

Institution: The University of Edinburgh		
Unit of Assessment: UoA5 Biological Sciences		
Title of case study: Understanding the genetic diversity of forest trees has led to creation of the UK's first two genetic conservation units and changes to conservation policy		
Period when the underpinning research was undertaken: 2016 – present		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Prof Richard Ennos	Personal Chair in Ecological Genetics	Oct 1983 – Aug 2015
Dr Carolyn Riddell	Honorary Professorial Fellow Post-doctoral researcher	Aug 2015 - Jan 2010 – June 2016
Period when the claimed impact occurred: 1 st Aug 2013- 31 st Dec 2020		
Is this case study continued from a case study submitted in 2014? Y/N No		
1. Summary of the impact Attribution: Research at the University of Edinburgh into the genetic diversity and susceptibility to disease of forest trees has led to greater understanding of forest management, policy change and conservation of natural forests. Impact on public policy and services: The research has had Scotland-wide and UK-wide influence on policy for conservation, disease management and tree planting. It also provided a support for the reporting framework for the international Aichi Target 13. Impact on environment: The research has led to creation of the UK's first genetic conservation unit (GCU) in Benn Eighe by Scottish Natural Heritage, as well as the more recent development of a second GCU in Benn Shielraig by the Woodland Trust. The research's policy outcomes, especially the Woodland Trust's 'UK and Ireland Sourced and Grown' labelling, influenced the planting of 2,000,000 trees per year in the UK, and has had a significant impact on the government's targets to increase wooded areas to 3-5% of the UK. Impact on economy: The 'UK and Ireland Sourced and Grown' branding and influence on planting policy have had significant effects on the forestry industry. It has been estimated that the economic impact attributed to the UK forestry policy has a saving potential of GBP15,000,000,000 due to implementation of the research by comparison to the cost of Ash Dieback. Beneficiaries: The UK's general public and natural biodiversity via the conservation of heritage woodlands and environments; charities, trusts and commercial forestry via disease resistant, genetically diverse tree populations; European forestry and international conservation efforts via the Aichi targets and GCUs. Significance and Reach: Preservation of forests and forest diversity is critical in a world faced with climate change. Impact has been local (Scotland), national (UK) and international.		
2. Underpinning research Richard Ennos's group has been involved in long-term research to study genetic adaptation in the UK's native tree species. The underpinning research has shown that the Beinne Eighe Scots pine population, which lies at the extreme north west of the species' distribution, was		

genetically unique in terms of its morphology, phenology, physiology [3.1] and disease resistance [3.2], making a compelling case for its genetic conservation. Conservation of genetic biodiversity is one of the key Aichi targets set by the International Convention on Biological Diversity to which the UK is committed. For forest tree species, one of the most effective vehicles for delivering this target is the establishment of dynamic gene conservation reserves containing populations with unique adaptations. As part of an initiative by the European Forest Genetic Resources Programme (EUFROGEN) such reserves have been established throughout Europe, but prior to 2019 not a single reserve had been designated in the UK. This research was key to identifying a uniquely adapted Scots pine woodland, Beinne Eighe, that in 2019 was designated as the first **Gene Conservation Unit** in the UK.

One of the major threats to forest biodiversity worldwide is the introduction of exotic pathogens. An understanding of the processes by which exotic pathogens are introduced is critical to the management of such threats. As part of the Tree Health and Plant Biosecurity Initiative (a multi-disciplinary initiative to develop the widest possible research capacity to address tree health in the UK), Ennos led research to determine the origin of the emerging *Dothistroma* needle blight disease (DNB) on native Caledonian Scots pine [3.3]. The research found that the current outbreak is caused by three species of the pathogen, one of which is indigenous and has caused insignificant levels of damage in the past. The other two species now present in the Caledonian pinewoods cause far more damage, but the natural genetic diversity of the indigenous Scots pine means that they develop resistance to the disease much more rapidly than exotic pine species (such as Corsican and lodge pole pine) that have been selected for yield rather than diversity [3.4]. The research makes clear that removal of exotic pine species from the vicinity of native pine is a vital first step in reducing the threat from DNB. Ennos's research has also had significant impact in the response of forestry and government to climate change. Two particularly influential papers, [3.5] and [3.6], were cited by policymakers and organisations as having a significant impact on their work. [3.5] focuses on the impact of importation of trees and the genetic diversity of native woodlands, concluding that there is no benefit to the importation of tree species intended to grow in a changing climate. A major outcome of the research in [3.6] was that there are significant issues with tree health in importing trees from milder climates due to synchronisation of pollination and frost intolerance. These have significantly impacted the Woodland Trust's and the UK's planting policies.

3. References to the research

- [3.1] Donnelly, K., Cavers, S., Cottrell, J. E., Ennos, R. A. (2018) Cryptic genetic variation and adaptation to waterlogging in Caledonian Scots pine, *Pinus sylvestris* L.. Ecology and Evolution, 8, 8665–8675. <https://doi.org/10.1002/ece3.4389>
- [3.2] Perry, A., Wachowiak, W., Brown, A. V., Ennos, R. A., Cottrell, J. E. & Cavers, S. (2016) Substantial heritable variation for susceptibility to *Dothistroma septosporum* within populations of native British Scots pine (*Pinus sylvestris*). Plant Pathology, 65, 987-996. <https://doi.org/10.1111/ppa.12528>
- [3.3]. Piotrowska, M. J., Riddell, Hoebe, P. N., Ennos, R. A. (2018). Planting exotic relatives has increased the threat posed by *Dothistroma septosporum* to the Caledonian pine populations of Scotland. Evolutionary Applications, 11, 350-363. <https://doi.org/10.1111/eva.12562>
- [3.4] Perry, A., Brown, A., Cavers, S., Cottrell, J. E. & Ennos, R. A. (2016) Has Scots pine (*Pinus sylvestris*) co-evolved with *Dothistroma septosporum* in Scotland? Evidence for spatial heterogeneity in the susceptibility of native provenances. Evolutionary Applications, 9, 982-993. <https://doi.org/10.1111/eva.12395>

[3.5] Whittet, Richard, et al. "Seed sourcing for woodland creation in an era of uncertainty: an analysis of the options for Great Britain." *Forestry: An International Journal of Forest Research* 90.2 (2017): 163-173. <https://doi.org/10.1093/forestry/cpw037>

[3.6] Whittet, Richard, et al. "Substantial variation in the timing of pollen production reduces reproductive synchrony between distant populations of *Pinus sylvestris* L. in Scotland." *Ecology and evolution* 7.15 (2017): 5754-5765. <https://doi.org/10.1002/ece3.3154>

4. Details of the impact

Work led by Ennos on the genetic diversity of UK native tree species has directly impacted conservation policy and action.

Impact on public policy and services: The research has had Scotland-wide and UK-wide influence on policy for conservation, disease management and tree planting. Ennos's work has been helpful in supporting Scottish Natural Heritage, Scottish Forestry and the Woodland Trust's vision for genetically diverse native forests.

Ennos played a key role in the development of the Convention on Biological Diversity ("Aichi") 13 reporting process. He was one of the six project leads to produce the world's first wildlife genetic conservation indicator, both in developing the method [5.1], and in compiling the document where he assessed or reviewed a number of species reports [5.2 & 5.3]. This report outlines a national approach for the conservation of genetic diversity suited to Scotland and how it can be applied internationally [5.3].

Ennos's research [3.6] was specifically referred to at a UCL policy commission on Climate Change Science by the director of conservation of the Woodland Trust, and referred to in a submission on the role of ancient woodland restoration and natural regeneration for carbon sequestration for the Minister of State for Climate change, Environment, Conservation and Biodiversity Zac Goldsmith [5.4]. Ennos's research in collaboration with Forestry Scotland is currently under review by Scottish Government with a view to altering seed zones, based on the genetic evidence from [3.5] [5.4].

"Influencing government policy is important to the Woodland Trust, and the main support that the policy team requires is in the form of evidence reviews. Richard's work has significantly influenced the Trust's position on a number of issues: his evidence is well presented and robust, so his work has been influential, especially for position statements on, for example, provenance." [5.2]

Impact on environment: Ennos's research was the driving force for Scottish Natural Heritage's interest and focus on genetic diversity in woodlands [5.5]. This has resulted in the creation of the UK's first genetic conservation unit (GCU) in Benn Eighe by [5.5]. The GCU, which opened in March 2019, constitutes the UK's current contribution to EUROFORGEN – The European Forest Genetic Resources Programme. The Woodland Trust, also citing Ennos's research as an influence, has driven the more recent development of a second GCU in Benn Shildaig.

"Richard's work focuses on species choice for woodland creation projects and promoting the use of natural regeneration or natural colonization to expand woodlands. This research is timely because of the climate change committee's work demonstrating that in order to become net zero, we need to do more woodland creation in this country." [5.4]

The research's policy outcomes, especially the Woodland Trust's 'UK and Ireland Sourced and Grown' labelling, influences the planting of 2 million trees per year in the UK, and has, and will have a significant impact on the government's targets to increase wooded areas to 3-5% of the UK. [5.4]

Impact on economy: Ennos's research has had wide ranging impacts on the economy via changes to the provenance of new tree plantations and the changes to policy regarding disease resistance and imported stock. Specifically, Riddell and Ennos's research promotes the planting of genetically diverse native trees in commercial and public woodlands, exemplified by his research on Dothistroma needle blight [3.3], [3.4] and the effects of importation on survivability and reproduction of non-native trees [3.5]. This has led to the development of 'seed zones', especially for Scots pine, which are genetically diverse and climate-specific zones where new trees can be sourced and matched to a new plantation [5.6]. Led by Forestry Scotland, the Scottish Government is currently reviewing the seed zones, based on the genetic evidence from [3.6].

"Along with the implications for the 'UK and Ireland Sourced and Grown' branding, the economic value of Richard's work could be very large. The government's aim to increase woodland by 3-5% of the land area of the UK could be a disaster for nature conservation if the wrong kind of trees are planted. If Richard's research showing the benefits of native trees for healthy woodlands is taken into account, this will have long term significant effects on the entire UK natural environment." [5.4]

The Woodland Trust estimated that the impact of Ennos's work on the economy could be as large as GBP15 billion, which is the cost to the UK economy of Ash Dieback. A healthy, genetically diverse population of trees would prevent such an occurrence in the future [5.4] and [5.7].

Beneficiaries: of the impact include: the UK's general public and natural biodiversity via the conservation of heritage woodlands and environments; charities, trusts and commercial forestry via disease resistance guidance, genetically diverse tree populations; European forestry and international conservation efforts via the Aichi targets and GCUs.

5. Sources to corroborate the impact

[5.1] Testimonial: Biodiversity Evidence and Reporting Manager, Scottish Natural Heritage, Inverness

[5.2] Scotland's Biodiversity Progress to 2020 Aichi Targets- PDF pgs Contributors, 26, 31, 32 <https://www.nature.scot/sites/default/files/2020-01/Scotland%27s%20Biodiversity%20Progress%20to%202020%20Aichi%20Targets%20-%20Aichi%20Biodiversity%20Target%2013%20method%20report.pdf>

[5.3] Scotland's Biodiversity Progress to 2020 Aichi Targets. Aichi Target 13 – Genetic Diversity Maintained – Supplementary Report 2020-PDF- pgs Contributors, 11, 15, 19, 32, 71, 77. <https://www.nature.scot/sites/default/files/2020-01/Scotland%27s%20Biodiversity%20Progress%20to%202020%20Aichi%20Targets%20-%20Aichi%20Biodiversity%20Target13%20supplementary%20report.pdf>

[5.4] Testimonial: Woodland Trust, Lincolnshire

[5.5] Testimonial: Scottish Natural Heritage, Woodland Advisor, Great Glen House, Leachkin Road, Inverness

[5.6] Testimonial: Environmental Policy Advisor @ Scottish Forestry (formerly Forestry Commission Scotland).

[5.7] Information on Ash Dieback from Woodland Trust:

<https://www.woodlandtrust.org.uk/trees-woods-and-wildlife/tree-pests-and-diseases/key-tree-pests-and-diseases/ash-dieback/>