top down hierarchal approach. However we did encourage the inclusion of ESC within processes where it was to the advantage of promoting good practice.

- Multi-faceted approach including training, informal meetings and presentations, and being available to meet the customer in a forum that works best for them.
- Provision of consultancy option where required.

2.5. Lessons learned

It was fortunate that ESC was instigated at a time when open data was the default model for dependencies external to the FC. If ESC was developed today, this section would be dominated by intellectual property considerations.

Much of the ESC impact developed organically through local initiative and the good will of the staff involved and their managers to support their involvement in the research and development. Although best practices for user involvement of projects include customer representation, this was not always in a constructive or useful form. For example some user group members may not have been appropriate to the use case being considered and it was only by coincidence that connections were made that facilitated progress.

It is easy to look back at this project and ascribe impact as luck. However the structures around the project (i.e. flexibility of staff to cooperate as necessary when they wanted to) also facilitated a level of independent action that created opportunities for co-production of tools between FR and for example Galloway Forest District. Additionally strong support was secured at a high level (at FES at least) that carried sufficient momentum to drive the project into new areas; this was very influential as it facilitated much of the work on the underpinning soil data requirements.

Technically lessons can be learned on the curation of data artefacts and the processes used to develop them. Staff turnover early in the project resulted in the loss of some knowledge associated with the creation of underlying data, and the absence of centralised data stores meant that some data were backed up on devices that are no longer available on the market.

In terms of process it is difficult to say whether more would have helped or not. Clearly there was process in the form of user groups but as alluded to earlier those were often not well constructed for the use cases under development (e.g. operational staff driving planning tools or vice versa). For instance they might not meet more than once, included individuals who were disconnected from the process or who would not represent an intended user. So a lesson learned is that the selection of user community representatives should reflect the intended user group, and they should meet frequently such that iterative processes can take effect. Unfortunately cross organisation working groups often ceased to meet or lost inertia as a result of other priorities.

As a research programme, one key lesson is the need to sustain capacity such that the tools and processes continue to be relevant, and supported within the forestry community. Presently much of this happens through the alignment of various strands of work that collectively created a meaningful user base for ESC.

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3. Slowing the Flow at Pickering

Tom Nisbet

Physical Environment Science Group

3.1. Introduction

The 'Slowing the Flow at Pickering' project was established in April 2009 to look at how changes in land use and land management can help to reduce flood risk in the town of Pickering in North Yorkshire. Pickering has a long history of flooding, with four floods in the last fifteen years (1999, 2000, 2002 and 2007). The 2007 flood was the most serious to date, causing an estimated £7 million of damage to residential and commercial properties. Whilst a flood alleviation capital scheme had been proposed to alleviate the problem, a cost-benefit analysis showed this to be unaffordable when set against national cost-benefit thresholds and other priorities.

The 'partnership' project led by Forest Research (FR) represented a new approach to flood management that sought to work with natural processes to help reduce the risk of flooding for affected communities. It was one of three pilot projects funded by Defra under their multi-objective flood management demonstration programme in response to Sir Michael Pitt's Review of the 2007 floods in England and Wales. The Review called for Defra, the Environment Agency and Natural England to work with partners to deliver flood risk management projects involving greater working with natural processes.

A crucial element of the approach was to understand better how floods are generated in a catchment and how the way the land is used and managed affects the speed and volume of flood flows. The combined effects of past land management practices by humans over centuries are thought to have increased flood risk by promoting rapid runoff and increasing siltation within river channels. There are four principal land uses in the *c.* 69 km^2 catchment of the Pickering Beck that drains to Pickering, comprising forest, arable farming, heather moorland and improved grassland. The overall aim of the project was to demonstrate how land use change and improvements in management practices could help to restore the catchment's natural flood attenuation capacity.

While the focus of the project was on managing flood risk, it was also recognised that working with natural processes via the planned 'measures' would deliver wider environmental, economic and social benefits. An attempt was made to evaluate these ecosystem services so that they could be recognised and factored into future flood risk management planning and related decision making processes.

The project has involved three phases of work. The first (2009-2011) focused on building a strong local partnership of organisations to help drive the project forward and bring the local community on board. Efforts during the second phase (2011-2015) concentrated on delivering an agreed set of land management interventions designed to reduce the chance of flooding in the town from 25% to 4% or less in any given year. The study has now entered a third phase of longer-term monitoring to capture the effects of the measures on future flood flows. The total cost of the project is estimated to be around £4m to date.

3.2. Description of research activity

Early on, a Programme Board comprising senior representatives from the main partners and funders was established to help steer and oversee the project, while a Programme Delivery Group was formed with representatives of the regulatory bodies and land owners and managers to guide the development and implementation of the agreed interventions. The main partners are:

Lead partner and Grant Holder: Forest Research (FR)

Funding and Regulatory agencies: Defra (lead funder), Forestry Commission England (FC(E)), Environment Agency, Natural England (NE) & Yorkshire Flood & Coastal Committee.

Major Land Owners: FC(E), North York Moors National Park Authority (NYMNPA), Duchy of Lancaster Estates & North York Moors Railway.

Local Authorities: NYMNPA, North Yorkshire County Council, Ryedale District Council, Pickering Town Council & Sinnington Parish Council.

Community Representatives: Ryedale Flood Research Group, Pickering Civic Society & Pickering Flood Defence Group.

Research: FR, Durham University.

Initial efforts focused on identifying and agreeing priority sites for implementing selected measures. Most of these were targeted to the Pickering Beck catchment but some extended into the neighbouring catchment of the River Seven to help contribute to managing flood risk for the village of Sinnington. A total of seven measures were originally planned with clear targets set for their delivery.

A start was made to implementing the measures in Phase I of the project but most were delivered in Phase II, requiring longer time to agree plans and secure funding. The 4-year extension of the project allowed nearly all of the original objectives to be achieved or exceeded, with the main flood storage area the last to be completed in September 2015. Efforts have since focused on maintaining the measures and monitoring their performance. The following measures have been implemented to date:

1. 129 large woody debris (LWD) dams constructed within the Pickering Beck catchment and a further 38 in the River Seven, exceeding the project target of 150 dams. An additional trial of two novel 'timber bunds' were installed in the latter catchment.
2. 187 heather bale check dams constructed within moorland drains and gullies, no-burn, 10 m wide buffer zones established along all moorland watercourses, 3.2 ha of heather reseeded and 800 m of eroding footpaths repaired in the Pickering Beck catchment, achieving the original target of blocking any problem drains and establishing no-burn buffers.
3. 19 ha of riparian woodland planted within the Pickering Beck catchment and 10 ha in the River Seven. The partnership worked hard to maximise the level of woodland creation but could not meet the target of 50 ha riparian woodland and 30 ha floodplain woodland due to biodiversity and landscape sensitivities in the Pickering Beck catchment and landowner financial considerations in the River Seven catchment.
4. 15 ha of farm woodland planted in the River Seven catchment, exceeding 5 ha target.
5. Site operational planning revised within Cropton Forest and the wider Forest District to help secure opportunities for forest re-design and management to maximise benefits and minimise risks for flood mitigation, in line with project target. 5.9 ha of riparian buffer restored in the two catchments; 3.3 ha (1,470 m of streamside) in the Pickering Beck catchment and 2.6 ha (1,309 m of streamside) in the River Seven catchment.
6. Roof, yard and related works undertaken on 10 farms in the Pickering Beck and River Seven catchments under Catchment Sensitive Farming, including the construction of check dams (no specific target set for the number of farms or works).
7. A large flood storage bund constructed in the Pickering Beck catchment, as per the original target.

The contribution of these measures to flood risk management can be assessed in terms of flood storage creation, with the large bund making the greatest contribution by providing 120,000 m^3 storage, followed by an estimated 8,000-9,000 m^3 for the woodland measures and ~500 m^3 from the moorland and farm measures. The woodland measures in the neighbouring River Seven catchment were estimated to provide 7,000-8,000 m^3 of flood storage to help reduce flood risk to Sinnington. The delaying effects of the wider catchment measures are not accounted for in these figures and are predicted to significantly enhance the flood attenuation effect.

Much effort has been spent on reporting and promoting the work of the project, which has resulted in it gaining a strong national profile and being extensively cited as a case study demonstrating the value of working with natural processes. A summary of the main knowledge exchange activities during Phase II of the project is provided in Appendix 14.7 of the final project report (see: www.forestry.gov.uk/fr/infd-7zucqy).

Project management, co-ordination, research and reporting were primarily funded by Defra (£480k between 2009-2015). Match funding from partners for project support and implementation of measures totalled around £3m over the six years. Additional costs were involved in completing the main flood storage bund in summer 2015. Longer-term project management, monitoring and evaluation costs in Phase III are £20-30k/yr and primarily funded by the Forestry Commission to date.

3.3. Impacts

The main focus of the project has been reducing flood risk for the town of Pickering and the adjacent village of Sinnington. The partnership and more importantly, the local community, believe the project has been very effective in this regard by delivering a set of measures that observations suggest are already working and modelling predicts should more than meet the target level of flood protection for the town of Pickering (reducing the chance of flooding from 25% to 4% or less in any given year). This has improved confidence among regional and national stakeholders and policy makers in the role of natural flood management in managing flood risk, as well as being able to deliver wider benefits.

A monitoring programme was established to quantify the effect of the measures in reducing flood flows. Although some of the land management interventions such as woodland creation will take time to become fully effective, an attempt was made to determine if they had any impact on the first high flow event recorded in November 2012. The local community believed that the measures implemented by then (which pre-dated bund construction) helped to prevent an expected flood but an analysis of the data proved inconclusive, possibly due to the multiple peak nature of the event.

The next main storm event was on Boxing Day 2015, when 50 mm of rain fell over a 36-hour period. An analysis of the flow measurements concluded with a relatively high degree of certainty that the project measures prevented flooding to a small number of properties in the town. It was estimated that the measures reduced the flood peak by 15-20%, with around half of the reduction due to the upstream land management interventions and half due to the flood storage bund. The results are consistent with other observations that show the measures to be working as expected in reducing flood generation by storing and slowing flood waters within the catchment.

Other important impacts of the project have been:

1. Helping to guide and integrate the implementation of government policy on flood risk and land use management by influencing policy makers (e.g. through site visits by senior government officials, committees and politicians). In particular, it has underpinned key regional and national initiatives on Woodlands for Water, including the use of opportunity mapping to identify priority locations for planting to reduce flood risk, and the introduction of a Woodland for Water grant payment of £2,000/ha under the previous English Woodland Grant Scheme. This led to 867 ha of targeted planting of woodland to reduce flood risk and/or diffuse pollution in Yorkshire and the North East Region by December 2014, and 1,857 ha across England. More recently, it has helped shape the Countryside Stewardship Scheme and a new national forest industry initiative on the role of productive woodland in water management. This includes directly informing the design of two sizes of large woody debris dam, which were added as new capital items to the Scheme in 2017.
2. Creating a more joined up and inclusive approach to flood, water and land use management (through greater awareness and consideration of the benefits of working with natural processes), driven by stronger local and regional delivery partnerships. This includes informing the development of the Local Flood Risk Strategy and Flood Risk Management Plans, as well as the Derwent Catchment Strategic Plan for tackling related water quality issues. Nationally, the project has informed FC guidance on managing forestry and flooding, the EA's Working with Natural Processes Framework and the Catchment Sensitive Farming Delivery Initiative.
3. An engaged local community (in particular those residents and businesses affected by flooding and their Local Authority representatives), who have embraced the concept or working with natural processes and believe this new approach to flood risk management is making a difference. The local community were kept fully informed by local champions sitting on the Programme Delivery Group (e.g. via feedback to flood groups, social media and articles in local and regional press), through three community engagement days, newsletters, and via the project website.
4. Helped raise awareness of the multiple benefits/services provided by working with natural processes and informed the economic evaluation of ecosystem services. This included involving local practitioners and community representatives in a working group to assess the likelihood of impact of the measures across the full range of ecosystem services, followed by a more detailed economic evaluation of significant positive and negative impacts. The working group exercise was highly valued in promoting understanding of the role of ecosystem services, and directly influenced national stakeholders by helping to test draft guidance on applying the approach in practice.
5. Trained a NYMNPA team of Modern Apprentice Estate Workers plus helped develop contractor skills in constructing large woody debris dams and timber bunds. This

provides a local resource of skills and knowledge to extend flood risk management measures locally and regionally.

Forest Research played a key role in delivering the above impacts. Aside from overall project management and grant holder duties, FR led the implementation of the upstream land management measures, were responsible for much of the monitoring and assessment work, took the lead in the majority of knowledge exchange activities, including reporting, presentations, site visits and local engagement, undertook the ecosystem services evaluation, and not least, influenced changes in policy and grant support on woodlands for water.

3.4. Reasons for impact

A key reason for impact was careful catchment and site selection, informed by research experience plus modelling and mapping tools. Central to the selection of the Pickering Beck catchment for the project was that around half of the land was either in public ownership or owned by the Duchy of Lancaster Estates, providing greater flexibility and likelihood of success in delivering measures on the ground. Another important factor was the availability of models and mapping data from previous projects. In particular, a Rural Economy and Land Use (RELU) study had pioneered new ways of incorporating local knowledge into strategic flood risk management, including the development by Durham University of a new hydrological model 'OVERFLOW' for assessing the role of land management interventions (Odoni & Lane, 2010). In addition, FR had already identified opportunities for targeted woodland creation within the catchments for flood risk reduction as part of a Regional Forestry and Flooding Initiative by the FC and the Environment Agency (Broadmeadow & Nisbet, 2010). Models were also used to design and test the effectiveness of measures, especially the low-level bunds.

Another reason for impact was the focus on strong project governance and partnership working. A partnership approach has been crucial to the successful delivery of the project, helping to resolve inevitable issues over land use and management changes within an environmentally sensitive catchment, deliver change on the ground and avoid risk aversion. The partnership was also important in formulating a clear set of objectives and success criteria, providing achievable but challenging targets.

The close involvement of the local community was also key to delivering a successful project, both in terms of helping to inform the approach and in managing expectations. The community strongly backed a more natural approach to flood management and became strong advocates by observing changes in river response, seeing how the individual measures acted during flood events and 'surviving' two near-floods that impacted on communities elsewhere in the region. However, they were also quick to accept that the measures had their limits and could not prevent all floods, the town remaining vulnerable to much larger flood events.

Other reasons for impact included the existence of base-line monitoring supplemented by additional site measurements to help evaluate the impact of the measures and provide scientific rigour in demonstrating changes to flood flows. Adequate resources were also critical, including a realistic time-scale for delivery; the original two-year time-scale was quickly recognised as being too short.

Knowledge exchange activities have also been key, with much effort spent on sharing and promoting the work of the project. It has received much local and regional TV, radio and press attention, as well as national interest, including on Sky News, the BBC's Politics Show and most notably as part of an episode of the BBC's science programme 'Bang Goes the Theory'. Many invited presentations have been given at conferences, workshops and training events held around the country and more than 20 site visits hosted for a range of key individuals (including high level government officials) and groups. A local 'champion', Mike Potter, also played a key role in knowledge exchange, both within the community and further afield. This included raising awareness of the project through national forums, such as winning the Judges Special Prize in the Civic Voice Design Awards 2015.

3.5. Lessons learned

Key lessons are considered to be:

1. The original plan was to use a series of low-level, earthen storage bunds that would collectively provide the required volume of flood water storage to help protect Pickering from flooding. In the end this proved not possible because of the Reservoirs Act, which treated these bunds as reservoirs 'in cascade'. As a result, they breached the limit for safe storage and therefore each bund required reinforcing, greatly increasing build cost. 'Value' engineering led to a single, large bund being the most cost effective option, reversing the original idea of creating a series of cheaper, more natural flood storage areas. This is an important lesson and potential constraint for future projects, with major implications for project funding.

2. The project benefited from being able to utilise an existing spatially distributed, combined hydrology-hydraulic model (OVERFLOW) that had already been calibrated to the Pickering Beck Catchment by Durham University under a previous RELU funded project. This and other models played a key part in the placement and design of the flood management measures to enhance their effectiveness in reducing downstream flood risk. Unfortunately, it was not possible to further develop or join up the different models to integrate the effects of the different measures, particularly the interaction of the upstream measures with the large flood storage bund. A number of factors contributed to this problem, including lack of resources, ownership rights and time constraints. It is important to be aware of these potential issues and try to address them at the start of a project to facilitate a fully integrated approach. More work is also

needed in improving process representation within models; one should always check which processes are included and how they are parameterised.

3. The OVERFLOW model provided a very useful tool for optimising the location of land management interventions. It demonstrated that slowing the flow at some sites can increase rather than decrease flood flows as a result of synchronising catchment contributions. It also showed that, in general, measures are likely to be most effective when placed in the upper half of a catchment (with the exception of flood storage bunds).

4. From a woodland perspective, efforts concentrated on delivering woodland creation and installing large woody debris dams, as well as amending forest operational plans to facilitate the latter. Initially, little consideration was given to wider forest design planning and the impacts of this on the level of existing forest cover. It is important to recognise that forest felling will temporarily reduce the forest effect, while other activities such as forest conversion to open land for habitat restoration or linked changes in forest type can also reduce or remove the benefit. These aspects need to be factored into the overall approach and efforts made to compensate for their impacts.

5. Measuring the impact of land management measures on flood flows at the catchment level is extremely difficult. For the evaluation of demonstration studies on sites lacking longer-term baseline data, it may be better to focus on measuring the effects on relevant site processes. These numbers can then be used by models to predict outcomes for flood risk management.

6. The focus of attention in flood management demonstration projects is inevitably on delivering measures on the ground to reduce downstream flood risk for impacted communities. However, all measures have a limited design life and thus consideration also needs to be given to developing a maintenance plan to ensure future effectiveness. This can prove to be a difficult issue as project funding will not cover costs and partners are less inclined to commit core resources in an uncertain financial climate. It can also act as a barrier to expanding measures to further reduce flood risk, especially where costs are not evenly spread between project partners and not part of ‘core’ business. More work is needed on developing systems for funding longer-term maintenance work, perhaps based on payments for ecosystem services.

7. Demonstration projects should include a formal ecosystem services assessment, which needs to be carefully planned from the outset. An initial qualitative assessment of the expected costs and benefits would help to guide data collection and thereby assist a final quantitative evaluation. The exercise also needs to be properly costed and resourced, as well as include protocols for handling sensitive data.

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4. Sitka spruce breeding programme

Steve Lee

Forest Resources and Product Development

4.1. Introduction

Breeding of Sitka spruce (*Picea sitchensis* (Bong) Carr.) has been an active FR Programme for around 55 years. It started in early 1960s with the selection of the first plus trees (rare trees of fine phenotypic quality for growth rate and stem form) in public and private forests all over the north and west of Britain. Over the next 20 years, over 1,800 plus trees were selected. Progeny testing was employed to determine the genetic quality of the parent (plus) tree in trials planted from late 1967 to early 1990s. By 2005 it was possible to calculate the breeding value of the entire original selected plus trees and rank them for growth rate, stem straightness and wood density. In the late 1980s, the first single-pair controlled crosses (known as full-sib(ling) crosses) between re-selected parents were made and planted out for testing. Around the same time these same parent trees were multiplied using grafting techniques to form the first tested clonal seed orchards; others followed as more data became available. Delays in flowering within seed orchards led to the development and then operational deployment in the mid-1990s of improved material created by controlled pollination between re-selected parents in clonal archives and then mass-multiplication at the family level using vegetative propagation (VP). By 2010, full-sibling families were being re-produced for the VP market following determination of the best families for the traits under selection in the first full-sibling trials. By now, nearly 100% of the 30 million or so Sitka spruce plants required annually was from an improved source; 25% from VP and 75% from the seed orchards which were now in productive phase. Most of the above history is to be found in '50-years of tree breeding' located on the Forest Research website.

Following a 50% cut to the FR tree breeding budget (2010-2014), the 'Sitka spruce Breeding Co-operative' was created as a public/private partnership in 2013. This new body alone would take forward the Sitka spruce breeding programme following exclusive access to the existing Intellectual Property. In 2016 the Co-op expanded its remit to all conifers and changed its name to the 'Conifer Breeding Cooperative' (CBC).

Objectives

The aim of the 'Genetics Section' when Sitka breeding started in the late 1960s was '*To develop strains of trees showing increased vigour, improved stem form, better adaptation to adverse conditions, increased resistance to pests and diseases and* *improved timber quality'* . This was to be achieved by (i) selection and testing of plus trees (ii) development of vegetative propagation (iii) establishment of seed orchards, (iv) creation of intra- and inter-specific hybrids (v) resistance breeding and (vi) creation of radiation- induced mutations.

The objectives of the (now) CBC are contained within their Articles of Association as a company limited by guarantee, to take forward the seed orchard and vegetative propagation programme and further advance the breeding of Sitka spruce towards commercial ends. Full Membership (i.e. access to all IP) has grown from the founding three members to the present seven; in addition there are around 20 Associate Members who do not have access to the IP, but are kept informed of the CBC's activities.

The annual FR budget for tree breeding in 2010 was around £800k, reduced to £400k by 2014 at a time when more resource was being demanded by broadleaf and resistance breeding. The Co-op budget is around £70k/year; net cost to FR of being a Full Member is around £8k/year.

This work sits within Programme 5 and Science Group 9 (Forest Resources and Product Assessment).

4.2. Description of research activity

Inputs

There have been many years of investment into Sitka spruce breeding before tangible gains were obtained. Tree breeding is a long-term form of research with high up-front costs. Field trials can cost around £10k/hectare to establish and after that they have to be maintained and measured; there are nearly 400 Sitka spruce field trials each around one hectare in size. Although a more recent Cost Benefit Analysis study has found this investment to be very worthwhile (see below), it does require long-term buy-in from managers.

Today, the CBC is responsible for taking forward the applied Sitka spruce breeding programme. It has exclusive access to existing IP generated by FR, for which it pays an annual fee. The development into conifers other than Sitka spruce is very recent. Access to any other IP from FR for other conifers is non-exclusive and on a case-by-case basis. The seven full-members pay £5,000 membership fee and around £3,000 cost in kind (labour) each year. Two new Full Members joined last year. Any new IP belongs to the Co-op.

Activities

Apart from the plus tree selection, and large-scale field trails established in earlier years, Forest Research continues to carry out new research into Sitka spruce breeding which it has the right to carry out independent of the CBC. The CBC is responsible for the more applied part of the breeding programme. A recent new activity is 'Genomic Selection' whereby trees in the future might be selected based on their component DNA. This is commercial practice in cattle and chicken breeding but at an early development stage in forest trees. The work is being carried out in conjunction with Oxford University with a small financial contribution from CBC who can see the commercial advantages should the science prove successful. The new contract is known as '*Sitka spruced'*.

The Co-op is developing a strategy of how to take forward the Sitka spruce breeding programme. It is creating three new clone banks and wishes to retain all original plus tree selections so retaining a wide genetic basis to assist future breeding. The Co-op carries out a pollination programme each year and generates around 20,000 controlled pollinated seeds for the vegetative propagation industry leading to approx. 10 million trees/year. Each year the Co-op screens another series of older progeny trials for micro-fibril angle which is important in determining wood stiffness. This is done non-destructively using acoustic velocity tools and becomes the first new IP generated by the Co-op. Elsewhere the Co-op is creating a DNA database of all its more important parent trees, is collecting new mensurational wood quality data, is sponsoring PhD research into DNA-markers for frost tolerance, and co-funds Sitka spruced mentioned above. Plans for other conifers are at an early stage but include seeking out good stands for Norway spruce, Douglas fir, noble fir and western hemlock and then searching for new plus trees leading to new (untested) seed orchards. The expansion into alternative conifers seems to have recently attracted more organisations to become Full Members.

Outputs

The main 'output' from the Sitka spruce breeding programme is the improved planting stock from the seed orchards and VP programmes and the amount of it planted in British forests. More recently, the CBC is well known within the industry; it produces an annual newsletter and has an annual open meeting for all interested parties. It is now generating its own IP (AV scores; DNA fingerprinting). It is continuing to supply 10 million VP trees to the forest industry.

4.3. Impacts

i. Predicted gains of improved planting stock from seed orchards and the VP programme, compared to unimproved material important from Canada, are between 21% and 29% extra standing volume at rotation age and 35% to 135% extra green logs depending on source of planting stock (Lee and Matthews, 2004 and Mochan *et al* - 2008 respectively).

ii. Nearly 100% of all Sitka spruce planted is from an improved source (seed orchard 75%; or VP 25%) mainly due to the research efforts of FR, the promotional efforts of public and private sector nurseries, and the demands of FC field managers and managers of a major private forestry company.

iii. There is now a culture amongst foresters to demand improved Sitka spruce planting stock.

iv. If the impacts of Sitka spruce breeding were not clearly apparent to nursery and forest managers, the CBC would not have been formed.

v. A Cost Benefit Analysis (CBA) into Sitka spruce breeding found a C:B ratio well in excess of 200:1 (Coull, 2008; internal FC report, incidentally the C:B ratio was around 8:1 for oak breeding)

vi. The success of the Sitka spruce breeding programme is apparent to many different stakeholders including policy makers. For example, in Scotland a premium planting grant is available for stock coming through the VP process giving recognition to the extra quality gains available therein.

vii. Creation of the Conifer Breeding Co-op is an indication that a substantial improvement has been made to the level and quality of dialogue between researchers and key industry customers. As well as helping to fund the research, and ensure uptake of improved planting stock on a major scale, this dialogue helps all partners to agree upon research priorities and future developments. It also helps the industry interpret and use research findings.

viii. The CBC is made up of all major commercial conifer landowners (FC, Tilhill, Scottish Woodlands) and nurseries (Christie-Elite; Maelor; Alba, FC) and seed merchants (Plant and Seed supply Branch (FE(E) and Forestart). The Co-op is also a member of the new National Tree Improvement Strategy.

4.4. Reasons for impact

Historically the Sitka spruce breeding programme was successful because of the continuous commitment of the Forestry Commission and the financial support it provided. The establishment of the Co-op was a critical factor in ensuring the survival of the programme following the budget cut in 2010. Its formation was helped by the fact that similar initiatives had emerged in other countries, providing successful models to learn from. Most forest planting organisations across the world have invested time and money to improve the genetic quality and so financial return of their planting stock. Often this is paid for via the state, but increasingly it is carried out by co-operative ventures between industry, universities, and public research bodies. For the 40 years of Sitka spruce breeding, the Forestry Commission funded the research.

The time was right for the creation of this Co-op in 2013. Forest managers and nursery staff were becoming more aware of the outputs and impacts of the Sitka spruce breeding programme. They were also concerned that 50% budget cuts imposed on FR’s tree breeding programme could severely hamper Sitka breeding work as the reduced resources would be directed to broadleaved species and resistance breeding which were receiving a higher profile at the time.

Successful establishment of the CBC was also made possible because industry representatives were persuaded of its necessity. Key players from the industry were invited to an exploratory meeting at NRS and the penny dropped after about 1.5 hours of discussion. It took a further 12 months to agree the IP agreement with FR and the Articles of Association with the co-operative members. Two parties dropped out at the 11th hour on cost grounds; but since then both parties have joined. Key private sector champions to forming the CBC were Maelor Forest Nurseries and Tilhill.

Industry representatives were also reassured that the process would be managed effectively to deliver a fair return on their investment. There were already strong and trusting working relationships between FR researchers and industry, established over many years, which facilitated the formation of the original partnership. These links will also help the Co-op develop by bringing in new members and easing the process of negotiating access to IP, planting materials, and other terms of agreement.

4.5. Lessons learned

We should have consulted more widely for our first exploratory meeting. Some parties felt ignored and there had to be a rear-guard action to include them once the co-op was up and running. Things have calmed down now and interest in membership is growing.

References

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Volume gains from improved Sitka spruce

Quality gains from improved Sitka spruce

Launch of '*Sitka spruced'* – press release

Economics of Veg Prop and seed orchard planting stock

5. Adaptive genetic diversity

Understanding what drives adaptive genetic diversity and why it is important when considering choice of planting material

Joan Cottrell and Stuart A'Hara

Species, Genes and Habitat Conservation

5.1. Background

Climate change and the arrival of novel pests and diseases are currently presenting policy makers with major challenges. There is a need for high quality research results to underpin the development of appropriate policy to prepare our forests for these threats. Forest Research published the Read Report in 2009 which examined the potential of the UK's trees and woodlands to mitigate and adapt to our changing climate. Despite the key role of adaptive genetic diversity in enabling our forest genetic resources to adapt to biotic and abiotic challenges, the Read report made only passing mention of its importance when it stated that one of the measures that had been suggested to increase resilience is the inclusion of 'greater diversity of planting material both at the species and population genetic level'. Similarly, the role of adaptive variation in the host has been rather overlooked in contributing to resilience in pests and diseases with far greater research effort having been invested into the pathogen than into the variation in susceptibility in the host.

The pattern of adaptive diversity depends on the founding material that colonises a site, subsequent long distance geneflow which tends to homogenise genetic diversity across sites and natural selection which acts to favour individuals that are well adapted to local site conditions. Tree species tend to have large population sizes, long distant geneflow and enormous amounts of seed production, characters which suggest that tree species have large potential to adapt and evolve to novel conditions. This feature of high adaptive potential has been somewhat neglected in British policy on how to prepare for climate change and there is a need to raise awareness of this key element of resilience.

Until recently, there have only been limited data available from provenance trials of native British tree species but that which does exist indicates that our woodlands contain high levels of adaptive variation, the raw material necessary for adaptation and resilience. Although most of this diversity exists within rather than between populations, there is nevertheless a geographic pattern to the distribution of this diversity which is likely to be due to adaptation to local conditions developed over a number of generations. This pattern is revealed in provenance trials where trees from a range of sources are grown in a single or several replicated sites and characters such as timing of bud break, tolerance to drought or growth characteristics are seen to exhibit a geographic pattern. Recognising that forest genetic resources may be locally adapted, FC policy has drawn up an administrative system of four Regions of Provenance and 24 seed zones and recommends that planting material is sourced from the same seed zone as the planting site. However, there is a lack of evidence to underpin whether this system reflects the broad distribution of genetic adaptive variation in all tree species in Britain. There is also confusion and divergent views on the benefits/disbenefits of using locally sourced versus predictive provenancing (sourcing material from locations further south which currently experience temperatures British sites are predicted to be exposed to in the future as a result of climate change) in planting schemes based on native British tree species with timber production objectives.

Objectives

1. To raise awareness and understanding of the role of adaptive genetic diversity in adaptation and resilience in the context of climate change and threats from novel pests and diseases.
2. To measure existing provenance trials and to establish new provenance trials to provide novel data on the distribution of adaptive diversity across a range of traits in British tree species.
3. To improve our understanding of the origin and genetic connectedness of British forests using neutral molecular markers and phenological studies of pollen production across a range of distant populations grown *in-situ*.
4. To contribute to the debate relating to the pros and cons of local sourcing versus predictive provenancing of planting material in preparation for climate change, recognising that trees are grown for different purposes. This is with the ultimate aim of influencing policy makers, particularly those in England, to moderate their advice on predictive provenancing so that it is presented in a more balanced and cautious way that makes it clear that many uncertainties remain when making the most appropriate choice of planting material. Stakeholders need to be made aware that predictive provenancing and introduction of novel exotic species are not the only ways of preparing for climate change nor are they necessarily the best approaches.

5.2. Description of research activity

Inputs

Over the last 10 years Joan Cottrell in FR has established strong and productive collaborations with top class forest evolutionary geneticists in the University of Edinburgh (Professor Richard Ennos) and the Centre for Ecology and Hydrology (CEH, Dr

Stephen Cavers) in which we have jointly supervised five PhD students on this topic. This group also worked with a wider set of scientists from Queen Margaret's University, London (Richard Buggs), James Hutton Institute (JHI, Glenn Iason), Royal Botanic Garden Edinburgh (Dr Jo Taylor) and Oxford University (Dr David Boshier) on an LWEC Phase 1 funded project 'Deploying forest genetic resources for management of tree pests and pathogens – a review of prospects and capacity (GRIPP)'. The original group of three scientists were also partners in the much bigger LWEC Phase 2 project 'Promoting resilience of UK tree species to novel pests and pathogens: ecological and evolutionary solutions (PROTREE).'

Activities

We have published extensively on this topic (see references). This includes; i. reviews on the importance of forest genetic resources in Britain and in Europe and issues that hamper the use of locally sourced material, ii. refereed scientific papers on adaptive variation in provenance trials (measuring growth, phenology, drought and flooding tolerance and disease resistance traits), synchrony (and by implication potential for long distance geneflow) of pollen production across a range of distant sites and molecular studies of the origin of native tree species. These papers provide evidence that native species growing in British woodlands contain high levels of adaptive variation and, given opportunities to produce regular cycles of seedling regeneration, have enormous potential to adapt relatively quickly to climate change. In addition to scientific papers, we have produced more accessible articles to explain the importance of forest genetic resources to stakeholders and the wider general public. For example the articles we wrote for Woodwise, the magazine produced by the Woodland Trust, were widely read. In collaboration with other institutes we have developed a computer game, CALEDON to explain the principles of forest management with special emphasis on forest genetic resources. This has already been adopted as a teaching aid in universities.

Following the interest generated by publication of the Cavers & Cottrell paper 'The basis of resilience in forest tree species and its use in adaptive forest management in Britain', FC hosted a stakeholder workshop in 2015 'Getting the right plants in the right places - Forest genetics, breeding and climate change' to raise awareness and understanding of this topic. This was largely for FC/FR stakeholders with additional attendance and contribution from Natural England, CEH, Edinburgh University, SNH and Earth Trust. The day involved presentations by experts followed by semi-structured discussion.

FR staff have given talks on the importance of genetic variation and its role in adapting to threats presented by climate change and novel pests and diseases at : FR Research Update Seminars, several Woodland Trust Advisory Group meetings and events, Natural England, The Botanical Society of Scotland and Edinburgh University MSc students.

They have participated in PROTREE stakeholder meetings where the importance of genetic variation in pest and disease management is explained to practitioners. Forest pathologists have a tendency to concentrate on the fungal pathogen and PROTREE has raised awareness of the need to consider diversity in the host as well as the disease organism. FR staff contributed to the recent Gene Conservation Unit meeting held at Kew to increase awareness of the importance of establishing Gene Conservation Units and of the need to develop a Forest Genetic Resources Conservation Strategy in Britain. There is recognition that Britain is well behind Europe in this endeavour. We have written an Information Note (Hubert & Cottrell, 2014) on how to establish Gene Conservation Units and JC is in one of the recently established groups tasked with taking this initiative forward. The initiative for establishment of Gene Conservation Units has been led by EUFORGEN and FR staff are active participants in two of the current EUFORGEN working groups. JC serves on the Management Advisory Committee of the National Tree Seed Project coordinated by Kew where she has influenced the collection strategy to ensure that the collections reflect the genetic variation present in native trees across Britain and are structured in a way that is appropriate for research studies to be based on them.

In collaboration with CEH and JHI, JC has established a series of three provenance trials of Scottish sources of Scots pine. These have been the basis of much of our recent research into adaptive variation. We have also collaboratively made seed collections of native juniper and are in the process of growing this material with a view to establishing a similar provenance trial resource for juniper. JC is also responsible for provenance trials of rowan and ash which have been assessed for growth and phenological characters. Maximum value has been derived from the ash trials via the provision of scions of the ash material to Prof James Brown of John Innes Centre for his studies on development of resistance to *Hymenoscyphus fraxineus* (ash die back). The level of this disease in these ash trials is also being recorded within the DEFRA funded Living Ash project.

We have recently provided FC England with a rapid review on the evidence for changing seed sourcing policies for woodland establishment under environmental change in England. This work is now being progressed to develop the review into an FC England publication using financial support from the Woodland Trust. Included in this planned work is an event hosted by the Woodland Trust to present the findings to key policy makers to influence their thinking on future policy in this field.

JC & S A'H contribute to and act as British representatives of EUFORGEN, an international network that supports the conservation and sustainable use of forest genetic resources in Europe. This is a key activity as it allows British forest genetic scientists to meet and exchange ideas with scientists working on the same topics elsewhere in Europe, some of which come from regions which will experience the impact of climate change much sooner. Participation in EUFORGEN also allows us to contribute to EUFORGEN outputs on the topic of conservation of forest genetic resources. EUFORGEN publications are held in high regard by EU policy makers and influence their thinking on conservation of forest genetic resources.

S A’H provides scientific support for implementation of Forest Reproductive Material EU regulations and provides advice to ensure that choice of planting material adheres to this EU legislation.

5.3. Impacts

Scientists

i. We have filled a knowledge gap by advancing fundamental scientific understanding of the drivers and underlying processes that determine the distribution of adaptive diversity in our native tree species using Scots pine as our model species. We have provided novel data on origins of source material, actual and potential long distance geneflow and drivers of adaptive diversity.

ii. We have influenced tree breeders and pathologists to give greater consideration to the role of diversity in the host in adapting to novel pests and diseases. We have persuaded them that they are losing a resource if they remove all representatives of a given species in an area of high disease as those that remain in a healthy state may have a degree of resistance which form the basis of a breeding program.

Policy makers in FC and other forestry related organisations

i. We have improved understanding amongst stakeholders of the important role of forest genetic resources in adaptation and resilience.

ii. There is less certainty that predictive provenancing is necessarily needed as a strategy to prepare for climate change and the threat of novel pests and diseases. We are making significant progress in convincing policy makers to incorporate this thinking into their policy documents. For example the Woodland Trust are now committed to sourcing the plants used in their planting schemes entirely from nurseries in Britain and Ireland.

iii. We have raised awareness among policy makers of the reasons for bottlenecks in the supply of locally sourced planting stock from nurseries due to the uncertainties in demand from year to year.

Education

i. We have played our part in training the next generation of forest geneticists and scientists who can take on roles in science and policy with a sound understanding of the principles of genetics and adaptive evolution as well as having received some insight into the complexities of implementing science into policy and practice. This has taken the form of participation in formal MSc teaching and supervision of PhD students.

ii. We have participated in open days for young schoolchildren at nature events held at the Royal Botanic Gardens Edinburgh and various other venues. We have also contributed to the development of a computer game (CALEDON) to convey the principles of adaptive management of our forest genetic resource in an entertaining way.

5.4. Reasons for impact

1. The group of scientists we have been collaborating with are of a high calibre and the synergy between us has allowed us to produce a body of quality research results which have been correctly analysed and published in refereed journals as well as in more popular press.
2. We have established a high degree of trust within our group of collaborating scientists and the dialogue between us has allowed us to develop a unified and coherent argument for the importance of adaptive potential in our native woodlands. This has helped enormously in attempting to influence policy makers who hold strong views in favour of predictive provenancing and introduction of new species.
3. The development of policy on how to prepare for climate change has some strong industry champions who have raised awareness of this problem but have been biased in their support for predictive provenancing. This has made our research much more relevant to current policy and the commissioning of an evidence review by FC England demonstrates that they have now recognised that there are counter arguments to their currently articulated policy.
4. Our active participation in EUFORGEN has provided the opportunity to lobby for appropriate use and conservation of forest genetic resources at a European policy level. The backing of EUFORGEN has allowed us to promote creation of Gene Conservation Units and to receive industry support and backing for this initiative.
5. Several of our PhD students are now employed in forest science research and are in place to continue this work. We have participated in the education of the next generation of scientists who will contribute to this area of science in the future.

5.5. Lessons learned

Positives

By collaborating as scientists across several organisations we have achieved a deeper understanding of the issues and have generated a coherent unified view which we have successfully conveyed to stakeholders. Also the collaboration has allowed us to produce high quality research results. These, along with the opportunity to discuss and debate the various issues amongst ourselves, have given us the confidence to deliver a consistent message to stakeholders.

Negatives

Geographic distance between Alice Holt and Northern Research Station has meant that climate change scientists rarely have the opportunity to meet up with forest geneticists to discuss common issues. This has resulted in a dichotomy of thinking which has not been helpful in presenting a unified interpretation of various strands of science that impact on policy for choice of planting material. There is a lack of trust which has been strengthened by one sided representation of evidence and inflated certainty of the appropriateness of predictive provenancing by policy people in England.

Reduction in staff has made it difficult to continue to maintain and measure field trials distributed across GB. With this area being covered by JC alone, there is no opportunity to discuss ideas on this topic within FR which hampers creativity and makes it vital to establish strong external collaborations.

Heavy individual workloads means there is little time for inter-disciplinary discussions which hinders FRs ability to provide a balanced and consistent view on contentious topics relating to key policy issues.

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CALEDON game

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6. Population monitoring and management of feral wild boar

Robin Gill

Species, Genes and Habitat Conservation

6.1. Introduction

Background

Native wild boar are thought to have been exterminated in Britain during the middle ages. However a number of populations have become established in recent years from unauthorised releases of farmed animals. In view of their native status, no attempt has been made by government agencies to treat these animals as invasive pests and therefore management has been left to the discretion of the landowner.

Populations of feral wild boar are now established in several locations in the UK, although the largest is currently in the Forest of Dean. Wild boar are well known to have a higher reproductive rate than other animals of their size, but boar reared for meat on farms are sometimes crossed with domestic pigs in an effort to increase growth and fecundity even further. This high fecundity can make management problematic.

Between 2011-13, Forest Research and Defra collaborated on a joint project to develop methods to monitor wild boar populations and assess their impacts on woodland flora and invertebrates. The project completed successfully but at the time we carried out the field work in 2011-12, feral boar population densities were still quite low and this limited the value of some of the results.

At this time, managers in the Forest of Dean were being actively lobbied by some members of the public wanting more protection for the boar. Culling of wild boar had started in the Dean in 2009 but in response to lobbying culling was suspended for a year in 2013. However, the boar population then started to increase rapidly, but so too did the number of complaints from other stakeholders, concerned about their impacts. The managers felt that more accurate information on the population would help resolve controversy and clarify management needs, and in response we started to undertake regular monitoring, to estimate the population size and to assess fecundity from the reproductive tracts of culled sows.

Objectives

1. To estimate abundance annually in the forest of Dean

2. To estimate recruitment rates into the population by assessing pregnancy rates of culled sows

3. To obtain population projections to support decision-making on appropriate cull targets and to raise public awareness.

Budget

This project fell outside the formal funding structure for FR projects. The costs of the field work were covered by the Forestry Commission and data analysis and reporting by Forest Research.

6.2. Description of research activity

Resources

We used two field staff (Technical Services Unit) for population assessments, thermal imaging equipment (purchased previously) and a vehicle for nocturnal surveys; our technician assessed reproductive tracts and the project leader prepared reports.

Activities

We estimated the abundance of wild boar annually, between January and March, in the Forest of Dean using thermal imaging and distance sampling. We obtained uteri and ovaries from culled sows and estimated conception and pregnancy rates from the numbers of corpora lutea and embryos respectively.

Outputs

Reports on the results of annual surveys and population projections. Presentations to local stakeholders.

6.3. Impacts

Instrumental

The results of this project enabled local forest managers to plan management of the wild boar population. With an estimate of population size from the census and fecundity rates from culled sows, we were able to predict the level of control that was needed to stabilise the population.

Numbers of boar continued to increase for 2-3 years after we started this monitoring project. There were a combination of reasons for this - the wildlife rangers did not cull as many as indicated by our model and our census may have yielded a slight under-estimate. However there is no indication that it would have been outside the 95% confidence limits. The forest managers did not take a decision to cull more than the number required to simply stabilise the population. Nonetheless, the cull was substantially increased following the start of our project and this prevented the population from increasing much faster and resulting in even more serious damage.

Conceptual

The results were promptly disseminated through the internet and local media to stakeholders so the evidence underpinning the choice of cull target was available to the wider public.

Feral wild boar have high fecundity, with litters of up to 12 piglets per sow. The results of our model projections revealed a huge potential for a population increase if no culling were to take place. This helped local stakeholders to appreciate what needed to be done (and what was being done) to adequately manage the wild boar population. As a result, debate has moved on to discussion about appropriate action rather than disagreement about actual or perceived numbers of wild boar.

Capacity-building

We gave training to the wildlife rangers so they now carry out the annual survey themselves, using methods developed by Forest Research.

Who was influenced?

Researchers, practitioners (forest and wildlife managers), forest verderers and the general public.

6.4. Reasons for impact

With high fecundity rates, populations of wild boar can increase very rapidly and achieving effective control requires prompt action. However the problems we were presented with, namely to estimate the population size and potential rate of increase, and to establish a cull target, are familiar in wildlife management. We were able to draw on previous experience of adopting similar approaches for the management of deer populations. We had also previously developed a survey method that was suitable for wild boar populations.

When the population of boar increased, the impact of the animals became increasingly evident in and around the forest of Dean. Feral boar dig over turf along roadsides, football pitches and gardens, and these impacts are very evident to the public. Complaints from farmers also began to increase. Initially, damage was evident to pastures and fruit crops, but later concerns were expressed about disease transmission to pig farms and predation on new born lambs by sheep farmers. These, as well as other notable incidents such as boar chasing horse riders and getting into school playgrounds, were well publicised by the local press. As a result, stakeholders were very aware of the reality of a boar population increase and the consequences of it.

The results of our monitoring were made available to stakeholders through the internet and local media and at occasional meetings. They made the evidence underpinning our population projections clear so a management policy adopting our target cull would neither eliminate boar from the forest entirely, nor would it allow the population and damage to escalate out of control.

6.5. Lessons learned

Our project did not include any social research, or any structured attempt to inform public opinion. Although the local Forestry Commission managers and staff were actively engaged with the public, it would have been helpful to have some social research to assess how attitudes developed in response to events and information provision by Forest Research, the Forestry Commission and other bodies.

Our project did not include any aspect of monitoring the impact of boar. Although this had been included as part of a Defra supported contract mentioned before, continuation of the study would have been more useful as the population of boar increased. An understanding of more of the ecological effects of boar (on tree regeneration, flora and soil fauna for example) as well as impacts on human livelihoods (pasture and crop damage etc.) would be more informative.

It would have been helpful if we could have had FC funding agreed from the start for this project. With extra funding, we could have continued with the project for longer to assess how effectiveness of the monitoring developed through time. The release of wild boar has presented a unique opportunity to develop management and stakeholder engagement of a new keystone species.

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7. The health and wellbeing benefits of trees, woods and forests

Liz O'Brien

Social and Economic Research Group

7.1. Introduction

Increasing interest in the potential health and wellbeing benefits of trees, woods and forests (TWF), as places for people to enjoy and access, in the early 2000s led to Forest Research (FR) being asked by the Forestry Commission (FC) to develop and organise conferences in England, Scotland and Wales in 2004 to bring together health professionals as well as forestry and other environment professionals. The objectives of the conferences were to debate and discuss the role of TWF and their impact on people's health and wellbeing and to focus the discussions on policy, practice, promotion and research. An accessible publication of the conferences was produced by FR. The debates, interest and publication led FC in England and Scotland to develop a number of health focused interventions through the use of woodland grants, the public forest estate and working in partnership with other bodies including health organisations, and to organising training for some FC staff. A body of research and delivery activity has developed over the past fifteen years and has contributed to the increasing amount of evidence on the broader topic of the health and wellbeing benefits of nature.

The objectives of the research developed over time to include the following:

- Encourage discussion and debate of the role of TWF for health and well-being
- Monitor and evaluate woodland based interventions that aimed to increase physical activity and mental well-being
- Explore how partnerships were being developed, work with the health and sport sectors, and enable partnership working
- Carry out evidence reviews to identify existing evidence and gaps in research
- Encourage recognition of the value of trees and woods in health care settings for health and wellbeing via the 'NHS Forest' programme in England and 'NHS Greenspace' in Scotland
- Undertake empirical research to gather new evidence
- Collaborate in knowledge networks nationally and internationally

- Provide advice and communicate the role of TWF for health and wellbeing in a variety of ways
- Review existing research methods for capturing health and wellbeing benefits of TWF.

7.2. Description of research activity

The focus on health and wellbeing has involved a range of activities that FR has been involved in, as outlined below:

- Organisation and development of 3 conferences in England, Scotland and Wales to raise debate in 2004
- Evaluation of forest health related interventions – including evaluation of the Chopwell Wood Health project, Health Woodland Improvement Grant in the West Midlands, Active England, Active Forests, Woodlands in and Around Town (WIAT) challenge fund evaluation
- Active involvement in a European Cost Action on forests, trees and human health that ran for four years (2004-2008) and a Cost Action on Green Infrastructure that ran from 2013-2017
- Involvement in a one year Outdoor Health Network funded by Medical Research Council and Economic and Social Research Council
- Acting as member of advisory boards including the National Institute of Health Research funded project on physiological benefits of Forestry Commission Scotland's Woods in and around Towns programme led by Edinburgh University, and the Beyond Greenspace Project led by Exeter University
- Primary research with publics and health professionals to understand self-reported health benefits of woodlands and the attitudes of health professionals to greening health care settings
- Contribution to international work e.g. involvement in International Union for Conservation of Nature (IUCN) 'healthy parks, healthy people' guidelines, World Health Organisation review of urban health greenspace interventions
- Production of evidence reviews on urban health and health inequalities, and mindfulness
- Provision of advice and engagement in debates about the direction of research.

The work described above involved members of the Social and Economic Research Group; other research groups in FR have also focused on health in relation to the role of trees in reducing air pollution, reducing noise and providing shade – however, this work is not part of this case study.

Outputs

The outputs produced have been written and developed for a wide ranging audience including policy makers, practitioners, academics, because the audience for the research was broad and included the Forestry Commission, forestry, environment, health, and sports sectors (see end of case study for full list of outputs).

7.3. Impacts

Instrumental

Instrumental impacts include direct decisions to continue funding, and decisions on how to fund (e.g. via partnerships) programmes including WIAT and Active Forests. It has also led to a more confident use of evidence by FC and others to inform policy statements and the direction of travel for WIAT and Active Forests. It has informed programme design for Active Forests and changes to the targets for the programme. For example, an original target set was to reach 24,000 people who were new to sport. However, due to the data gathering information on sporting visits rather than sporting individuals it was not possible to scale up from the survey data to the overall number of sporting visits (as this included individuals who made numerous visits). Therefore, after discussion it was agreed that the target would change to reaching a 5-10% proportion of people who were new to sport. Another example is that the evidence gathering highlighted the popularity of play on the day activities such as table tennis and volleyball and it was decided to extend these activities to other sites once they had been trialled at one site.

Conceptual

Conceptual impacts have been realised in the better understanding amongst FC staff as well as other organisations of the role of TWF for health and wellbeing. The Chief Medical Office for England in 2005 endorsed this by putting his signature to the foreword written by FR for its publications on ‘Trees and Woodlands: Nature’s health service’.

Capacity-building

Capacity impacts included for example, training for FC staff to assist in the operational and survey data gathering for the evaluation of the Active Forest programme. Some FC staff have also used the approach to gather their own survey data for projects other than Active Forests. The research has also helped position FC to win new funding to run programmes, e.g. Active Forests, and helped FR position itself as the preferred choice to undertake the evaluations.

Connectivity

Connectivity impacts have been realised between FC and FR and parts of the health sector, between FR and international academics. For example links were made to Deakin

University (via contacts made at a conference in the USA and followed up at a conference in Australia) due to interests and work on health, and funding was sought to enable two researchers to come to Britain to carry out research on the health and wellbeing benefits of environmental volunteering. Another academic from Melbourne University spent three months with FR to carry out an evidence review on urban health and health inequalities. FR was asked to join an IUCN steering group to contribute to guidance on 'healthy parks, healthy people'. Contacts via the forests and health COST Action led to a bid for EU Framework 6 funding which was unsuccessful.

Culture change

Culture change impacts include greater understanding of the importance of technical reports of evaluations and research that outlines exactly what was done, how, and what was found. FR worked with others such as FC and Sport England to identify key results to pull out of the Active Forests evaluation in a short summary and the development of a communications plan to publicise the research.

7.4. Reasons for impact

Problem framing

The initial conferences mentioned above provided an opportunity for the FC and a range of academics, environment sector organisations and health professionals to explore whether TWF could contribute to the health and wellbeing agenda and how the FC might work in partnership or lead specific projects. The increasing interest in the role of nature and its impact on physical and mental health provided an opportunity to gain traction and expertise in research for FR and delivery of interventions on the ground for the FC. The issue of health and wellbeing is still as important, if not more so, as it was when FC and FR first got involved in the early 2000s with the importance of preventing ill health rising up the agenda. The work in recent years has broadened out to move beyond health to focus on wider wellbeing.

Management

The research was developed through various strands as outlined above, so a multi-faceted approach to research and evaluation allowed FC and FR to approach the issue in various ways which assisted in making new links, and identifying new opportunities. The work developed, somewhat organically, via these new links and opportunities. As evidence accumulated, FR became more widely-known which led to other contacts and opportunities and involvement in wider networks such as the Outdoor Health Network and the Valuing Nature Network.

Inputs

Funding for research has been patchy and the capacity of FR to involve more staff in the work has not been easy to facilitate due to increased pressure of work and parts of FC (particularly in England) thinking enough evidence has been produced on the health benefits of woodlands. While much progress has been made, and the importance of nature for health and wellbeing is recognised in health strategies and sport strategies, there is still limited funding for research and the replication or scaling up of existing interventions that have focused on health and woodlands. Much of the funding to date for interventions has come via lottery funding which FR has been involved in evaluating.

Outputs

A wide range of outputs (see below) have been produced from this body of work including briefing notes, two-page summaries of research, grey literature, book chapters, academic papers, and these have been made available at conferences, through email bulletins and networks, via web pages, through research gate and LinkedIn. These outputs have been used when developing new partnerships, trying to develop new programmes and when engaging with the health sector as well as in FC bidding for new funding. However, the evidence is that usually only one component contributes to FC engaging with others on health.

Engagement

Dialogue between researchers, policy makers and practitioners were key elements of the two COST Actions mentioned above, and this provided new ideas and highlighted new evidence. It allowed learning across individuals and a better understanding of research and practice taking place in different countries. Partnership working between FC and other parts of the environment sector and health sector led to FC being able to position itself as an organisation that can contribute to different public's health and wellbeing. There was active engagement at the beginning from policy and practice stakeholders in the conferences in England, Scotland and Wales in outlining different research needs and requirements. Environment sector organisations looked to FC to take a lead and FC did so by creating demonstration projects, such as the Chopwell Wood Health project, and FC looked to FR to support evaluation of these projects.

Social and organisational factors

FC England organised training for staff via the British Heart Foundation to provide staff with the key messages they could discuss with their staff and with publics. An FC policy maker acted as a champion for these key messages in the early years and this has now been taken up by an FC development manager who is trying to develop new partnerships and win new funding. There have been difficulties in engaging with the health sector due to numerous internal re-organisations so that contacts made and developed can disappear. Funding in the health service is also primarily focused on treating illness and not on preventing ill health and the public health does not have as high a profile in the Western medicalised model of health. However, having a body of evidence and delivery provided FC and FR with opportunities to adapt and make contact with new structures and personnel e.g. Public Health England.

7.5. Lessons learned

Work has been undertaken by FR to help FC better understand the values and attitudes of publics and how they can and do use woodlands, particularly the Public Forest Estate, to ensure that interventions that are developed target specific audiences. Taking a multi-faceted approach to interventions as highlighted by FR's research has been important including changes to the physical environment, reaching out to target groups, communications etc.

The research funding is often sourced when opportunities arise, which does not enable FR to carry out innovative new approaches such as combining physiological approaches with self-reported health benefits. The use of recognised validated questionnaires on health was not implemented due to resistance from FC over concerns that the questionnaires would become too long for participants, and funding was not available for the extra time and analysis this might involve.

FR researchers are often viewed as practitioners or policy makers by academics who want to involve FR on steering and advisory groups rather than involve them as active researchers on projects. The status of FR in terms of having to be sub-contractors to universities in Research Council bids has also made it sometimes more difficult to engage and get involved in research.

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Conferences

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External Funding to supplement core funded work on health

2005 FCE: *Production of health publication and flyer.* £7.5K. LOB lead.

2004 FCE: *Interface NRM contract on Health Woodland Improvement Grant research*. £10K. LOB lead.

2002-2003 FC: *Funding for health and well-being conferences*. £20K. PT lead.

2009 ESRC and Medical Research Council: *Outdoor and health network*. Consultant to Inverness College £9.589K. LOB internal lead.

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2014-2017. Forestry Commission England. Monitoring and evaluation of the Active Forests programme. 60K. LOB lead.

2014 Advisory work for Forestry Commission Scotland to produce briefing note on NHS Greenspace. £2575

2017 Green Exercise Partnership – interviews with NHS professionals on NHS greenspace 10K

2017-2022 Forestry Commission England. Monitoring and evaluation of the Active Forests programme. £140K

8. Economic analysis helping underpin development of the Woodland Carbon Code

Gregory Valatin

Social and Economic Research Group

8.1. Introduction

Background

The Woodland Carbon Code is a voluntary standard developed by the Forestry Commission in partnership with other organisations to apply to UK woodland creation projects that make claims about the carbon dioxide that they sequester. A wide range of parties are involved in developing such projects – including landowners, carbon market intermediaries, public sector and Non-Governmental Organisations (NGOs). Launched in July 2011, the Code aims to ensure that claims made by the project developers about carbon sequestration are robust and was developed to provide investor confidence in a context where there was a danger that conflicting information and perspectives about the benefits provided could undermine the emerging market for UK forest carbon.

Objectives

The Forestry Commission commissioned three economic studies to help underpin development of the Code. The studies review approaches under other carbon standards to: i) carbon valuation and risk management; ii) additionality; and iii) harvested wood products and carbon substitution.

Other details

Work on i) carbon valuation and risk management commenced in 2008, on ii) additionality in 2009, and on iii) harvested wood products and carbon substitution in 2014. Budgets were set on the basis of the number of days expected to be required. Work on all three studies was commissioned under the Realising the Economic Value of Ecosystem Services (REVES) research programme, with the study on iii) harvested wood products completed under WA 3.2 of Programme 4 on Valuing & Governing Ecosystem Services. Each of the studies was undertaken by the Social and Economic Research Group (SERG).

8.2. Description of research activity

Inputs

In each case the review constituted a desk study. This was undertaken by FR's Senior Economist with a budget allocated to cover the time needed. For example, 25 days were allocated at the outset for the review on additionality. Other staff (e.g. CESB Head of Centre) played a useful role subsequently as part of the QA process once the final draft had been completed.

Activities

The findings of each study were presented and discussed at meetings of the Woodland Carbon Code Advisory Board. Chaired by CFS, the Board includes representatives from a range of forestry sector organisations and stakeholders (including CONFOR, ICF, the Woodland Trust, private businesses and government forestry departments), providing an expert forum to guide development of the Code by the FC.

Outputs

Initial FR Discussion Papers (e-monographs) on i) risk management and ii) additionality were published in 2009, with copies made available at the London launch in November that year of the Read Report (https://www.forestry.gov.uk/readreport). FC Research reports on risk management and additionality were then published in 2011. An open access journal article on additionality was published in 2012 in Forestry, and a book chapter and European Forestry Institute Technical Report in 2014. Preparation of a FC Research Report on iii) harvested wood products and carbon substitution was completed in 2017. This report is being published as an FR report on FR's website.

8.3. Outcomes and impacts

Instrumental

The studies have been influential within the Forestry Commission in decisions concerning development of the Woodland Carbon Code. The studies contributed to decisions about the design of the Woodland Carbon Code. These include the decision to incorporate a risk buffer for carbon units issued under the Code in case biotic factors (e.g. tree pests and diseases) or abiotic factors (e.g. wildfire) lead to unexpected releases of the carbon stored and lower carbon benefits than anticipated. It also contributed to the choice of approach to additionality to adopt, such as the decision to incorporate an 'investment test' to determine whether a project would be financially viable or the most financially attractive activity in the absence of carbon finance.

The studies have contributed to a robust Code which has guided land managers in the public, private and voluntary sectors on how to design and manage woodland carbon projects. By helping provide a sound evidence-based underpinning for the Woodland Carbon Code, the studies leave the Code less open to external challenge from potential critics and help make UK woodland carbon projects more sustainable.

Conceptual

The reviews clarified for the FC and the Woodland Carbon Code Advisory Board the multidimensional nature of concepts such as additionality, rebound effects and double counting. It also developed new typologies – distinguishing 23 types of additionality, 20 types of rebound effect, and 8 forms of double-counting. The work also highlighted potential for perverse incentives associated with incomplete baselines if some categories of carbon benefits are not taken into account.

Studies have been publicised on (and in most cases are available via links from) the FR website and from ResearchGate, influencing thinking by researchers in other organisations. Statistics from Google Scholar, for instance, indicate that the article on additionality published in Forestry has been cited by authors from several other countries, including Australia, Canada and New Zealand. Impacts on the general public are more indirect but the Code contributes to wider awareness and confidence in the role of woodlands in tackling climate change.

Capacity-building

By helping provide a sound evidence base to underpin development of the Code, the studies contributed to the Code's success in attracting investment into woodland creation in the UK. As at 30th June 2017, a total of 242 projects were registered under the Woodland Carbon Code, covering an area of 16,200 hectares of woodland and projected to sequester 6.0 million tonnes of carbon dioxide over their lifetime (see: https://www.forestry.gov.uk/pdf/wccjun2017.pdf/$FILE/wccjun2017.pdf).

Interactions resulting from the studies related to the Woodland Carbon Code between the researcher and the members of the Woodland Carbon Code Advisory Board provided the inspiration for a subsequent successful application, led by FR, to create a pan-European research network - the PESFOR-W COST Action (http://riojournal.com/articles.php?id=13828) to explore potential for developing a Woodlands for Water Code.

Connectivity

Helping provide a sound evidence base to underpin the Woodland Carbon Code has increased levels of trust between stakeholders from organisations with different perspectives on the role of forestry in climate change mitigation and the significance of forest carbon. It has increased trust in the Code and role of forest carbon both among the private sector and NGOs, as well as trust between these sectors.

8.4. Reasons for impact

Presenting and discussing the findings of the studies at meetings of the Woodland Carbon Code Advisory Board helped achieve greater impact. This is the main stakeholder forum for considering evidence to underpin development of the Code.

Carbon standards continually evolve over time as new versions are published. Given lags in the publication process, a challenge was ensuring reviews remained up to date prior to final publication. A further challenge relates to the complex nature of some of the issues and explaining them in an accessible way in order for research to interest a wider audience. Feedback from a technical editor advised that significant changes would be needed if the report were to interest a wider audience. Instead of spending further time changing the report, a decision was taken by CFS to focus on producing a Research Note (with FR publishing the report online as grey literature).

Problem framing

Research questions in each case were aligned from the outset to evidence needs in developing the Woodland Carbon Code, with initial research briefs drawn up in consultation with key Forestry Commission stakeholders.

Management

The studies provided timely evidence upon which to base decisions in developing the Woodland Carbon Code.

Inputs

Sufficient time was allowed to complete initial drafts and to subsequently revise and extend reports taking into account comments and suggestions received.

Outputs

The FC research reports each included a short accessible Executive Summary highlighting key findings, research gaps and recommendations.

Engagement

Comments and suggestions on initial drafts were received from a range of interested stakeholders and led to significant reworking of the initial texts leading to further work, for example, exploring issues of potential double counting in relation to covering carbon substitution benefits of harvested wood products.

Presentation of findings at the Woodland Carbon Code Advisory Board stimulated lively discussions, including in questioning the rationale for issuing fewer carbon units under the Code to projects producing harvested wood products than to those not doing so in cases where aggregate carbon benefits are higher where wood products are produced.

Presentation of the findings at conferences and seminars has also been well received. The typology of forms of additionality, for instance, was included in presentations given at Keio University (Tokyo) and Beijing Forestry University during 2017.

Social and organisational factors

The Woodland Carbon Code Advisory Board includes industry ‘champions’ and ‘knowledge brokers’ from organisations including CONFOR and ICF.

The studies reinforced the value of such research in the minds of the Woodland Carbon Code’s Advisory Board. In particular, they demonstrated the value of having sound science and analysis to underpin the Code.

Context and contingencies

The FC Research Reports took longer to finalise for publication than initially anticipated. In the case of the harvested wood products and carbon substitution study this was partly due to a change in the interpretation of internal FR rules on QA (and whether CFS policy advisors who had served as initial reviewers could legitimately do this).

8.5. Lessons learned

a) What might have been done differently?

The publication process could have been speeded up to publish the FC Research Reports more quickly (e.g. the carbon valuation and risk management and the additionality reports might have been expected to have been published in 2010 rather waiting until 2011, given that the e-monograph versions were published in 2009).

b) What could (or will) be done differently in the future?

E-monographs (used to initially publish the results of the studies on carbon valuation and additionality) are no longer sanctioned as a means for FR to publish initial results quickly. Initial findings are therefore likely to take longer to publish in future.

Clarification of interpretation of internal FR rules should help avoid someone being asked to undertake a QA function in future that they are not mandated to carry out and eliminate a potential source of delay in finalising reports for publication.

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9. Woodland Creation and Ecological Networks (WrEN)

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Land Use and Ecosystem Services

9.1. Introduction

The Woodland Creation and Ecological Networks (WrEN) project is a long-term, large-scale natural experiment studying biodiversity in woodlands created in UK landscapes over the past 160 years. The project is a collaboration of academics, policy makers and practitioners. WrEN began in 2013 in Scotland and was expanded to England in 2014 as a collaboration between Forest Research, University of Stirling and Natural England. The core team also work in partnership with, and are funded by, a broad range of organisations including Scottish Natural Heritage, Defra, Forestry Commission Scotland, Forestry Commission England, Woodland Trust, The National Forest, NERC and Tarmac.

Ecological networks, and the central elements of ‘bigger, better, more and joined up’, are considered to be an effective response for biodiversity conservation in fragmented landscapes and are a major policy driver (Lawton *et al*. 2010). However there is limited empirical data on the relative importance of these different elements of ecological networks, especially in relation to habitat creation. Much of the existing evidence to inform landscape-scale conservation comes from studies of landscape fragmentation. WrEN uses a large-scale natural experiment approach to collect evidence from historical woodland creation to inform future landscape restoration. Woodlands in temperate agricultural landscapes in the UK have a long history of habitat loss and fragmentation, followed by decades of woodland creation. WrEN has imposed an experimental design to these historical woodland creation sites and is collecting empirical data from these secondary woodlands in England and Scotland in a natural experiment designed to address these evidence gaps. The woodlands were selected to represent distinct elements of ecological networks and key variables (ecological continuity/woodland age, woodland size, woodland characteristics, amount of surrounding habitat, and degree of spatial isolation) that can potentially influence biodiversity.

WrEN is managed by a fairly formal steering group of the main project partners (FR, University of Stirling and Natural England), and more informally with a wider group of partners and interested stakeholders.

Objectives

The project aims to test the relative impact of different site (patch size, quality and age) and landscape (amount of surrounding habitat, degree of spatial isolation, and nature of the surround matrix) attributes for many different groups of woodland species including plants, lichens, insects, small mammals, bats and birds which are expected to respond at different spatial and temporal scales. The results will help to develop recommendations on the design of future site and landscape conservation strategies for a range of woodland species.

Other details

WrEN is an on-going, long-term project of the Land Use and Ecosystem Services science group working in Programme 1 (Work Package 2.5) of the CFS programme matrix. The CFS budget for 2015-2019 for this work is around £40k per year. However, a large element of the funding and in-kind support to date, which is approaching £1 million, has come from a wide and diverse range of funding sources. The modular nature of the WrEN project has meant that many funders and partners can come on board to fund additional areas of work and add considerable value to the overall project. Most recently, some work on flying insects which has just been published in the Journal of applied Ecology was primarily funded by Tarmac (£150k) as they could see the benefits from this work to further inform their restoration work on former mining sites. Likewise, the Woodland Trust were interested in the development of soils in secondary woodland sites, so they were able to fund a study (£25k) to compare WrEN sites to similar and nearby ancient woodland and surrounding agricultural land. It is this modular nature that has allowed this project to develop from a small prototype post-doc project in Scotland, with very limited funding, to a major research project. There are still many areas within the project that could provide additional research opportunities and income e.g. work on functional networks within the woodland ecosystem and as a potential source to undertake manipulative experiments.

9.2. Description of research activity

Kevin Watts (FR) established the WrEN project with Professor Kirsty Park and Dr Elisa Fuentes-Montemayor at University of Stirling, and latterly with Dr Nick Macgregor formerly of Natural England (a key policy contact in England), with a vision to undertake a large-scale natural experiment. The opportunity to establish such an experiment had been identified earlier than this by Kevin Watts, who was then able to realise these ideas when policy demand and funding became available. The University of Stirling initially provided some short-term postdoc funding for Dr Elisa Fuentes-Montemayor to conduct a proof of concept pilot study and to act as a dedicated project manager for the project as it has developed (with additional funding) - this has been a key role in the project's success. Kevin Watts and the WrEN team have invested considerable time in giving the project an identity, developing a brand and logo, website, twitter feed, disseminating information and attracting external funding from a wide range of sources. The three core partners have also signed a Memorandum of Agreement which has enabled the transfer of funds rapidly between the organisations as they become available and avoid the need for slower procurement procedures.

One of the initial activities was a comprehensive literature review. This literature review underpins the work of WrEN, having identified the site and landscape variables that can influence biodiversity within fragmented forest landscapes and reviewed the existing evidence base. The review informed the site selection process, during which 106 secondary and 27 ancient woodland sites across Scotland and England have been selected using a range of woodland datasets, and historical maps to verify woodland age. The review has been published as both a report (Humphrey *et al*. 2013) and journal article (Humphrey *et* al. 2015). A journal article (Watts *et al*. 2016) has been published on the method for establishing the natural experiment, as a novel approach for landscape scale ecological research.

Wildlife and habitat surveys have been carried out by a number of surveyors and species specialists, while the surrounding matrix has been analysed using GIS and land cover datasets. The outputs of the fieldwork so far have been published in journal articles (Fuentes-Montemayor *et al*. 2017; Fuller *et al*. 2017; Whytock *et al*. 2017), with more analysis and papers on the way.

9.3. Impacts

Instrumental

WrEN findings are being used to inform the design of woodland and agricultural grant schemes in England, in terms of woodland size, quality and proximity to other woodland. Also there is potential to inform the actions of the National Forest planning and Tarmac restoration activities (TBC).

Conceptual

The project has already collected evidence to show that species may not behave as they have been assumed to, and that the quality and size of woodlands may be more important than providing woodland corridors (a common response from policy and practice). This is an important change in knowledge that can inform policy and practice for landscape restoration.

Capacity-building

The WrEN project has been responsible for developing new expertise among the researchers' as the large-scale natural experiment approach is still a fairly novel approach with its own benefits and challenges. Similarly, the modular approach of the project, combined with the adhoc funding model, has been a new, and at times complicated, challenging and rewarding, way of working for Kevin Watts and the WrEN team. The collaborative funding model has enabled many project partners to increase their capacity to access research through contributing to a larger, long-term and ongoing research project – increasing the 'bang for your buck'. The project is also using Structural Equation Models in data analysis, which are still fairly novel in ecology. This has also increased the skills base of the WrEN team and also FR statistician Jack Forster, who has been able to use this approach on other FR projects.

Connectivity

The project has had several impacts in developing or securing relationships with other partners and within FR, with the initial project having generated many associated projects, including projects on soils (lead by colleagues in FR) and with other academics on soil biodiversity, genetics and functional networks. The WrEN project has strengthened existing relationships with the University of Stirling as well as leading to new networks with researchers in North America, Estonia and a new potential link in Australia. It has increased links with surveyors and species specialists who have carried out fieldwork. The WrEN project has been presented at many international, European and national conferences and published in many general articles. The WrEN webpage (http://www.wren-project.com) is regularly updated and visited and the twitter account currently has 341 followers.

Culture change

The project has achieved some culture change impacts. This project has identified the importance and value of involving stakeholders and end users right from the start of the project. This co-development has ensured that we fully meet the needs of the end users and closer collaboration has been key to the success of the project, for instance the inclusion of Natural England as a key collaborator ensured that we met their needs and had access to funding. Similarly, the involvement of the National Forest and the Woodland Trust helped us to identify and gain access to suitable study sites.

9.4. Reasons for impact

Problem framing

The project has a well-framed, tractable problem that is easily understandable and addresses a key policy driver.

Management

Project management has been a major contributor to the project's impact. The passion and energy of Kevin Watts has been central to bringing partners and funding for the project that has required time, dedication and commitment. In addition, the dedicated project manager Elisa Fuentes-Montemayor at University of Stirling has been central to coordinating the day-to-day management of the project, maintaining social media and web presence and presenting at conferences. The vision, branding and identity of WrEN together with the initial investment to develop the proof of concept has been key to attracting additional funding and new partnerships.

Inputs

The modular and adaptable nature of the project, where additional projects can be added to the existing work, is a strength of the project as it can respond to new funding opportunities, and in particular attract small or short-term funding as it can deliver more than a small stand-alone project which is attractive for partners. However, securing this funding has been time consuming and it remains a 'hand to mouth' existence. There is now an interest in submitting a proposal for longer-term funding. Funding for a dedicated project manager has underpinned the progression and management of the project.

Outputs

The research has been justified by the literature review, which identified important knowledge gaps and key variables for the experiment design. A number of journal articles have been published from the work and many more are underway. In time, the project aims to be able to generalise findings for landscape restoration and woodland creation.

Engagement

There has been dialogue between researchers (e.g. partnerships; interdisciplinarity), and between researchers and stakeholders (e.g. user groups; co-production) throughout the project cycle. Research by landscape ecologists, ecologists, geneticists (metabarcoding), foresters, soils experts and ecosystem services researchers is contributing to the project methods and outputs. For example, WrEN soil samples have been shared with University of Newcastle PhD student and FR physical environment team. A number of students from universities across Britain have worked on the project. The WrEN informal steering group team is made up of researchers, policy makers and practitioners from FR, FC England, University of Stirling, Natural England, Tarmac, the National Forest Company, Woodland Trust, who together have contributed to the project through framing the research questions and agenda.

The project has involved a large time input from the core partners (FC and University of Stirling) publicising the project at conferences, on social media, to build its brand and form new networks. Engagement with researchers and other stakeholders has included writing for different audiences (journal articles, blogs), conference presentations and meetings. It is difficult to quantify the relative influence of each event. Some have directly brought in more funding (Tarmac, Woodland Trust). Kevin and Kirsty also organised a session at an international British Ecological Society conference in 2015 on 'large-scale experimentation' which brought together researchers from across the globe and discussions are underway for future collaborations.

Social and organisational factors

Initially the project developed from existing research networks and personal contacts; then once the project was established new research networks and partnerships have been formed, such as with Tarmac and researchers in the US. Some industry champions have emerged, self-named WrEN ambassadors at SNH, Natural England (Emma Goldberg), Tarmac (Sharon Palmer) and RSPB (Adrian Southern). FC England & Scotland are particularly interested in project outputs to inform future woodland grant schemes.

Context and contingencies

The project has been constrained geographically to England and Scotland as a consequence of funding and proximity to research/partner locations (Stirling and the National Forest in central England).

The project relies on key players, and as a consequence it is at risk of being affected by staff changes. For example, the funding for the post-doc researcher at Stirling (who also acts as the project manager) is not long-term, so the project is not able to provide job security and there is a risk of losing the funding and this key team member. Also, Nick Macgregor from Natural England (who has been a key link with a key policy customer and funder) has recently moved to Australia. His role has been filled and the impact on the project is difficult to know yet, as new trust needs to be built with his replacement. There is also a potential risks for the project if landscape scale conservation loses political support.

9.5. Lessons learned

There are strengths and weaknesses of the project's approach to doing research. The strengths have been its modularity, and the ability of funders to join a wider project which may be attractive for them where they have small short term funding. The project has also aimed to be responsive to different stakeholder needs and retain flexibility for the project tem. However, this raises difficulties for the project, as it is less able to plan long- term work, and it is hard to develop the capacity to respond to large amounts of funding becoming available quickly. The nature of the project's working model means that it is more difficult to plan work strategically. In future it would be better to secure more longer term funding, to enable long term planning and secure the role of project manager.

The project could have communicated more widely with other stakeholders from early on; however the funding from Natural England came in too quickly for this to be possible. There has been a focus on existing contacts and the usual stakeholders, and there are opportunities in the future to disseminate more widely. Also we are looking at ways to communicate research and outputs in other formats that are more useful.

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10. i-Tree: quantifying and valuing urban forest benefits

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10.1. Introduction

"The urban forest comprises all the trees in the urban realm – in public and private spaces, along linear routes and waterways and in amenity areas. It contributes to green infrastructure and the wider urban ecosystem" (Davies et al., 2017). It provides a diverse array of benefits to human society and it does so in vast quantities. These benefits include: giving character, beauty and a home for wildlife; regulating local climate; intercepting rainfall, and filtering out airborne pollutants.

Maintaining a healthy and diverse urban forest is critical to sustaining delivery of these benefits and resilience in delivery under austerity and a changing climate. Expanding the resource is required to address delivery inequalities across a city. Such management and maintenance requires a clear understanding of the urban forest resource, including: species and age composition, size, spatial distribution, and health status. The urban forest however is complex: it is spread across many land uses and, therefore, owners and a full inventory is uncommon for publically managed trees let alone for the wider distribution across a town or city. National understanding of urban forests is similarly bleak: the last comprehensive analysis of the structure of England's urban forests (Trees in Towns II) was published in 2008 and requires updating. Producing detailed datasets for individual towns and cities is a basic data requirement for their effective management as resilient forests, for setting baselines from which to develop goals and for monitoring progress.

i-Tree is a suite of open source and continuously improved software tools developed by the USDA Forest Service and collaborators to help manage urban tree populations for the benefits they provide. i-Tree Eco and i-Tree Canopy are two tools in this suite. i-Tree Eco uses field data along with local climate and air pollution data to characterise the structure of the tree population, quantify the environmental functions it performs, and value these benefits. Eco employs peer-reviewed scientific models and provides reliable and statistically robust data. i-Tree Canopy is a free-to-use online point-based canopy cover assessment tool. Sample points are randomly generated within a defined study area and reviewed over Google maps using the i-Tree Canopy programme.

i-Tree Eco is providing for the first time a detailed picture of trees across UK urban areas. This is enabling analysis of urban forest structure, revealing proportional distribution by ownership and land use and facilitating risk assessment to pests, diseases and the wider impacts of climate change. i-Tree Canopy is enabling cost-effective canopy cover quantification at ward and city level to inform targeted planting strategies, as well as to build the case for tree retention in light of felling orders.

Work streams related to i-Tree Eco occur in Programmes 1, 3 and 4. In P1, £12k enables the provision of expert advice to support the growth and uptake of Eco and to catalyse future projects. In P3, data from ten city-wide Eco projects is being used to model the life span change in ecosystem service provision of small, medium and large stature trees in the urban environment. In P4, primary research is undertaken to validate the suitability of the i-Tree Eco engines for use in the UK and develop complementary science to increase is relevance and accuracy. As more UK cities complete an Eco project, a national urban forestry picture can be developed. Already, analysis of data from the twelve city-wide Eco projects is being used to evaluate differences in urban forest resilience across the UK. Separately, relationships between urban canopy cover and socio-environmental inequality are also being investigated.

i-Tree Eco work is principally carried out by the Urban Forest Research Group. The Social and Economic Research Group are also engaged, in evaluating the impacts of i-Tree Eco projects across the UK, and the in the review of the economic valuation approach employed by i-Tree Eco, and similar models such as CAVAT and Treezilla.

10.2. Description of research activity

A broad mix of i-Tree activities has taken place to raise the profile of the urban forest: a current state of knowledge document has been produced, 'Introducing England's Urban Forest'; baselining of the canopy cover of 283 English towns and cities has been reported via a presentation to the international Tree, People and Built Environment 3 conference; two city-level reports on ward-level canopy cover have been produced under external commission; and fourteen city- and catchment-area level i-Tree Eco projects have been conducted by FR or in partnership; and 'full inventory' i-Tree Eco evaluations have been performed for two local authorities, in partnership with the social-enterprise Treeconomics.

A distinction is drawn between delivering an i-Tree Eco (or Canopy) study, which is a monitoring exercise conducted in partnership with a local authority or other land owner, and post-hoc evaluation of multiple Eco studies, which is a research activity for learning lessons and for closing knowledge gaps as currently underway jointly between the Urban Forest Research Group and the Social and Economic Research Group.

An i-Tree Eco valuation of an urban forest has specific project objectives, for Wrexham County Borough Council for example:

- Support delivery of i-Tree Eco project in Wrexham to provide a review of the state of its urban forest and value the ecosystem services it provides.
- Provide advice and recommendations for policy and management based on survey's results.
- Support training and CPD throughout the project.

To meet these objectives, a steering board was convened, training was delivered to Forest Research staff and student volunteers and a field-survey campaign conducted. For other Eco projects, training has been provided to arboricultural contractors and the general public. i-Tree Eco based CPD events have also been held.

For the Wrexham County Borough Council Eco project, a full technical report and a two-page summary were produced. Natural Resources Wales (the lead commissioning partner) also produced a two-page infographic for wider communications of the results; no other knowledge exchange was actively conducted. Subsequent Eco projects have sought a much wider impact and knowledge has been disseminated via technical reports and two-page summaries, partnership newsletters, newspaper articles, trade journal articles, blogs, Twitter and Facebook, evening talks, stakeholder workshops and conference presentations. Two international conference articles have also been produced, with another in press.

The objectives of an i-Tree Eco based research project varies with the research question of interest. For example, the 'Comparison of urban tree populations within four UK towns and cities' conference paper sought to answer the following research questions:

- How many trees are in the urban environment?
- What ecosystem services do they provide?
- What drivers are determining urban tree populations?
- What challenges do urban trees face?

This small study comparing four UK urban tree populations was presented at an international conference and published in the conference proceedings. It was an abbreviated parallel to the oft cited 2008 'Trees in Towns II' study and a demonstration of the potential of i-Tree Eco to provide data for a Tree in Towns IV evaluation. Similarly, two peer-reviewed journal articles have been produced directly related to i-Tree Eco work, with another in review and two in preparation.

A minimum of two presentations are made annually. Some are to local audiences presenting the scope for a new Eco project or the results of a recently completed project, others are to international conferences presenting on the national programme of work for implementing i-Tree Eco in the UK (FR is central to this programme along with the Arboricultural Association, Treeconomics, and tdag.org). Furthermore, two blog items for the ICF have been used to communicate work progress; trade journal articles have been produced for the ICF and the Arboricultural Association, and Forest Research's work has been featured by HortWeek.

In addition to the activities outlined above, Forest Research has undertaken 17 evaluation interviews with stakeholders involved in six i-Tree Eco surveys from across England, Wales and Scotland. The specific i-Tree studies included in this evaluation exercise are: Torbay, Sidmouth, Edinburgh, Glasgow, Bridgend, and Swansea and the Tawe catchment. A further four interviewees provided an overarching national (GB) perspective. The sections which follow draw upon the data from these interviews and from a published impact evaluation of the Wrexham County Borough i-Tree Eco study to report impact, barriers to impact and lessons learned.

10.3. Impacts

10.3.1. Instrumental

Instrumental impact by contributing to a new Urban Forest Management Strategy (or similar) is a primary objective for an i-Tree Eco report or related canopy cover assessment, as achieved in Wrexham County Borough in 2015. A new woodland management strategy was written for the County Borough using the information from the Eco project, including a target to increase tree canopy cover to 20% (from a baseline of 17%). Evidence of the value of the urban forest legitimised retaining an urban tree officer and current budget in a climate of shrinking departmental budgets. Wrexham's findings have also gone on to influence national policy, adding rationale for urban forest themes within the Woodlands for Wales Action Plan and the NRW Corporate Plan 2015, and received local and national press coverage (Jaluzot and Evison, 2016).

As noted above, 17 evaluation interviews were conducted with stakeholders involved in i-Tree Eco surveys from across Great Britain. Data from these interviews provide additional evidence of instrumental impact, within local authorities, city councils and national bodies. Interviewees reported that the i-Tree Eco surveys results had been used or were being used in the following ways:

- To get support for a tree planting programme in the city;
- To feed into a 'Trees in the City' policy;
- To inform the Local Development Plan;
- Facts and figures from i-Tree were included within a neighbourhood plan;
- The study results are referenced within a Green Infrastructure Strategy;
- Results were fed to the Climate Change team within the local council for meeting climate change adaptation and targets;

- Results are being fed into a Landscape Design Package, a piece of work (still in the pipeline) looking at tree planting, hedge laying, hedge planting and the species composition of that;
- Within a 'Task and Finishing Forum' within the Council looking at the tree service;
- Fed into and influenced an evidence pack for the local Public Services Board;
- To bridge the gap, in policy terms, between a more traditional rural forestry focus and urban forestry;
- To encourage more planting in a large urban park in a town council area;
- To be fed into Supplementary Planning Guidance on trees and development as it comes up for review;
- To help shape the Open Space Strategy in a city;
- Helped to build a case for a broader approach to tree management;
- Helped to get people talking more about trees in urban environments and peri-urban environments rather than in traditional woodland settings;
- Figures were used by an Ash Resilience Forum, looking at the impacts of Ash dieback in the region; and the data in terms of species populations, age structure, etc. were used for master-planning and the management of the urban forest.

10.3.2. Conceptual

Conceptual impact is common within the project board and end users of i-Tree Eco reports. At the simplest level this is because the information generated is extremely novel and informs what is otherwise only 'guestimated' or anecdotally known, such as the most common species and land uses associated with the most and largest trees. Within Wrexham County Borough, the report raised awareness across Local Authority departments around the importance of urban trees (including in public health, planning and housing) and through awareness raising led to a re-prioritisation of the urban forest within policies of these groups (Jaluzot & Evison, 2016). While translation into policy revisions is currently limited across the six i-Tree Eco projects herein evaluated, the knowledge has changed awareness, attitudes and opinions of project related tree officers/managers; for example, perceptions of Sycamore (*Acer pseudoplatanus*) in Edinburgh changed from being simply a non-native invasive to a primary deliverer of regulatory ecosystem services to the city.

The evaluation interviews conducted with stakeholders involved in i-Tree Eco surveys revealed additional evidence of conceptual impact on the knowledge and attitudes of both interviewees and others. Examples included the following.

Interviewees reported being surprised at the results in terms of the valuations of the trees. There was also surprise at the replacement value, that being something they hadn't previously considered, i.e. how much it would cost to put all the trees back, following a large fire or pest out-break, for example.

Interviewees also reported that they understood more about how important urban trees are within catchments, and had a much better idea of which trees should be planted.

One of the interviewees noted that having the i-Tree evidence and the financial valuation, and needing to understand it before briefing others, improved their understanding of the different services, how they are provided, and the economic valuation techniques.

Others also noted they previously had very little grasp of the value of trees, in terms of ecosystem service provision, and that, as such, i-Tree Eco had been "a real eye opener and really powerful".

Some noted how useful the quantitative data was for engaging with staff in other departments, such as air pollution removal data, when dealing with road engineers.

It was noted that it is important to have the evidence, when talking to other departments, that trees are good for health and well-being because they scrub out air-borne pollutants, and they help protect sewage infrastructure by intercepting and filtrating rainwater.

By raising the profile of trees i-Tree Eco helped people understand that woody plants are very important in a planting structure for urban landscape and for gardening, and this helped with the parks department of the district council.

Within their own organisation, some commented that the senior board members had become aware of i-Tree Eco and what it can be used for, and had engaged well with the approach. They believed that anybody who has been exposed to the i-Tree Eco study has a better understanding of how urban trees could be valued, and the range of benefits provided.

Interviewees noted that the i-Tree project contributed to a change in attitude from some professionals towards recognising the value of green infrastructure. As one interviewee put it "there's no doubt in my mind that i-Tree has had a positive effect in terms of raising the profile of the urban tree environment and getting people talking about the importance of urban trees".

10.3.3. Capacity building

Regarding capacity-building impact, eight current and former FR staff and four volunteers have been trained in the i-Tree Eco methodology, along with professional contractors who have gone on to train volunteers in subsequent projects, and university students. Volunteers have been the primary delivery mechanism in the Ealing, Lewes, London, Petersfield and Sidmouth i-Tree Eco projects.

The evaluation interviews conducted with stakeholders involved in i-Tree Eco surveys in England, Wales and Scotland revealed a few examples of capacity building impact, in terms of skills development and changes to funding, as detailed below.

Skills development

One interviewee reported that "In one area, of the 14 or 15 people who took part in the i-Tree Eco survey none of them had done a tree survey before, so they all learnt something new".

For another interviewee there were multiple areas of skills development. Having to pull together an i-Tree Eco study with colleagues involved understanding the methodology, being able to train people such as volunteers, and carry out fundraising to make that happen. So, the engagement in the activity helped skills development on all those fronts.

Due to staff turnover within one organisation an interviewee reported having to continually educate new staff in the use of i-Tree and train them to deliver projects. Also, due to the development and adaptation of i-Tree over time individual capacity has grown through more awareness of the tool and its capabilities.

Following an i-Tree Eco study in Lewes, with a group of students from Plumpton College who were involved with data collection, it was integrated into part of their course curriculum. Another college (Myerscough College, Lancashire) now includes i-Tree as part of their BSc course.

Funding

Interviewees reported a few examples of how i-Tree had resulted in additional funding opportunities, either from external or internal sources.

In one area a Heritage Lottery Fund proposal had been agreed for an i-Tree trail, a tree-based initiative to get people walking for improved health.

At one council in England they were able to secure funding and support from Members for additional arboricultural officer posts.

In another area it was noted that prior to the i-Tree Eco study the tree officer was faced with budget cuts and a tree planting budget that had almost disappeared. After the study the tree planting budget was reinstated, and he was promoted to a position where he was involved in more strategic thinking.

In other cases it was felt that the i-Tree work led to the preservation of budgets during a period when many department budgets were being cut.

However, as one interviewee noted, things might have been different if the i-Tree surveys had been carried out before the start of the recession in 2009. It was noted that the 'big issues' are education and social care, and as budgets contract they soak up most of the resource, making it particularly difficult to secure additional funding for tree planting and management.

10.3.4. Connectivity

Connectivity impact flows when steering groups for Eco projects have been carefully considered, and invitations to them accepted, including the presence of Highways, Planning, and Water-boards; as achieved in the Tawe Catchment project.

The evaluation interviews conducted with stakeholders involved in i-Tree Eco surveys in England, Wales and Scotland revealed a number of examples of new or increased collaboration within and between organisations as a result of involvement in i-Tree work. These included:

- Collaboration with additional teams and departments within local authorities, such as the climate change adaptation team, transport department and sustainability unit.
- i-Tree Eco projects had led to new or improved collaboration with a wide range of bodies including: private businesses, the Highways Agency, local schools, local interest groups such as a Hedge Group, the local AONB, councils, the health sector and local surgeries, the Woodland Trust, the Landscape Institute, universities, and Forest Research.

Other networks and forums were mentioned as being very active in bringing diverse organisations together. These included:

- the Urban Forest and Woodland Advisory Committee's Network (the 'Urban FWAC Network'), and
- the Trees and Design Action Group (tdag.org).

Overall, the i-Tree Eco surveys appear to have had much positive 'connectivity impact'. As one interviewee put it "I would say it's [involvement in i-Tree] reinforced our [positive] attitude to collaboration".

10.3.5. Culture Change

Regarding culture change, errors made during the knowledge exchange of the Wrexham study taught project commissioners that effective transfer requires pre-project planning, not just post-project dissemination of a report. This led to greater levels of partnership working, the use of workshops and additional outputs for different audiences in subsequent studies.

The evaluation interviews conducted with stakeholders demonstrated recognition that knowledge exchange and communication and dissemination of findings was an area of the i-Tree Eco studies that had not always been successfully planned and delivered, as detailed below, and for many, studies began without a clear idea of who was the audience.

As figures revealed the proportion of canopy cover found on private land it became more clear to project teams how important it might be to have results accessible to the general public so that they could have a greater understanding of the benefits provided by the trees on their own property.

Others reported the realisation that they needed to learn the lessons about failings in knowledge exchange and "do a better job at promoting and presenting the findings of the report".

There were reports from other interviewees that they had attempted to do revisions of their document to make it more accessible for other departments to enable them to take and utilise information of relevance for them. In some cases this resulted in a summary document being written at a later date, a significant time after the initial report.

There was a recognition that there needed to be an output "in plain English" so that groups such as community forums in deprived wards could access and utilise the findings.

Beyond the public and community groups, and other internal council departments, others recognised the importance of articulating the findings to other organisations who do not plant or maintain trees. However, it was recognised that other land managers such as social housing associations might be able to utilise i-Tree findings if they are made relevant and accessible to such a body.

Some talked about the need for translation of technical findings, and dumbing down of language; others about using different types of output, or adding further explanation, and others still about the need to "tease out the relevant bits of information for the audiences".

One comment suggested talking to, for example, health and highways departments, to understand from them what kind of information might be of interest and use, and how they would need it presented.

There was a recognition that in some projects there had been a failure to appreciate how much time would be needed for knowledge exchange and dissemination.

In many of these responses it was clear that understanding about how knowledge exchange needed to be varied and tailored to different groups had developed through the process of the i-Tree £co project.

10.4. Reasons for impact

Wrexham County Borough Council's new woodland and tree management strategy was substantially informed by the i-Tree Eco project, yet it was not created 'because' of the project. New policy creation is dependent on local need – Wrexham County Borough Council were looking to renew their Strategy and commissioned the Eco project to inform its writing. Impact from the Wrexham Eco study was bolstered by the active interest and involvement of an Elected Member champion: proposed policies require scrutiny and review before adoption and the right champion backing the document and facilitating necessary revisions on-route can prevent the policy being delayed or even rejected. The Elected Member acted as a catalyst, which raised the profile of the Eco project and the ensuing strategy, and generated interest and ultimately helped translation of the findings in the new adopted policy. Timing was key in Wrexham; the data was contemporary and relevant to the policy preparation need. Impact was also ensured through regular and detailed dialogue between FR researchers delivering the project and the steering board, who were engaged and critical to ensure that the data and its interpretation met their requirements.

Data from the evaluation interviews revealed a range of barriers to impact. These are elaborated here:

- Funding within local authorities is not necessarily allocated to the departments that need it to apply tree planting / tree management changes as a result of the i-Tree Eco survey results.
- There is a lack of resources to analyse all of the results to their fullest potential.
- There is a lack of funding within Local Authorities to take on new tree management activities.
- There was a failure to ensure at the outset that there were enough resources to take the outputs as far as they needed to be taken, and consider analysis, dissemination, and application/ next steps (in a financial climate where it was also difficult to secure sufficient funds to make the Eco project happen).
- Staff move around within local councils and continuity is lost.
- The i-Tree Eco surveys coincided with structural change within local councils and national bodies such as NRW - hence timing was coincidentally poor, resulting in reduced impact.
- The Council has not publicised results as much as they could have done; they could have been more proactive.
- There was a lack of an i-Tree Eco survey champion within the local authority.
- There was a lack of senior level buy-in at the council – this was needed at the start.

- In the devolved nations there was a lack of consistency in the types of tree benefits valued across different studies (this relates to developments to the i-Tree software, but also to project specific aims and opportunities).
- Greenspace management has been pushed down the agenda in most local authorities and now lacks a senior level staff member with access to Directors.
- The issues central to i-Tree Eco surveys are not high on people's agendas.
- The i-Tree Eco surveys fail to relate urban forestry to health issues clearly and strongly enough to justify extra spend on green infrastructure.
- Departments such as Highways and Health do not have access to i-Tree survey information in a way that is meaningful to them, i.e. relating to SUDS and well-being, respectively.
- It is a challenge to overcome concerns about costs of maintenance of urban trees, and potential negative impacts, for example leaves, damage to cables or buildings, and creation of areas of shade (and corresponding concerns about safety).
- Some i-Tree reports were overly technical.
- There was a lack of clarity in some cases about who the results were for.
- Trying to produce results that are for use both as an advocacy tool, and a tool for planning and management is problematic.
- Expectations may have been misguided, with users perceiving i-Tree Eco survey reports to be documents for action and delivery, rather than reports containing data and information.

10.5. Lessons learned

An influential project champion has been identified as vitally important for translating i-Tree Eco information into influential new policy. Such a champion may not always be present and Eco projects are also conducted at the grass-roots level - for awareness raising, lobbying and to draw a local champion. Data relevance, however, has been shown to be central to the effectiveness of an Eco project in having impact. Project design can be tailored to ensure maximum appropriateness to local policy needs, and more co-design of future Eco projects would optimise this.

The reporting mechanism has been identified as a fundamental challenge. A specific dilemma has been the need to provide useful knowledge, typically done through a main or 'technical' report, yet package information accessibly for multiple targeted users, including lay readers who require less methodological detail, and more interpretation and identification of explicit active next steps for implementation. The later audience would benefit from a colour glossy magazine-style read, which can be as expensive as, or more costly than, the primary report, which is itself essential as a repository of information for future actions to hang off. Planning and provision for multiple outputs is an important lesson learnt for future projects to monopolise on.

Communication of a study's results, in terms of both report structure and dissemination approaches, could be improved by targeting specific audiences separately which may have increased engagement and uptake by more diverse groups (e.g. wider LA departments, the public).

The 17 evaluation interviews revealed a number of opinions about extra information that would be valuable in future i-Tree Eco projects and reports.

- There is a need to provide more information about the links between urban trees and health indicators (e.g. prescription use, asthma sufferance, obesity, hospital recovery, and also the impact of trees on our mental wellness, in terms of providing places where people are able to relax and de-stress).
- Information is needed about the capital requirement for managing the urban tree resource – so the i-Tree Eco survey results need to say 'the urban tree resource is worth this much, it provides benefits to this value, and it needs this much investment to manage annually'.
- It would be useful if future i-Tree Eco surveys could provide information (or more information) on: biodiversity values; health and social values; distribution of ownership (public/private) so as to inform pest and disease management; the aesthetic value of the trees (incorporated into some, but not all studies via a CAVAT valuation); a social damage cost for $PM_{2.5s}$ (requires the UK Government to produce one), and a value for noise abatement provided by urban trees.

Other areas for improvement and suggestions for future change have been revealed by the interview data:

- i-Tree needs to be able to demonstrate how urban trees are important to the health agenda.
- There is some argument for saying that the i-Tree reports need to move beyond presenting evidence to interpreting that evidence to make it more meaningful.
- Interviewees wanted to see i-Tree results being more forcefully used to make the case for why urban trees are important.
- A multitude of outputs is needed – infographics for key facts easily understood by all; summary document with a bit more detail; technical report for tree specialists; scientific publication.
- There is a need for more simplified training in how to do an i-Tree Eco survey.

- Some interviewees wanted to see better connections between community groups carrying out i-Tree Eco surveys so as to share experiences.
- Local Authorities need to carry out i-Tree Eco surveys in different cities at the same time (specifically, within the devolved nations) so there is increased collaboration and inter-city co-operation.
- Project teams may need to buy in professional communications guidance (on how to get key messages out there).
- Project teams should consider involving citizens ("ordinary people") in i-Tree Eco surveys, perhaps by linking with Treezilla, in order to help more people understand the importance of their own trees and those around them.
- There could be greater use of i-Tree Eco survey results to inform target setting, for example for canopy cover and species diversity.
- i-Tree needs to be able to provide results about social and health benefits because that is what people are interested in.
- i-Tree project teams should engage more with friends groups, community groups, and neighbourhood groups (e.g. City of Trees in Manchester, the Red Rose Forest, Trees for Cities in London, the Tree Council etc.) to increase impact of i-Tree Eco surveys.
- Project teams need to keep using the data / information and get it to decision making organisations in a digestible format.
- Project teams should find further opportunities to raise awareness about the i-Tree Eco survey results.
- More i-Tree Eco surveys are needed across the country to fully understand the national picture.
- Repeat surveys are needed in specific locations to understand trends and changes in quality of the urban tree resources.

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- Reports for i-Tree Eco projects led by FR can be viewed at: www.forestry.gov.uk/fr/itree
- Other i-Tree Eco project reports and the canopy cover values of over 300 UK towns and cities can be viewed at: www.urbantreecover.org

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11. Forest carbon and biomass policy

Robert Matthews

Forest Mensuration, Modelling and Forecasting

11.1. Introduction

11.1.1. Background

The story behind this research goes back to the first meeting of the Intergovernmental Panel on Climate Change (IPCC) held in November 1988 and the preceding World Conference on Changing Atmosphere held in June 1988. Around the time of these meetings, there was a chance encounter between then British Prime Minister Margaret Thatcher and the Director of the Forestry Commission's Research Division (now Forest Research), Arnold Grayson. The Prime Minister asked Mr Grayson how much carbon was stored in the UK's forests. The next day, he returned to Alice Holt and called Robert Matthews (then a junior scientist with two years of experience at Forest Research) to his office. He instructed Robert to build a computer model for estimating carbon stocks and stock changes in trees and the wider forest sector. The development of the resultant model, CARBINE, represented the first attempt to model systematically and comprehensively the exchanges of carbon between the atmosphere and various types of forest system, and other relevant carbon reservoirs. So began what turned out to be a research endeavour that has been sustained for nearly thirty years, and which has closely supported the development of UK and international policy on the contribution of forests and harvested biomass towards the mitigation of climate change.

11.1.2. Objectives

The specific objectives of this research have changed over the years, but the general aim has always been to address questions about the carbon and greenhouse gas (GHG) balances of forestry systems, and to inform the development of forest policy and practice, particularly with regard to the goal of climate change mitigation. Examples amongst the wide range of more specific research questions addressed by the research include:

- What are the carbon stocks in a defined area of forest?
- What is the impact on land-based carbon stocks and sequestration of establishing new areas of forest on a defined area of land?

- What impacts do different silvicultural systems have on the development of carbon stocks and sequestration in a defined area of forest?
- What emissions and removals of GHGs should be reported for a defined area of forest for the purpose of reporting GHG inventories under the UNFCCC?
- What contribution could a defined area of forest make towards meeting climate change mitigation targets (e.g. UK national targets)?
- What would be the impact on carbon stocks and sequestration of introducing a programme of regular harvesting for wood production in a forest area that previously was not subject to significant human intervention?
- What carbon accounting approaches would provide the appropriate incentives for managing forests and utilising harvested wood to mitigate climate change?
- What would be the impact on GHG emissions of changing the uses of harvested wood, for example diverting the wood from use in timber products to use for bioenergy?

Intended users of the research

The main intended users of the research are policy makers in the UK Government and Devolved Administrations, also aiming to inform EU and international policy. However, the development and adoption of effective policies also requires the support or consent of diverse set of stakeholders including forestry practitioners, the wood-based industries, energy producers, regulators, environmental NGOs, academics and the general public. Hence, whilst directly supporting policy makers, the research aims to reach out to wider stakeholders to communicate impartial evidence to inform debates about how forests should be managed and harvested biomass should be utilised to help meet climate targets.

Intended outcomes and impacts of the research

The main intended outcome and impact of the research is the adoption of robust policies on forestry and the utilisation of harvested wood, which will contribute towards the ultimate goal of preventing dangerous climate change. A secondary intended outcome and impact is for policy positions advocated by the UK and wider stakeholders to have a credible basis in the best available sound scientific evidence.

11.1.3. Research budget, timescale and location in FR

Budget

Annual funding from the Forestry Commission for research on this subject has been very variable over the years, from roughly £20k to £250k. Currently (2017-18) Forestry Commission funding of roughly £100k is allocated as part of the research under Work Package 5 of the Science and Innovation Strategy (SIS) Programme 6, Innovation in Modelling, Data and Tools. It should be noted that the level of funding is effectively subject to annual review by the Programme 6 Steering Group. Current funding under Programme 6 supports specifically the development and improvement of forest carbon models such as CARBINE and some development of related tools such as the FC Woodland Carbon Code (WCC) lookup tables, and provision of advice (including participation in IPCC activities). Explicitly, the Forestry Commission has de-prioritised and de-funded all research on biomass across the SIS.

It is only possible to sustain research on this topic by FR, and the capacity within FR to undertake such research, by winning competitively tendered external income, particularly to support any research on the roles of harvested woody biomass. This varies annually but has amounted to roughly £100k pa in the last three years.

Timescale

As already explained (Section 11.1.1), this has been a long-term research endeavour. As a consequence, the FR researchers involved have been able to develop deep knowledge of the subject and build strong relationships with policy makers and influencers within the UK, EU and internationally. The priority attached to the research is the subject of annual review and also dependent on external income (see 'Budget' above). Going forward, the research is likely to continue as long as support to policy on climate change mitigation through forest management and wood utilisation remains viewed as important by stakeholders, notably research funders.

Location in FR

The bulk of the research is undertaken within the Forest Mensuration, Modelling and Forecasting (FMMF) Science Group of Forest Research with some contributions from the Climate Change Science Group. As already explained, FC core funding is allocated via Work Package 5 of SIS Programme 6 (see 'Budget' above).

11.2. Description of research activity

11.2.1. Inputs to the research

FR staff involved in research

The main input to this research is the expertise and industry of the staff involved, most of whom are based in the FMMF Science Group. A small team works closely together on the fundamental development of forest carbon models and the provision of evidence to support forest policy and practice:

- Robert Matthews (Science Group Leader, technical direction and planning of research, leader of bids for external income, national and international representation)
- Paul Henshall (lead developer of CARBINE model, Project Leader for compilation of UNFCCC GHG inventory results for Forest Land in the UK)

- Tim Randle (fundamental development of models of forest carbon processes, construction of forest carbon lookup tables for FC WCC)
- Ewan Mackie (systems analysis of forest management and wood supply chains)
- Geoff Hogan (forest carbon and bioenergy outreach and knowledge exchange).

The work of this team is supported by other modellers in the Science Group who develop other forest models that form components of the carbon models such as CARBINE:

- Catia Arcangeli (development of forest growth models such as M1 and MOSES-GB)
- Hannah Gruffudd (development of fundamental forest growth relationships)
- Ian Craig (management of the sample plot network that provides essential validation data for models).

Researchers in the Climate Change Science Group also provide important support through the provision and interpretation of relevant fundamental scientific data.

Key partners in research

The long-standing track record of the research team has enabled them to develop a number of very important strategic partnerships:

- North Energy Associates environmental consultants (collaboration on wood supply chain life cycle assessment)
- Centre for Ecology and Hydrology (collaboration on GHG inventory compilation for LULUCF Sector, i.e. all land uses)
- Ricardo environmental consultants (collaboration on GHG inventory compilation and climate change mitigation strategies at national and global scales)
- University of Bristol (collaboration on regional- and global-scale modelling of vegetation management for climate change mitigation)
- University of Aberdeen (collaboration on forest soil carbon and land use modelling)
- SUPERGEN Bioenergy Hub through University of Manchester (collaboration on modelling of bioenergy systems)
- EC Joint Research Centre (collaboration on regional and global scale modelling of forest management for climate change mitigation and associated mitigation strategies and forest carbon accounting approaches; collaboration on life cycle assessment of bioenergy supply chains)
- Alterra/Wageningen University, Netherlands (collaboration on land use modelling at EU scale)

- VTT Technical Research Institute of Finland (collaboration on modelling of bioenergy systems and climate change mitigation strategies at national and global scales)
- International Energy Agency Bioenergy Task 38, Greenhouse Gas Balances of Biomass and Bioenergy Systems (until approximately 2007, collaboration on modelling of bioenergy systems and climate change mitigation strategies at national and global scales, contact still maintained).

In addition to research partners, the effectiveness of the research has relied upon strong and constructive links with influential policy advisors and policy makers in the Forestry Commission (England and Scotland), the Welsh Government, UK Government (BEIS, previously DECC), the European Commission (DGs CLIMA, ENV, ENER and SG) and the IPCC.

Main resources required for research

Apart from staff effort the most important resources required for undertaking the research are the models developed by the research team and, crucially, sufficient computing resources. Funding for travel to meetings with collaborators and stakeholders has also been essential in maintaining engagement between the research team and the frontline of research and policy developments.

11.2.2. Main research activities

The research activities are vertically integrated, i.e. joining from end-to-end fundamental science through to policy outcomes, involving all relevant steps in the process:

- Regular review of state of the art of fundamental science
- Fundamental development and validation of relevant models
- Application of the models to policy-relevant problems
- Interpretation and communication of the results of modelling to policy makers and other stakeholders, via presentations, workshops and face-to-face meetings
- Some involvement in actual policy formulation, in collaboration with policy makers
- Background technical support to international negotiations on climate change mitigation in relation to forestry and other land uses
- Development of practical standards, guidance and tools to implement policies
- Outreach to the forestry and wood processing industries and other actors involved in responding to policies.

11.2.3. Outputs of the research

The outputs of the research can be categorised as “hard” and “soft”.

The hard outputs consist of:

- A significant body of scientific and technical reports, usually produced directly to the specification of clients
- Peer-reviewed scientific journal articles
- Technical communications such as Research Information Notes, FR Monographs
- Computer models for use internally by Forest Research and externally as part of collaborations
- Tools to inform forest policy and support forest practice (e.g. the FOR_KP software tool for evaluating forest-based climate change mitigation potentials in Annex I countries to the Kyoto Protocol; the FC WCC forest carbon assessment protocol and forest carbon lookup tables).

The soft outputs are less immediately apparent than the hard outputs but can have very high impact, consisting of:

- The adoption of a policy as a direct result of the research by a business, government department or under an international agreement, such as the agreement reached in 2011 to make Forest Management a mandatory activity in the Second Commitment Period of the Kyoto Protocol and to apply Reference Level accounting for Forest Management
- A change in position by a stakeholder (e.g. policy maker, business, NGO or academic) in response to the research, regarding forest management, wood utilisation and the mitigation of climate change, such as the gradual adoption by some environmental NGOs of a more nuanced position with regard to forest biomass used for energy.

11.3. Impacts

Over the years, the research has had many impacts at many scales on a number of areas of forestry and climate change policy, and on related forestry practices. Table 1 highlights the most important examples of impacts, in broadly chronological order.

It is important to note that work on some of the later subjects described in Table 1 is ongoing, hence the details should be regarded as sensitive.

Table 1 Main examples of impacts of forest carbon and bioenergy research

Policy/ Practice area	What kind of change?	Who was influenced?
Roles of harvested wood in reducing GHG emissions	• Conceptual: recognition that decisions about managing forests to mitigate climate change need to be made by considering the impacts of management options beyond the forest gate, i.e. within forests and also across economic sectors such as energy and construction; recognition of harvested wood as having a role in supporting climate change mitigation • Instrumental: The debate about climate change mitigation through forest management shifted from thinking just about carbon sequestration in forests to considering the holistic impact across sectors. • Capacity-building: Forest Research was recognised by some new clients as providing relevant research and evidence. • Connectivity: The research team first became recognised internationally and developed important links in Australia, Canada, Finland, Netherlands, New Zealand, Russia and the USA. • Culture change: recognition of Forest Research as contributing to the debate about how to manage forests to mitigate climate change.	• Leading researchers in the countries listed under "Connectivity" • Policy-makers in the countries listed under "Connectivity" and in IPCC Working Group 3.
Roles of woodland creation and woody energy crops (e.g. SRC)	• Conceptual: recognition that afforestation and establishment of woody energy crops could make an important contribution towards meeting climate change mitigation targets, particularly in the UK • Instrumental: The UK and Devolved Administrations consider afforestation targets as a policy option when determining carbon budgets; a decision by the Forestry Commission to develop the Woodland Carbon Code. • Connectivity: The research team developed close partnerships with forest policy makers in the Devolved Administrations and in FC GB.	• Researchers in other Science Groups within FR and certain influential research groups in the UK (e.g. Kings College London) and internationally (e.g. IEA Bioenergy Task 38) • Policy-makers in FC GB, BEIS, FCS, FS, Welsh Government • Practitioners engaging in forest carbon projects under the WCC. • Businesses interested in funding 'green' initiatives.

Table 1 (continued) Main examples of impacts of forest carbon and bioenergy research

Policy/ Practice area	What kind of change?	Who was influenced?
England and Scotland wood fuel policies	• Conceptual: recognition that developing an energy market for woody biomass could support rural development, woodland improvement and also help meet climate change mitigation targets, but that this requires careful management • Instrumental: Forestry Commission England introduced a Wood fuel Strategy and the Scottish Government revised its bioenergy policy to take account of the scale of energy generation installations • Capacity-building: The Biomass Energy Centre was created in Forest Research, initially funded by the Forestry Commission with Defra; funding was reduced and finally cut in 2014 • Connectivity: Strong links developed with other bioenergy researchers in the UK • Culture change: recognition of Forest Research as able to directly support policy development.	• Bioenergy researchers in the UK (e.g. at IBERS, Rothamsted and the Universities of Aberdeen, Manchester and Southampton) • Policy-makers in FCS, FC England, Defra, Natural England and the Sustainable Development Commission (Scotland) • Many practitioners working in the wood fuel market (via the Biomass Energy Centre) • Local communities interested in better utilising their woodlands.
Inclusion of Forest Management in the Kyoto Protocol	• Conceptual: Recognition that existing approaches to accounting for the contribution of Forest Land towards climate change mitigation targets needed improvement and that Reference Level accounting was one possible better option, whilst acknowledging substantive risks • Instrumental: International agreement was reached on Forest Management as a mandatory activity during the Second Commitment Period of the Kyoto Protocol; adoption of Reference Level accounting for Forest Management in the Second Commitment Period • Capacity-building: Forest Research was recognised by some new clients as providing relevant research and evidence. • Connectivity: The research team developed a close partnership with two of the major policy architects of international climate change agreements and developed links with key policy shapers in a number of countries • Culture change: recognition of Forest research as contributing to the debate about the role of forests in international efforts to mitigate climate change and appropriate accounting approaches to support effective forest management.	• Researchers supporting climate change negotiations working at the EC JRC, EFI and IIASA • International policy-makers • International environmental NGOs.

Table 1 (continued) Main examples of impacts of forest carbon and bioenergy research

Policy/ Practice area	What kind of change?	Who was influenced?
Inclusion of LULUCF in the EU Climate Reduction Commitment	• Conceptual: recognition that decisions about managing forests to mitigate climate change need to be made by considering the impacts of management options beyond the forest gate, i.e. within forests and also across economic sectors such as energy and construction; recognition of harvested wood as having a role in supporting climate change mitigation • Instrumental: The debate about climate change mitigation through forest management shifted from thinking just about carbon sequestration in forests to considering the holistic impact across sectors. • Capacity-building: Forest Research was recognised by some new clients as providing relevant research and evidence. • Connectivity: The research team first became recognised internationally and developed important links in Australia, Canada, Finland, Netherlands, New Zealand, Russia and the USA. • Culture change: recognition of Forest research as contributing to the debate about how to manage forests to mitigate climate change.	• Researchers supporting climate change negotiations working at the EC JRC, EFI and IIASA • International policy-makers • International environmental NGOs.
UK GHG inventory completeness	• Conceptual: Understanding amongst stakeholders that that it was a tractable problem to model forests in existence in the UK before 1920 and include GHG emissions and removals due to them in UK GHG inventories • Instrumental: Repeated requests from UNFCCC Expert Reviewers for inclusion of these forest areas in GHG inventories were addressed before the Reviewers imposed Adjustments on the UK • Capacity-building: Forest Research was recognised within the UK as having the capability to lead the compilation of GHG inventory results for Forest Land. • Connectivity: The research team developed a close partnership key policy makers in BEIS • Culture change: recognition of Forest research as undertaking world-leading research on this subject.	• Researchers working on modelling Forest Land at the EC JRC, and Forest Land GHG inventory compilers in many countries, particularly in the EU • Policy-makers mainly within the UK including the Devolved Administrations.

Table 1 (continued) Main examples of impacts of forest carbon and bioenergy research

Policy/ Practice area	What kind of change?	Who was influenced?
EU bioenergy policy post 2020 (N.B. ongoing)	• Conceptual: In a politically-charged and polarised debate, the representation of impartial evidence and its interpretation; gradual recognition amongst at least some industry and NGO stakeholders that the GHG impacts of using bioenergy are neither universally good nor universally bad • Instrumental: Development by the EC (DG SG) of a circumspect proposal for the consumption and regulation of bioenergy in the EU post 2020 • Capacity-building: Forest Research recognised by some European NGOs as providing relevant research and evidence. • Connectivity: The research team developed a links with stakeholders both in industry and amongst certain environmental NGOS and occasionally able to facilitate dialogue • Culture change: recognition of Forest research as undertaking world-leading research on this subject and an honest broker in developing, interpreting and communicating relevant scientific evidence.	• Researchers supporting EU bioenergy policy-makers • Policy-makers in the European Commission • Practitioners in the biomass power generation sector • UK and European environmental NGOs.
Accounting for LULUCF (Forest Land) in the EU post 2020 (N.B. ongoing)	• Conceptual: In another politically-charged and polarised debate, the representation of impartial evidence and its interpretation; eventual recognition amongst some Member States of where compromise may be possible and what the “red line” issues are • Instrumental: Support amongst Member States for an “honest” initial proposal from the EC; rallying of Member State support behind compromise proposals not breaking fundamental scientific principles • Capacity-building: Forest Research recognised by some EU Member States as providing relevant research and evidence. • Connectivity: The research team developed a links with policy makers from a number of EU Member States • Culture change: recognition of Forest research as undertaking world-leading research on this subject and an honest broker in developing, interpreting and communicating relevant scientific evidence.	• Researchers supporting EU LULUCF policy-makers • Policy-makers in the European Commission and European Union Member States • UK and European environmental NGOs.

Table 1 (continued) Main examples of impacts of forest carbon and bioenergy research

Policy/ Practice area	What kind of change?	Who was influenced?
IPCC Good Practice Guidance (N.B. ongoing)	• Conceptual: Small but important contributions towards recognition by participants possible approaches to developing guidance, in particular opportunities for compromise whilst remaining consistent with essential scientific evidence and understanding • Instrumental: Small but important contributions towards reaching agreement or consensus reached on IPCC 2014 KP Supplement (work on 2019 Refinement is ongoing) • Capacity-building: Forest Research recognised by the IPCC (e.g. Technical Support Unit) as able to contribute effectively to development scientific evidence and innovations in guidance • Connectivity: The research team has developed strong links with many officials and researchers involved in the IPCC processes • Culture change: Forest Research recognised by IPCC and participants in development of guidance as making objective and impartial contributions and introducing new ideas.	• Researchers involved in the developing the relevant IPCC Good Practice Guidance • Policy-makers and government officials involved in the developing the relevant IPCC Good Practice Guidance • IPCC officials (notably the Technical Support Unit).

11.4. Reasons for impact

11.4.1. Problem framing

It was fortunate that the initial problem set by the Prime Minister and Director of Research was relatively simple and narrowly defined, i.e. to work out how much carbon there is in UK trees and harvested wood. This made it possible to work out answers relatively quickly, demonstrate substantive progress and publish results in a relatively short timescale.

Subsequently, the policy questions to be addressed by the research have become more complex. Occasionally, this has raised issues with policy-makers and other stakeholders struggling to define problems and consequent policy and research questions clearly and precisely. As the research team has gained experience, sometimes they have been able to "educate the client" to help them arrive at a clear statement of the question needing to be asked. Sometimes the question only became clear after the research was part way to project completion – in these cases successful outcomes were still possible when clients and the research team worked flexibly towards a solution, e.g. accepting revised research scope or goals or being prepared to wait longer for results (see Sections 11.4.2 and 11.5).

There have been occasions when the research team has avoided getting involved in proposals for research with very poorly stated problems and/or goals. This has enabled the research team to stay focussed on salient, policy-relevant problems and demonstrate effective delivery of research evidence in policy fora.

11.4.2. Management

Outcomes have been most successful when policy-makers have worked with the research team as partners and collaborators, and less successful when it has been required to work strictly as "customers" and "contractors".

The research has always been strongly focussed on the questions posed by policy-makers (but see Sections 11.4.1 and 11.4.5). As a consequence the development of the fundamental science and models applied to address the questions has tended to be *incremental*, i.e. the models have only been improved or further developed as necessary to meet policy needs. However, the research team has also "horizon scanned" to foresee the questions policy-makers are likely to ask next or in the more distant future. This has been used to inform pre-emptive developments of the models or to collect relevant research data in preparation.

Great care is needed when incorporating new scientific understanding or introducing new models – policy-makers do not thank you or congratulate you if new evidence or model results make their country's planned carbon budget unachievable or undermine attempts to reach a negotiated agreement amongst parties.

In general, policy and industry clients cannot justify supporting “blue sky” research or fundamental model development that does not address their immediate problems. This is another reason why the research team tend to adopt an incremental approach to model development and application. However, the team also sets a strategic direction for the modelling, i.e. a vision for what the models need to be capable of addressing in the medium and longer term. Hence, the development of the models is both responsive to the immediate needs of clients whilst seizing opportunities to improve the models in a structured way towards a more comprehensive modelling framework. Whilst this means that “great leaps forward” in model development are hard to identify, in practice the approach has ensured that Forest Research models such as CARBINE are widely recognised as at the forefront of research in this subject area.

11.4.3. Inputs

Funding

Core funding for the research has always been tight, often short term and sometimes non-existent (as is currently the case for core funding of biomass research). The adoption of an incremental approach to the research within a strategic framework (see Section 11.4.2) has mitigated the worst risks associated with general under-funding.

Staff

The research team includes a number of very talented and creative scientists who have maintained the models at the cutting edge but capacity is seriously constrained when compared with the expectations of internal FC/FR and external clients for the research. Risks of shortfall in delivery due to capacity issues have been mitigated to an extent by cultivating and getting work done by a small community of external collaborators and contractors capable of taking on some aspects of model or software development, when funding has permitted this.

An important factor has been the long time that many members of the research team have been able essentially to work on the same research topics over many years (even decades), in the process developing deep knowledge, expertise and skills. Such opportunities are now relatively rare in scientific research but this long-term commitment to staff development has been a critical success factor. The staff also understand each other well and work together extremely effectively as an integrated team. Whilst this gives the team immense strength and flexibility, there are serious downsides. On the one hand, the viability of the team could be easily compromised by the loss of one of its individual (“singleton”) experts; on the other hand the contributions of individual team members are often unappreciated and significantly undervalued, notably when the grading of individual jobs and the promotion prospects of team members are judged by conventional narrow academic criteria (for example such as applied in the FR Science Promotion Procedure).

The research team has also been maintained as a unit through several major structural reorganisations within the Forestry Commission and Forest Research over the years; keeping the research team together as a vertically-integrated capability has been critical to the success of the research.

Facilities

Computing facilities can also constrain progress and the research team has occasionally needed to respond by doing modelling work “off grid”, i.e. acquiring non-standard computers not integrated into the Forest Research network or using their own computing systems.

11.4.4. Outputs

Outputs have always been designed to the client’s requirements. This is critically important when working in areas of research close to sensitive policy subjects. Academic research frequently achieves impact through “disruption”, i.e. by challenging and shifting established paradigms. In contrast, successful policy development and any associated negotiations rely ideally upon unchanging facts and continuity in the development of scientific understanding. When new and potentially challenging information needs to be communicated in a policy context, this needs to be handled with extreme care.

Reports

Most of the outputs of the research consist of “grey literature” reports and briefing papers, some of which have remained purposefully unpublished or unpublicised at the request of clients, due to their extreme sensitivity. There are examples of important outputs produced by the research team which remain effectively unknown about publicly, but which have had significant direct influence on major policy decisions and successful outcomes of negotiations. (These outputs cannot be listed in the key references given at the end of this report.)

Peer-reviewed scientific journal articles

In contrast to “grey reports”, the research team publishes relatively few articles in peer-reviewed scientific journals. This has led to occasional criticism of the team (internally and externally) as not engaging with the wider scientific community. In fact there is no lack of appetite amongst team members for producing such papers but it is extremely difficult to give this priority. This is due to the minimal staff capacity of the research team compared with the workload (and client expectations), and generally very high pressure upon the team to move on to the next policy problem as soon as the previous problem has been addressed. It should also be noted that many of the grey literature reports produced by the team are in fact subjected to intense review by scientific peers and policy-makers.

Presentations, workshops and briefings

When requested to do so by clients, the research team will engage in the dissemination of research outputs through formal presentations, workshop discussions and (policy-relevant) briefings. However, the sensitivity of much of the research requires these activities to be carefully managed (see Section 11.4.5).

Models, software, tools and guides

None of the outputs discussed above or the impacts described in Section 11.3 would be possible without the fundamental outputs of the research:

- Internal synthesis of new scientific data and understanding by the research team
- Incorporation of new insights and new functionality into the research team's models, to ensure the models are based on the most robust available science and fit for addressing emerging policy questions.

Generally, the models developed by the research team are used internally by Forest Research and are an important resource for helping the research team stay at the forefront of informing policy and its delivery.

Nevertheless, a case could be made for "democratising" the use of the models, for example by permitting policy-makers and other researchers easier access to the models. This would undoubtedly have significant positive impacts but also with equally significant associated risks:

- Users may lack sufficient understanding of the models to use them correctly
- The models could be used (or even misused) to destructively undermine policies or negotiations
- Ultimately, open access to the models could undermine the research team that developed them, due to the team's loss of an important unique selling point.

Whilst acknowledging such risks, the research team is exploring ways to provide wider access to the models, modelling approaches, and model results. One important way of achieving this is through the structure packaging and dissemination of the research outputs in the form of guides and software tools. Relatively recent examples include:

- The woodland carbon assessment protocol published in support of the FC Woodland Carbon Code (WCC)
- The woodland carbon sequestration lookup tables, also published in support of the FC WCC
- The FOR_KP software tool, made available internally within the FC and BEIS, which enabled the investigation of projected forest GHG balances for countries participating

in the Kyoto Protocol, and the potential impacts of different options for accounting rules for forest land.

11.4.5. Engagement

The research team was fortunate to be "in right at the start" of this emergent policy problem (see Section 11.1.1). The team needed to learn, sometimes from mistakes, how to engage professionally in complex and frequently politically charged debates. Relatively early on, members of the research team benefitted from training and practicing advocacy and negotiation skills, through active involvement as trade union members and representatives within the FC and FR.

Discretion has been critical, i.e. knowing when not to agree to make a presentation at a workshop with a known political agenda, or not to comment publicly on a controversial "scientific" study or position statement, or to refrain from intervening in an exchange of views, or to decline to sign up to lobbying letters written by communities of scientists or others. The team has been fastidious in holding to a completely objective and impartial position, based transparently on the evidence from research. This has been a perilous tightrope to walk since it means stakeholders on all sides of the debate cannot count automatically on support from the team in taking a particular position on a policy issue.

With some exceptions the research team has earned the respect, trust and even friendship of policy-makers, industry bodies and environmental NGOs but it is important not to be seen as too close to any of these communities.

11.4.6. Social and organisational factors

The research team has benefitted immensely from (and at times been protected by) the strong support of several highly influential champions and knowledge brokers outside Forest Research, i.e. within the Forestry Commission, wider UK government and further afield. The research team sustains good relations with policy leads in the Welsh Government, FC England (FS) and FC Scotland (one of whom is an ex-member of the research team and one an ex-member for another Science Group in Forest Research). In recent years, the team developed a trusting and highly productive relationship with an official with BEIS (then DECC) who also served as a lead negotiator for the EU in climate change talks, and who was well connected within the IPCC. The team has sustained good relations with BEIS officials since then. Further afield, the team has won the confidence and support of leading researchers in Europe and more widely, notably at the EC Joint Research Centre (LULUCF and LCA research groups).

The close integration of the research team within the forest sector within the UK has helped to facilitate the translation of policy into practice, notably through the uptake of the FC WCC by proponents of forest carbon projects. The team members are well known in the sector and accessible to practitioners who may have questions or need practical advice. The research team reinforces this culture by regularly participating in major forest industry and trade events in the UK such as the Royal Welsh Show and the APF Show.

Ultimately, the success of the research has been founded on being able to maintain and market an almost unique capability represented by the suite of models developed by the research team and the modelling skills and expertise of team members.

11.4.7. Context and contingencies

The research team is concentrated in one location (Alice Holt Research Station) and this has facilitated strong team working and a community spirit. Physical proximity to some key policy stakeholders has undoubtedly helped with engagement and knowledge exchange. For example, key FC England (FS) officials are based at Alice Holt, whilst Westminster is just over one hour away by a direct train link; if necessary, a meeting can be attended in Brussels by a day trip. At the same time, the relatively long distance from Wales and Scotland (even including the Northern Research Station of Forest Research) has been a source of a sense of separation, both physical and cultural. The capabilities, track record of research and achievements of the research team have less profile there, although some presence is still maintained.

The trisection of the GB Forestry Commission and progressive devolution of forestry and land use policy presents risks of loss of support for research based almost entirely in England. As the situation develops, efforts may be necessary to maintain and strengthen existing links to policy groups in the Devolved Administrations.

It remains to be seen whether the research capability will survive the major political, structural and cultural changes currently taking place in the UK and more widely, and the general downward trend in support for public sector applied research.

11.5. Lessons learned

A number of lessons have been learned from the experience of the research undertaken over the last 30 years. The main lesson is listed here for each of the factors covered in Section 11.4.

Problem framing

- Defining a clearly stated research question, clarified and agreed with the client, is critical to the success of a policy-driven research project, and this should never be regarded as a formality or tick-box exercise. The research team has made increasing efforts to determine clearly defined and agreed goals and scopes for research projects at the time of project inception; projects can get into serious difficulties when this is not achieved.

Management

- Brigading limited and short-term funding to develop models incrementally within a strategic framework can be effective in achieving more with less. However, this tends to result in the continuous “patching” of models, rather than their coherent development. Ultimately, the incremental/strategic approach cannot entirely compensate for insufficient support for fundamental model development. The solution to this challenge is not yet clear.

Inputs

- Long-term investment in research staff, and the maintenance of a research team together as an integrated and coherent unit, have been and remain critical to the success of the research and to achieving positive policy outcomes.

Outputs

- It is well established that project outputs need to achieve an appropriate balance between the three factors of quality, timeliness and cost. When delivering outputs with potentially high policy impact and sensitivity, quality cannot be compromised. Timeliness is also sometimes important for outputs to be available in time to inform policy decisions and stakeholder debates; this can involve difficult scheduling choices and careful management of the expectations of clients when their outputs receive less priority than others. The research team must also work within available funding and balance its budget but flexibility is needed in the detailed allocation of staff to individual projects to ensure that high quality criteria and that policy-driven deadlines are hit.

Engagement

- It is absolutely critical to maintain objectivity and impartiality when interpreting and presenting research results in a policy context. Sometimes this can involve giving clients “bad news” but also helping them to identify positive responses and ways forward when faced with unexpected or unwelcome research outcomes. It is also very important to judge carefully when to engage and when not to engage in policy discussions and debates.

Social and organisational factors

It is vital to maintain the confidence of champions for the research and its results and to continually foster constructive relations with the key policy-makers and representatives of the main stakeholder groups, particularly when staff changes occur, which can be frequent. Ultimately, the research has the highest impact when working in partnership with policy-based knowledge brokers, notably official negotiators.

Context and contingencies

- The research team needs to build its presence with policy groups in the Devolved Administrations of the UK and with wider forest industry stakeholders, as the Forestry Commission disintegrates. The team also needs to sustain international linkages as the UK exits from the European Union. These are significant challenges (particularly given the team's size and limited capacity) and considerable efforts will be needed to identify and develop solutions.

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Appendix: Impact case study template

This template identifies six headings to cover in the case study report. For each heading we've provided some categories that you might find useful to structure what you write. Please don't feel you have to use all of these – they are just a guide to help capture the main points. The aim is to produce an engaging story about your research and its influence on the outside world.

1. Introduction

- **Background**: brief history and context of the research/policy/practice issue or problem
- **Objectives**: brief statement of how the research sought to address the problem (intended users, outcomes and impacts) i.e. the 'logic' behind the research project/activity.
- **Other details**: indication of budget and timescale; position within FR science groups and CFS programme matrix.

2. Description of research activity

Briefly, what was done? What was delivered, and to whom?

- **Inputs**: staff, partners, time, money, materials, equipment, infrastructure
- **Activities**: advice, training, presentations, demonstrations, dialogue, etc.
- **Outputs**: research notes, reports, journal articles, DSS, GIS, etc.

3. Impacts

What changed as a result of the research and its dissemination?

- **Instrumental**: changes to plans, decisions, behaviours, practices, actions, policies
- **Conceptual**: changes to knowledge, awareness, attitudes, opinions, motivations
- **Capacity-building**: changes to skills, expertise, funding, resources

- **Connectivity**: changes to the number and quality of links, relationships, and levels of trust
- **Culture change**: changes in attitudes towards knowledge exchange and impact

Who was influenced?

- **Researchers** (within and beyond FR and UK)
- **Policy-makers** (FCS, FS, NRW, other governmental bodies, including other sectors)
- **Practitioners** (public, private, NGO)
- **Communities** of place or interest, general public
- **Other** (please specify)

4. Reasons for impact

How were these impacts generated? What factors influenced success? Which **strategies or mechanisms** were used (by researchers, users or other stakeholders) to generate impact? Which **additional factors** (beyond the control of the project) helped or hindered its success?

Here is a generic list of possible factors that might be useful:

Problem framing:

- The policy/practice problem or issue was important and 'tractable' (or solvable).
- The research questions were framed appropriately, addressing underlying problems.

Management:

- The research aims, design and plans were a realistic and timely response to the problem.
- Users and other stakeholders, and their interests, influence and roles, were identified.
- The research was effectively managed by the project leaders.

Inputs:

- The work was adequately resourced by researchers and customers (funding, capable staff, access to equipment, professional advice, etc.)

Outputs:

- The outputs provided useful knowledge, packaged accessibly for targeted users.

Engagement:

- Dialogue between researchers (e.g. partnerships; interdisciplinarity), and between researchers and stakeholders (e.g. user groups; co-production) throughout the project cycle.
- The dissemination activities influenced the target audiences effectively.

Social and organisational factors:

- Influence of industry 'champions' and 'knowledge brokers'.
- Willingness/ability to use outputs, organisational culture & attitudes towards research.
- Incentives or reinforcement to encourage uptake, e.g. use of research outputs are a requirement for certification or grant approvals, or included in operational guidance.

Context and contingencies:

- Biophysical or geographical conditions of the locations where research was applied.
- Unforeseen events (staff changes, extreme weather, political support, etc.)

5. Lessons learned

What might have been done differently? What could (or will) be done differently in the future?

If useful, draw upon the factors listed under 'reasons for impact' above.

6. References

- Key references, links, acknowledgements.