Institution: University of Sheffield		
Unit of Assessment: A-05 Biological Sciences		
Title of case study: Controlling the spread of invasive non-native species in Great Britain and abroad		
Period when the underpinning research was undertaken: 2003–2014		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Mark Rees	**Role(s) (e.g. job title):** Professor	**Period(s) employed by submitting HEI:** 2003–2020
Period when the claimed impact occurred: 2013–2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

The uncontrolled spread of non-native invasive species costs the UK environment and economy an estimated £1.8 billion per year. Sheffield research has provided critical theory underpinning the assessment of risks associated with invasive plants in the UK through the Non-Native Risk Analysis Panel (NNRAP) which contributed to the decision to ban the sale of seven plant species in England and Wales. The work of NNRAP shapes eradication programmes and the work of community groups key to the monitoring and management of the UK countryside. The research has had significant impact on EU policy and practice as NNRAP protocols have provided the foundation for EU risk assessments on invasives.

2. Underpinning research (indicative maximum 500 words)

Assessment of the threat of invasive species, and measures of the efficacy of control, requires the use of mathematical models to predict the growth and spread of those species. However, conventional models based on size structure create problems by dividing a population into a set of arbitrary classes or "stages" whereas in reality population size is a continuous variable. To overcome this problem, Rees and colleagues have developed "integral projection models" (IPMs). These models can be applied to any population, determining the rate of population growth or spatial spread. These have been particularly useful in the study of invasive species and in the assessment of effectiveness of different management strategies to control their spread.

Underpinning theory for modelling invasive species

Work by Rees and Ellner showed how **integral projection models (IPMs) can avoid some of the limitations of matrix models when looking at species where individual demography is affected by multiple attributes that vary over the life cycle**. They developed IPMs to take into account complex demographic attributes such as dormant and active life stages, changes between discrete and continuous structure over the life cycle, and cross-classification by several attributes including size, age, and condition **[R1]**. Rees and Ellner also developed methods for creating and analysing IPMs that encompass interannual variability in survival, growth rate, and fecundity. By exploiting the close correspondence between stochastic IPMs and statistical analysis of trait-fate relationships in a 'hierarchical' or 'mixed' models framework, Rees and

Ellner demonstrated that IPMs can be parameterized in a straightforward way from data using conventional statistical methods and software **[R2]**.

Application of theory to provide knowledge on invasive species population dynamics

It was very apparent that such models are readily applicable to situations involving invasive plant species. For example, Rees and colleagues used the IPM approach to explore how habitat disturbance and propagule pressure (a measure of number of invasive species) determined the success of invasion, using two highly invasive species as exemplars (*Lantana* and *Mimosa*). When disturbance rates in both invasive occupied and unoccupied sites are the same, recruitment and mortality effects are exactly balanced, and successful invasion is independent of the disturbance. When disturbance rates between invasive occupied and unoccupied sites differ a novel mechanism occurs where the invasive can promote disturbance in sites it already occupies. This provided the insight that **single large-scale disturbances can result in permanent, dramatic shifts in invasive abundance. Conversely, reducing the population below a critical threshold can cause extinction. This work** (with [R1] and [R2]) **provides a critical theoretical framework** for the more effective and nuanced management of invasive species- an increasingly important point when considering the effects of human action and climate change on disturbance regimes **[R3].**

Use of theory to model specific invasive populations nationally and internationally

In addition to this general underpinning theory, Rees has also investigated the management methods of specific invasive non-native species. For example, his team developed a mathematical model of water hyacinth growth which can be used to assess the impact of a reduction in nutrients on plant dynamics and for planning population control **[R4]**. At an international level, Rees helped develop a model for pine expansion in ungrazed and grazed grassland in New Zealand. Pine invasion is a major problem in this country and **by incorporating uncertainty into the modelling process the confidence in the management strategies recommended was greatly increased [R5]**.

3. References to the research (indicative maximum of six references)

R1. Ellner, S. P., & **Rees, M.** (2006). Integral Projection Models for Species with Complex Demography. *The American Naturalist*, *167*(3), 410–428. https://doi.org/10.1086/499438

R2. **Rees, M.**, & Ellner, S. P. (2009). Integral projection models for populations in temporally varying environments. *Ecological Monographs*, *79*(4), 575–594. https://doi.org/10.1890/08-1474.1

R3. Buckley, Y. M., Bolker, B. M., & **Rees, M.** (2007). Disturbance, invasion and re-invasion: managing the weed-shaped hole in disturbed ecosystems. *Ecology Letters*, *10*(9), 809–817. https://doi.org/10.1111/j.1461-0248.2007.01067.x

R4. Wilson, J. R., Holst, N., & **Rees, M.** (2005). Determinants and patterns of population growth in water hyacinth. *Aquatic Botany*, *81*(1), 51–67. https://doi.org/10.1016/j.aquabot.2004.11.002

R5. Buckley, Y.M., Brockerhoff, E., Langer, L., Ledgrad, N., North, H. and **Rees, M.** (2005). Slowing down a pine invasion despite uncertainty in demography and dispersal. *Journal of Applied Ecology*, *42*(6), 1020–1030. https://doi.org/10.1111/j.1365-2664.2005.01100.x

4. Details of the impact (indicative maximum 750 words)

Invasive non-native species (INNS) represent a major threat to the UK environment and cost the UK economy on average £1.8 billion per year, mainly affecting agriculture, forestry, horticulture, utilities, construction, and transport infrastructure **[S1]**. They have detrimental effects on the native species they supplant, as well as on human health and business. Their presence has accelerated with the expansion of global trade. Research at Sheffield has shaped **national and international environmental policy and practice to combat INNS.**

The Non-Native Species Secretariat (NNSS) acts as the central hub in Great Britain for the collection and dissemination of information regarding INNSs, with the Non-Native Risk Assessment Panel (NNRAP) the principle body informing the NNSS of the risks that different species pose. **This evidence directly informs the Great Britain Programme Board which consists of senior representatives of several major agencies (including Defra, Scottish and Welsh Governments, the Forestry Commission, HMRC, and the Joint Nature Conservation Committee) who use the evidence to prioritise activities and fulfil legislated commitments**.

Rees was invited to join the NNRAP in 2007. His research on modelling invasive species has impacted their work via both the insight provided into specific species and, at a wider level, by providing the general critical theory required to judge whether the risk assessments implemented for a spectrum of invasive species are appropriate. As the sole plant scientist on the panel, 'Professor Rees's work on the NNRAP has had **'an important impact on the strategic approach to dealing with invasive non-native species in GB**' **[S2]**, as detailed below.

Plant species have been banned and eradication protocols implemented at a national level

Under the auspices of Defra, the code of practice in England dictates that 'the environmental authority must consider available information on its likely impacts, in particular any risk assessment carried out by the Great Britain Non-Native Species Secretariat' **[S3]**. This authority encompasses the Secretary of State, the Environment Agency, Natural England, and the Forestry Commissioners. Although Rees aids in analysing all species risk assessments, the application of the modelling approach developed in his research, coupled with his botanical expertise, has in particular ensured that the assessments of *Parrot's Feather, Water Fern, Floating Water Primrose, Floating Pennywort, two species of Water Primrose, and Australian Swamp Stonecrop* were fit-for-purpose. As a result of these assessments**, The Wildlife and Countryside Act was updated in 2014 and these species were banned from sale in England and Wales [S2][S4]**. In addition, the assessments have underpinned actions to eradicate selected invasive species. For example, in 2010, based on NNRAP advice, NNSS identified a high risk of establishment of water primrose (an economic pest due to clogged waterways and drainage streams, and increased the risk of flooding) and initiated an eradication programme**.** As stated by the Senior Technical Advisor, Environment Agency ***"I have no doubt that the 2014 ban was crucial to the potential success of our eradication programme"*** and *"if our [the UK's] intervention had been left any later I doubt we would still be aspiring to achieving eradication"* **[S5]**.

The UK has seen a decrease in the area of surviving water primrose coverage from 858.5m^2 in 2017 to less than 100m^2 in 2019 [S5]. This has been achieved at a cost of just £10,000 [S5] per year instead of the project cost of £241,908,000 if the risk was left unchecked for longer [S6]. The programme has resulted in greater success in eradicating water primrose in England than can be seen in other countries that have been invaded by the species, such as France and Japan [S7].

Improved management of the threat of non-native species by local communities

Local Action Groups (LAGS) have played a key role in the control of widespread non-native species, but also for awareness raising in communities **[S5]**. NNRAP (via NNSS) provides vital support for these groups. For example, all NNRAP risk assessments are available online, with detailed fact sheets on identification, impacts, and control methods for 300 INNS (http://www.nonnativespecies.org/factsheet/index.cfm). **This resource has enhanced the knowledge of more than 50 LAGs who report that "*the work of the NNSS and NNRAP are vital for our operations"* to target species and inform management guidance.** Representatives from these LAGs have stressed the importance of the information on the website and the NNSS workshops to enable them to train volunteers and raise awareness with landowners to tackle INNS **[S8]**.

Critical theory from plant population dynamics has influenced EU legislation and regulatory practice.

Non-native species invasions are an international problem, costing the EU an estimated €12 billion per year. The work of NNRAP has guided international standards in this area, informing EU risk-assessment templates, and the modelling methods used to ensure that risk assessments are appropriate. **Consequently, many species have been banned in the EU based on NNRAP findings [S2, S9]**. In addition, Rees was appointed to an EFSA (European Food Safety Authority) working group on non-target terrestrial plant risk assessment in 2013, resulting in the publication "Scientific Opinion addressing the state of the science on risk assessment of plant protection products for non-target terrestrial plants" in 2014 **[S9]**. These assessments are used to develop and implement new concepts and approaches in EFSA's risk assessment practices, thus **"*Rees' work has resulted in critical theory from plant population dynamics being used to underpin scientific advice used at both European and international levels*" [S10]**.

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

S1. House of Commons Environmental Audit Committee Invasive species First Report of Session 2019 (https://publications.parliament.uk/pa/cm201919/cmselect/cmenvaud/88/88.pdf).

S2. Letter from Deputy Chief Non-native Species Officer (England) of the GB Non-native Species Secretariat (18 March 2019), corroborating Rees's role within NNRAP

S3. Defra, July 2017. Species Control Provisions: Code of Practice for England (2.4.3)

S4. Wildlife England. The Wildlife and Countryside Act 1981 (Prohibition on Sale etc. of Invasive Non-native Plants) (England) **Order 2014.** No. 538, list of banned plants.

S5. Combined: confirmation of contribution of work of NNRAP to the water primrose eradication programme, programme progress and associated cost. The GB Water Primrose *Ludwigia grandiflora* eradication programme: 2019 progress report. Environment Agency (2020) and factual statement from Senior Technical Advisor, Invasive Species, Environment Agency.

S6. Williams et al (2010) The Economic Cost of Invasive Non-Native Species on Great Britain. CABI Project No VM10066. This report details the estimated cost of an early-stage eradication programme for water primrose against the cost of late-stage eradication programme.

S7. Kamigawara, K., Nakai, K., Noma, N., Hieda, S., Sarat, E., Dutartre, A., Renals, T., Bullock, R., Haury, J., Bottner, B., & Damien, J.-P. (2020). What kind of legislation can contribute to on-site management?: Comparative case studies on legislative developments in managing aquatic invasive alien plants in France, England, and Japan. *Journal of International Wildlife Law & Policy, 23*(2), 83–108. https://doi.org/10.1080/13880292.2020.1788778

S8. Emails from Local Action Groups (Norfolk non-native Species Initiative, Isle of Wight Non-native Plants Project, Medway Valley Countryside Partnership, and Bollin Valley Partnership) describing how they use information from NNSS and how it impacts their work controlling INNS.

S9. EFSA PPR Panel (EFSA Panel on Plant Protection Products and their Residues) (2014). Scientific Opinion addressing the state of the science on risk assessment of plant protection products for non-target terrestrial plants. (2014). *EFSA Journal, 12*(7), 3800. https://doi.org/10.2903/j.efsa.2014.3800

S10. Letter from a member of Biosecurity Ministerial Advisory Committee, NZ, detailing Rees's work with NNRAP and EFSA. February 2020.