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Everything is proceeding as hypothesised

Well, that wasn't supposed to happen

Unintended consequences in environmental science

EDITORIAL

Is ignorance an excuse?

"As we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns – the ones we don't know we don't know..."
Donald Rumsfeld[1].

This quote neatly expresses the way that unintended consequences can arise from new environmental technologies and developments. There are consequences or issues we have planned for or know will occur (the known knowns). There are the consequences we may suspect could occur (the known unknowns); these we can model or predict to a greater or lesser extent. Then there are the unknown unknowns, the consequences we had no idea might occur, and these are the ones that may catch us out.

History is littered with unforeseen consequences from our development and industrialisation:

- the extinction of species due to hunting and habitat loss;
- Chlorofluorocarbons (CFCs), developed to provide a safe and stable alternative to more dangerous refrigerants, coolants and propellants, became responsible for damage to the ozone layer that protects us from solar UV radiation; and
- the internal combustion engine, which gives us personal freedom, but blights us with noise, air pollution and communities that are cut off from one another by busy roads that cannot easily be crossed.

As unforeseen consequences are unpredictable, why is this issue of the environmental SCIENTIST exploring it? The answer is simple: in our professional roles we should be aware that such consequences may occur. We should not be seduced by 'shiny new things' to the extent that we accept without question all the benefits, and do not seek out potential consequences. This includes new environmental technologies, where sometimes we can see the benefits so clearly as to be blind to any negative effects.

Examples of these new environmental technologies with potential consequences will be many, but could include:

- LED lighting to reduce energy usage: does it have effects on wildlife when used for street lighting? Are there effects on human eyesight?
- wind farms: do they have significant effects on bird migrations, or on wildlife sensitive to low-frequency noise?
- electric vehicles: will the push to reduce CO_2 emissions and clean up our urban air cause environmental damage and degradation from the mines and processing needed to obtain the rare earth metals required? Where will we source the electricity for charging the batteries?

What about the effects of new technologies that we are not yet aware of, the unknown unknowns? While it is not possible for us to be aware of unforeseen consequences, I hope that this issue, in discussing and examining some that have occurred, will make us, as environmental professionals, more aware of the potential impacts, more questioning and more open about the negative aspects of new environmental technologies.

David Holmes works as an independent Environmental Practitioner with 30 years of experience in noise, air quality, nuisances and abandoned mines. He is a member of the IES Council.

REFERENCES

1. Rumsfeld, D. (2002) DoD News Briefing – Secretary Rumsfeld and Gen. Myers. U.S. Department of Defense ‹archive.defense.gov/Transcripts/Transcript.aspx?TranscriptID=2636›

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It's time to look beyond the intended consequences of our actions

How often in our chequered history have we done things with the best of intentions, only for the eventual outcomes to turn around and bite us? **Mark Everard** considers decision-making in the face of complexity.

From the unanticipated devastation caused by species introduced for the narrow purpose of biological control, food production, horticulture, aquaculture, through to dichlorodiphenyltrichloroethane (DDT), polychlorinated biphenyls (PCBs), various drugs and all manner of other chemicals introduced into human and ecological systems for targeted reasons, our good intentions have often been obstructed by our failure to look beyond the intended benefit. There are also many examples of unanticipated beneficial outcomes from environmental management, such as the reintroduction of grey wolves to Yellowstone National Park in the USA resulting in improved river channel stability, water quality, flow regimes and riparian botanical diversity as large grazing animals sought the sanctuary of higher ground. Our history is rife with narrowly focused decisions, technologies and resource uses implemented for beneficial reasons yet, with the benefit of hindsight, generating hosts of unanticipated consequences. However, now that we understand and recognise the importance of systems thinking, at least in theory if not yet in widespread practice, is there any longer an excuse, as we look ahead, for the myopia of focusing solely on limited outcomes?

EMBRACING UNCERTAINTY

A recent paper in *Philosophical Transactions of the Royal Society A*[1] addressed the importance of doubt or uncertainty as an inherent part of the scientific method, and therefore of scientific prediction. The acknowledgement of uncertainty as an essential element of prediction rather than a flaw is important precisely because of the inherently chaotic nature by which complex systems tend to evolve, albeit on the basis of laws that may themselves be deterministic and precisely known. Prediction of weather systems is one obvious example, as is the way in which ecosystems recover after disturbance. Also, predictions can themselves influence the evolution of systems, as in the ways that economies move forwards. Faith in an objectively certain reality is in most cases misplaced, at least given our current level of understanding of

INTRODUCTION

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the deeper workings of natural systems. Embracing uncertainty as useful guidance rather than viewing it an enemy thwarting understanding is important for decision-making in complex, chaotic systems.

The notion that we have to be certain before taking decisive action may provide a political rationale for inaction or refusal to pursue potentially unpalatable policy options within a short term of elected office. However, 'certainty addiction' is surely a recipe for disaster if it results in failure to take action to pre-empt likely yet uncertain outcomes from trends in climate change, chemical accumulation, deforestation, desertification, resource depletion, biotic homogenisation (the process by which species invasions and extinctions increase the genetic, taxonomic or functional similarity of locations, constituting one of the most prominent forms of biotic impoverishment worldwide), and growth in human numbers with its associated resource demands.

"Embracing uncertainty as useful guidance rather than viewing it an enemy thwarting understanding is important for decision-making in complex, chaotic systems"

This edition of the environmental SCIENTIST provides a rich feast of papers exploring unintended consequences in a range of settings. We see that biodiversity benefits from solar farms are significantly influenced by the fact that the 'crop' of energy is harvested without tillage on sites with diverse microclimates and from which disturbance is excluded, resulting in multiple consequences for botanical diversity and likely net winners and losers amongst different invertebrate and vertebrate groups. The way that quotas are set for UK marine fisheries can result in greater exploitation of non-quota fish stocks, particularly by small vessels that are not the principal target of the quota system, highlighting how natural resource management and regulation requires more focus on a bigger picture than provided by rights-based approaches. Air pollution controls are observed to have produced a range of intended as well as unintended consequences: in the past these drove investment in the UK on tall-stack chimneys for dispersion of the known pollutants from coal-fired power plants yet compounding the unanticipated problem of long-range acid rain deposition; currently the rising fine particulate and NO_2 concentrations are emerging as primary health concerns stemming from a variety of more dispersed sources. Given their role as ecosystem engineers, it is perhaps unsurprising to learn that many ecological benefits are associated with the reintroduction of Eurasian beavers into the UK and elsewhere in Europe, albeit that distributional issues associated with both benefits and perceived disbenefits (to farmers, foresters and others using riparian landscapes) require further study and consideration.

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USING SYSTEMS THINKING

The 'perfect storm' of closely interlinked nexus of energy, water and food demands of a growing human population has gained popularity in multinational political dialogue as we look ahead to the daunting challenges facing humanity in coming decades. Implicit in this is the recognition of tight interdependencies between these elements, and the need for connected solutions rather than damaging trade-offs between them.

"What is of overriding importance is that we think in connected ways about whole-system outcomes"

Systems models and associated tools now available to help us think and act systemically include the ecosystem services framework and the ecosystem approach, The Natural Step, the Five Capitals systems model for strategic planning, and others besides. In my work on water management from Africa to Asia and Europe, I have found STEEP (social, technological, environmental, economic, political) to be highly effective when used as a systemically interconnected model rather than a simple classification scheme, setting ecosystem exploitation and associated technology choice in wider socio-economic and governance contexts. What is of overriding importance is that we think in connected ways about whole-system outcomes: for all in society, for supporting ecosystems and their processes across a range of spatial and temporal scales, for economic implications, and for effective, nested governance systems.

ACTION IN UNCERTAINTY

The first of our addictions to break is the concept that ecosystem use and technology deployment to maximise a narrow benefit or set of benefits – for example, food production or urban water supply – will yield net benefits to all. I think we all know that the trickle-down effect (applied in natural resource exploitation contexts as a belief that benefits to the few trickle down through social strata as benefits to all) is at best a hollow myth and at worst a lie to reinforce established privilege and power relationships. Simply put, if ecosystems are damaged by exploitation for a limited subset of gains, then their multiplicity of ecosystem services and consequent value to an equally diverse range of beneficiaries are undermined (even were the generally fictional society-wide redistribution of economic gain to take place).

"We cannot halt the runaway juggernaut of society's development trajectory to view it dispassionately"

The second addiction, already alluded to, that we must urgently break is that we have to be certain before we can act. Developed-world society, for example, was certain that markets work well until the most recent economic crash hit it (as market corrections have repeatedly throughout the prior century). The apparent certainties of normally functioning markets are in reality founded substantially on uncertainties, the vast bulk of money flows now being related to speculation – in effect gambling based on probabilities or blind faith – when compared to the vanishingly small proportion linked directly to trade in tangible physical assets. Conversely, prevarication and failure to promote proportionate, proactive responses due to uncertainties associated with the implications climate change can in no way prevent a range of tangible and quite certain outcomes such as coral bleaching, inundation of low-lying land, and increasing storm and drought frequency and severity, all with associated profound economic ramifications.

This all matters a great deal for environmental science and scientists, as we try to grapple with pressing sustainability challenges. These challenges are far from unidimensional but are instead 'wicked problems': difficult or impossible to solve because of incomplete, contradictory and changing requirements along with complex interdependencies[2]. It is vital to take account of the multiplicity of closely interlinked outcomes arising from technology development and deployment, resource exploitation and management, policy formulation and other human activities if natural resources are not to be degraded along with their capacities to support humanity into the future.

We cannot halt the runaway juggernaut of society's development trajectory to view it dispassionately, immersed as we are in its dynamics and complexity. For all of us, our views are partial. So we cannot be sure of every outcome from the decisions we make, the actions we undertake and the options we consider (or overlook). However, we now have systems frameworks and tools to guide us in exploring their wider connected ramifications. We can, and should if we are committed to a genuinely sustainable pathway of development, use these insights to shape innovative solutions that avert unintended damage, to illustrate residual trade-offs, and to inform 'no regrets' options that may not be perfect but are at least transparent in embracing complexity and uncertainty in the decisions that we make. **ES**

Dr Mark Everard is Associate Professor of Ecosystem Services at the University of the West of England (UWE Bristol), an author and broadcaster on a range of sustainability matters, and a Vice President of the IES.

REFERENCES

1. Palmer, T.N. and Hardaker, P.J. (2011) Handling uncertainty in science. *Philosophical Transactions of the Royal Society A*, 369 (1956). doi: 10.1098/rsta.2011.0280.
2. Rittel, H.W.J. and Webber, M.M. (1973) Dilemmas in a General Theory of Planning. *Policy Sciences*, 4, pp.155–169.

Obstacles to climate policy

Rick van der Ploeg investigates the relationship between carbon emission reduction policy, fossil fuel demand and those hit hardest by bad policy-making.

At the 2016 international climate summit in Paris, 194 countries committed themselves to limiting global warming to no more than 2 °C and to striving for 1.5 °C above pre-industrial temperatures. A two-thirds chance of meeting this target means that from now the world as a whole cannot emit more than 600–1,100 $GtCO_2$ (gigatonnes of carbon dioxide) and must strive to emit less than 150–300 $GtCO_2$. This is

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called the carbon budget and is the key factor driving climate policy. If the world does not cut emissions, the carbon budget runs out in 2036–2051 for the 2 °C target and 2023–2027 for the 1.5 °C target. Running existing coal-powered electricity stations to the end of their normal economic lifetime is enough to overshoot the Paris targets[1]. Hence, very ambitious climate policies must be pursued by *all* countries to meet them. This will involve painful measures, such as scrapping assets that have not fully recouped their investments, and last-resort methods to ensure negative emissions, such as geo-engineering.

PRICING CARBON

The best method for achieving such a drastic reduction in emissions is to price carbon, which can be done by committing in advance to rising carbon taxes. Finland, Norway, Sweden, Switzerland and the United Kingdom have already done this. Alternatively, emissions can be reduced via a competitive market for emissions permits, such as the European Emissions Trading Scheme (ETS). The trading of the permits ensures that reduction takes place in sectors and countries where this can be done most cost effectively. The unforeseen disadvantage of permits is that the price can be volatile and thus the signal for industry and households to transition to carbon-free production and consumption is less strong. It is therefore ideal to combine the best of both by announcing and committing to a rising price for CO_2 and topping up the ETS price if it falls below the price of CO_2. The initial price could be at least 40 €/tCO_2 and from then on grow steeply at a rate of 5–8 per cent per annum to reflect the decreasing carbon budget.

Pricing carbon helps the transition to the carbon-free era in many ways. It curbs demand for fossil-fuel energy, encourages the substitution of carbon-intensive coal with less carbon-intensive oil and gas, stimulates green innovation, makes carbon capture and sequestration economically attractive, and forces fossil-fuel companies and nations to leave more coal, oil and gas in the Earth. Pricing carbon has the co-benefit of improving air quality in cities and thus saving many early deaths, especially of schoolchildren near busy roads[2]. China, for example, has shown that this is an important catalyst for getting rid of diesel-powered transport and for climate policy in general.

Although pricing carbon is the first-best policy, there is the no-brainer of getting rid of all fossil fuel subsidies. Worldwide these explicit and implicit subsidies have been estimated by the International Monetary Fund to amount to a colossal £4.5 trillion (6.5 per cent of world GDP) compared to a miserly £103 billion in subsidies for renewable energies[3]. These subsidies tend to be largest in countries that are oil or gas producers and have insufficient state capacity to redistribute incomes to the poor via the tax system.

CLIMATE SCEPTICS

One of the biggest obstacles to a successful climate policy is the rise of populism and climate scepticism. It is not clear whether populists really believe, despite all the evidence, that climate scientists are wrong or whether their scepticism is driven by the fossil-fuel lobbies. Assigning an implausibly high probability of say 10 per cent of sceptics being right hardly affects the carbon price. Also, the max–min principle of maximising outcomes under the worst possible view of the climate leads to carbon pricing[4]. The reason is that the cost of unnecessarily pricing carbon if the sceptics are right is modest (especially as the revenues are handed back to the private sector), but the cost of not pricing carbon is huge if the scientists are right and the temperature rises by 4 °C or more.

INTERNATIONAL & NATIONAL GAPS IN THE CARBON PRICE

To make sure that the transition to the carbon-free era is done most efficiently, it is crucial that the price of carbon and thus the cost per saved tCO_2 is the same throughout the world. By allowing trade in CO_2 permits, some countries that can get a lot of extra output per unit of CO_2 emitted (e.g. the cement industry) can buy permits from countries that can reduce emissions more efficiently (e.g. woods in Bohemia) and thus from a global perspective emission reductions are done in a more cost-effective manner. To persuade poorer countries to go along with one global price for CO_2 emissions (and to compensate for past emissions in rich countries), it is essential for rich countries to transfer funds to poorer countries. However, despite three decades of summits, such transfers have hardly been forthcoming. For efficient reductions in emissions, the cost per saved tCO_2 must also be the same across all sectors for the economy. However, in practice, they vary hugely. The reason for this is the piecemeal approach adopted by policy-makers and, for example, by the lobby to keep a steel plant open being stronger and more concentrated than the one to eliminate gas from all residential homes. Furthermore, the cost per saved tCO_2 must be the same for different climate policies but this is rarely the case. Politicians prefer renewable energy subsidies to carbon pricing, even though the latter is much more cost-effective – witness the huge solar subsidies in German power generation.

In Europe the biggest polluters, such as coal-fired power stations, airline companies and steel and aluminium producers, have been the most successful in claiming exemptions from carbon pricing. Furthermore, the practice of 'grandfathering' ETS permits (basing future emission entitlements on previous emissions) meant that in the past the biggest polluters got the most permits. The recent reforms of the ETS should get rid of some of these inefficiencies.

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Although fossil fuel lobbies have been incredibly powerful, we now see a rise in renewable energy lobbies trying to capture the climate policy rents. This is also dangerous, since business, not government, should pick winning technologies as they are much better informed. Government should promote renewable energies by pricing carbon, but take a neutral stance towards particular technologies. The potential here is that poor choices in renewable energy technologies could delay reduction in carbon emissions and increase the long-term cost to energy users.

THE GREEN PARADOX AND CARBON LEAKAGE

Politicians dislike carbon pricing and prefer subsidies to carbon pricing. They also procrastinate and commit their successors to more ambitious climate policies. The unintended consequences of such second-best policies lead coal, oil and gas barons to deplete their reserves more quickly as they realise that their reserves will become redundant more quickly. This depresses energy prices and boosts demand for fossil fuel, thus accelerating global warming in the short term. This so-called green paradox effect is costly, and stronger if the supply of fossil fuel reserves does not respond much to price changes. However, such second-best policies do lock up more carbon and curb global warming in the longer term. It is better for politicians to price carbon, commit to a steeply rising price, and to start immediately. Even without the green paradox effect, delaying climate action pushes up the cost considerably as the marginal damages of global warming rise steeply with worsening global warming.

The spatial equivalent of the green paradox effect is carbon leakage. This arises when only a subset of countries prices carbon, shifting some of the burden of the carbon price to producers. This causes energy prices abroad to fall, and thus emissions abroad rise while emissions at home fall. This carbon leakage effect is on average about 20 per cent. In countries such as the Netherlands energy is taxed, but CO_2 emissions are not taxed. Alongside this, coal use emits much more CO_2 per unit of energy than oil use and the latter emits more CO_2 than gas use. Therefore energy pricing rather than CO_2 pricing means that coal is undercharged from a social perspective. Put differently, energy pricing provides too little incentive to reduce carbon emissions with 'dirty' and 'clean' energy being equally taxed.

The beneficial impact of carbon pricing, if it were to be introduced in the Netherlands, would be partially offset by additional coal and gas imports from Belgium and Luxemburg, where carbon is not taxed. This carbon leakage effect is especially strong for the Netherlands, since it is an international gas hub for Europe. The reason is that the carbon price is partially shifted to the producers, so that the price of fossil energy in neighbouring countries falls and thus CO_2 emissions in these countries rise. Multilateral carbon pricing is therefore more effective than unilateral carbon pricing. It is best if pricing carbon can be done together with neighbouring countries, if necessary by offering transfers to persuade them to cooperate.

SPENDING CARBON TAXES

One of the biggest obstacles to a successful climate policy is the effect of carbon prices on the lowest incomes. Carbon pricing increases electricity prices and an unintended consequence is that the poor are hurt relatively more than the rich, especially if they live in poorly insulated houses. Therefore a key policy question is to decide what to do with the revenue from carbon taxes. If the tax system is already efficient, it is best to use it to make a lump-sum payment to all households, which helps those on the lowest incomes the most. Depending on political preferences, one could also use the carbon tax revenue for targeted transfers, such as for housing insulation subsides to the poor. If labour income or corporate tax rates are inefficiently high, the carbon tax revenue could be used to cut these tax rates. This would help to boost employment and labour activity. To maximise societal support for any of these, it is important to make the transfer as salient as possible by calling it a 'carbon dividend', for example[5].

It is often proposed that carbon tax revenue is used to subsidise research and development into new renewable energies. However, if there is a learning-by-doing or infant-industry case for such subsidies, these should be in place anyway. On the other hand, it is sometimes argued that carbon tax revenue should be used to get political support by compensating carbon-intensive industries such as coal-fired power stations and steel, as they will lose the most if climate action is stepped up. This should be avoided. Instead, the costs to these industries can be minimised by announcing the transition to the carbon-free economy as early as possible, keeping to a well-defined transition with rising carbon prices and formalising it in a special climate law.

INVESTOR VULNERABILITY

Proven coal, oil and gas reserves are a factor eight to ten times higher than the carbon budget. This implies that either climate policy lacks credibility or that fossil companies are overvalued. Both private and institutional investors are heavily exposed to fossil fuel companies and to the risk of climate policy becoming more ambitious in the future. For example, the largest stock in the portfolio of Dutch pension funds is Royal Dutch Shell. By contrast, last year the largest Swedish pension fund, AP7, sold its investments in companies that violate the Paris agreement (ExxonMobil, Gazprom, TransCanada, Westar Energy, Entergy and Southern Company). Pension funds could also hedge themselves by investing in low-carbon trackers, which give a similar return to ordinary trackers but also give good returns by avoiding stranded assets and losses in stock market value if climate policy is stepped up.

SUMMING UP

To keep global temperatures within safe limits, the world needs to change its almost absolute reliance on fossil fuel in the next few decades. This requires phasing out coal, stopping all fossil fuel subsidies and a commitment to steeply rising carbon prices for all regions and sectors of the economy. It is important to act multilaterally, resist carbon lobbies, redistribute revenue to the poor and subsidise home insulation and carbon-free heating for the poor. Waiting to take action will drive up the costs of decarbonisation and increases the risk of having to implement policies that lead to negative emissions. Leaving it to each of the sectors of the economy to come up with top-down plans to cut emissions or to the government to pick particular renewable energies to be subsidised is prone to rent seeking and will be much more expensive than pricing carbon. **ES**

Rick van der Ploeg is currently Professor of Economics and Research Director at the Oxford Centre for the Analysis of Resource Rich Economies, Department of Economics, University of Oxford. He was formerly the Chief Financial Spokesperson for the Dutch Parliament (1994–1998), the State Secretary of Education, Science and Culture of the Netherlands (1998–2002) and an Elected Member and the Vice-Chair of the UNESCO World Heritage Committee (2002–2007).
rick.vanderploeg@economics.ox.ac.uk

REFERENCES

1. Pfeiffer, A., Millar, R., Hepburn, C. and Beinhocker, E. (2016) The '2 °C capital stock' for electricity generation: committed cumulative carbon emissions, from the electricity generation sector and the transition to the green economy. *Applied Energy*, 196, pp.1395–1408.
2. Mayrhofer, J. and Gupta, J. (2016) The science and politics of co-benefits in climate policy. *Environmental Science and Policy*, 57, pp.22–30.
3. Coady, D., Parry, I.W.H., Sears, L. and Shang, B. (2016) How large are global energy subsidies? Working Paper 15/105, International Monetary Fund, Washington D.C.
4. Rezai, A. and van der Ploeg, F. (2017) Climate policies under model uncertainty: max-min and min-max regret. *Energy Economics*, 68 (S1), pp.4–16.
5. Klenert, D., Mattauch, L., Combet, E., Edenhofer, O., Hepburn, C., Rafaty, R. and Stern, N. (2018) Making carbon pricing work for citizens. *Nature Climate Change*, 8, pp669-677.

CASE STUDY

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Restoring a native mammal: A muddy picture?

Róisín Campbell-Palmer shows that bringing back a once-common animal is not without its problems.

The Eurasian beaver (*Castor fiber*) is a native species that was once widespread throughout freshwater habitats in mainland Britain but was hunted to extinction by the 18^{th} century[1]. A similar pattern of over-exploitation occurred across Eurasia, and by the end of the 19^{th} century only a few hundred individuals remained. The Eurasian beaver has now been reintroduced (both officially and unofficially) to over 25 European countries.

THE DEBATE FOR AND AGAINST

As an island, Britain has the ability to be selective about which species are reintroduced, and this leads to debate over what should or should not be brought back. While beavers may generate strong support from conservation groups, the reintroduction of beavers to Britain has indeed been a long-debated process. Other land-users, such as those involved in agriculture who may have to live with the consequences of beaver activity, can experience significant problems. This can result in strident objections to beaver reintroduction projects based on both perception and experience of their impacts, especially in heavily modified landscapes.

The official reintroduction system for species, especially controversial species, is widely perceived as slow, expensive, bureaucratic and loaded in favour of politically astute opponents. Anecdotal evidence suggests that mounting frustration with this situation is resulting in a rising tide of unofficial and illegal animal releases. In recent years, for example, a number of extinct species such as wild boar (*Sus scrofa*)[2] have regained some element of their British range by unofficial means.

The restoration of beavers has received much media attention as a combined result of public enthusiasm, academic investigation and political discussion. It has been a long-running, haphazard affair with the appropriateness and productiveness of unofficial animals appearing in certain parts of the country being fiercely debated. Where the official response has been to remove or suggest the culling of these individuals, public


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debate has commonly forced a swift change of policy to allow their retention. Unorthodox as this approach might seem, it has undoubtedly accelerated beaver restoration faster than conventional processes. The largest and most extensively dispersed population of beavers exists in the catchment of the Tay and Earn rivers in east Scotland, where unofficial reports suggest that they may have been present since the mid 2000s. The most recent and extensive distribution and population survey has determined a minimum of 105 active territories[3].

The origin and appearance of beavers in parts of Britain can long be debated but no government bodies have undertaken a cull to remove them and instead have permitted their presence. Tighter regulation on animal translocation and licensing of enclosed trials may be expected but with population number and distribution increasing, beavers will inevitably return across British riparian systems.

BENEFITS TO BIODIVERSITY

Bringing back beavers is not simply about releasing a charismatic mammal for its own sake. The pivotal role that this species plays in wetland ecology is widely recognised, so it could help to reverse some of the massive net loss of riparian biodiversity, flooding and soil erosion brought about by centuries of draining, the canalisation of our waterways and the replacement of riparian vegetation with mono-crops.

The positive impacts of beaver habitat modification and creation should not be underestimated and have been well documented across Europe: beaver-generated landscapes have seen increases in biodiversity (in species richness and abundance) of aquatic invertebrates, dragonflies, fish, birds and bats. As an example, the expansion of locally extinct species such as black storks (*Ciconia nigra*) in Sweden has been linked with beaver-created wetlands[4].

Increases in biodiversity are already occurring in Britain. As the enclosed beaver trial on a first-order tributary draining intensively managed grassland in Devon has demonstrated, one beaver family can significantly improve water storage, sediment retention and water quality[5]. This presents an exciting potential for the use of beavers as part of a wider strategy for delivering environmental ecosystem services and naturalising river catchments.

Concerns have been raised over species such as aspen (*Populus tremula*), aspen hoverfly (*Hammerschmidtia ferruginea*), Atlantic salmon (*Salmo salar*) and lichens (*Arthonia patellulata* and *Lecanora populicola*). Beavers are not considered serious threats to these species across Europe and the threat is yet to be realised in a British context. Perhaps somewhat unexpected has been the immediate feeding on non-native invasive plant species such as Himalayan balsam (*Impatiens glandulifera*), rhododendron (*Rhododendron ponticum*) and Japanese knotweed (*Fallopia japonica*), and native invasives such as bracken (*Pteridium aquilinum*). Whilst beavers will not remove these species they may have interesting grazing impacts.

WORKING TOGETHER

As significant modifiers of fresh water ecosystems, beavers come into conflict with particular human activities and land use. However, the appearance of beavers outside of official processes has fast-tracked the formation of multi-stakeholder forums and the development of appropriate management systems retrospectively. Such processes have been complicated by issues such as the legal status of these animals, public response, the varying opinions of a range of landowners, and the likelihood that Eurasian beavers will receive legal protection as a European protected species. Nevertheless, this has provided a valuable opportunity for a range of interest groups and statutory bodies to work together using a more holistic approach to wider issues that have been highlighted by beaver presence, such as flood alleviation, managing run-off from intensive farming along riparian habitats and wetland conservation.

CHANGES IN LANDSCAPE MANAGEMENT

Beavers have certainly raised a number of land management issues, crossing multiple statutory body remits – the Department for Environment, Food and Rural Affairs (Defra) for animal health, the Environment Agency (EA) and the Scottish Environmental Protection Agency (SEPA) for water management and Scottish National Heritage (SNH) and Natural England (NE) as government advisory and licensing bodies.

This also presents an opportunity to manage riparian zones more holistically, especially in relation to flood alleviation and the reduction of intensive farming impacts. The drive, where possible, to re-naturalise these systems already includes projects aimed at re-meandering water courses, creating water storage areas, increasing woody debris in water courses and building 'leaky dams' – all processes that beaver activities can create. Additionally, the naturalisation of riparian zones such as allowing buffer strips of vegetation to develop along water courses not only aids in sediment and pollutant run-off retention but reduces beaver conflict impacts. The ecological service potential of beavers is enabling a more holistic view of how we manage our riparian zones. With a move away from hard infrastructure solutions, beavers could be one of a range of tools, with sensible and effective animal management procedures to resolve any conflicts.

HEALTH CONCERNS

One of the main concerns is the health status of beavers from unknown sources. Health screening is essential to reduce the introduction of pathogens at release sites, protect existing wildlife, livestock and human health, and it is widely recognised as an essential good practice element of any reintroduction. A lack of traceability has resulted in the reactive application of resources towards trapping and retrospective health screening. Of particular concern is the introduction of non-native parasites and diseases, such as the fox parasite (*Echinococcus multilocularis*, a type of tapeworm) which has been identified in a wild-caught Bavarian beaver imported into an English captive collection[6]. Although other routes of transmission of this parasite to the UK are more likely, such as improperly wormed


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CASE STUDY

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pets or the illegal imports of puppies from continental Europe, the perceived risk that the illegal release of beavers will introduce notifiable diseases has gone some way to undermining the restoration process, particularly with statutory bodies and the agricultural sector.

Health checks ensure that any individuals potentially unlikely to survive or to experience welfare challenges on release are identified[7]. Significant progress has been made in the veterinary knowledge and diagnostic methods applied to beavers specifically given this situation in Britain. Such science should be balanced with a common-sense approach[8], i.e. not automatically excluding individuals displaying previous exposure to common diseases or parasites that are already present in local wildlife, such as leptospirosis. To date no significant diseases or parasites of concern have been found in any wild beaver population.

GENETIC CONCERNS

Apart from the Tayside animals, beaver populations in Britain are small and widely distributed. Small populations are vulnerable to stochastic events and therefore more liable to die out. Investigations into their genetic diversity suggest that many are closely related. This situation could have important repercussions for their long-term viability. The Tayside population currently has levels of genetic diversity that are slightly reduced compared to wild Bavarian populations as they are much more closely related. Other populations, such as the River Otter animals, have high levels of inbreeding. These populations are likely to require future genetic management to ensure the best possible chance for future adaptation and long-term survival in Britain.

Existing Eurasian populations have low levels of genetic diversity[9] so it may be assumed that genetic diversity and inbreeding are not significant in the restoration of this species. However, such populations can result in reduced fitness due to inbreeding effects and loss of adaptive potential, which have been suggested as possible factors in reintroduction failures[10]. Genetic management could include augmentation or translocation under a meta-population management plan. Active management is normally undertaken in any reintroduction programme to ensure that inbreeding is reduced.

THE WRONG BEAVERS

Another perceived issue raised with the appearance of beavers from unknown origins is the concern over the introduction of the North American or Canadian beaver (*C. canadensis*), a highly similar but genetically and geographically distinct species. This species has been kept in captive collections, including on the Isle of Bute in the 1800s. The introduction and current spread of North American beavers in Europe (e.g. in Finland) is of serious concern, requiring considerable wildlife management[11]. To date only Eurasian beavers have been confirmed, while North American beavers are no longer present in many captive collections.

FUTURE REINTRODUCTIONS

As natural resources come under increasing pressure, and funds for conservation become ever more stretched, there are tough questions about the range of habitats and species we aim to preserve or restore. The future of species conservation could be more proactive in its vision and take steps to improve ecosystem resilience, ensure long-term viability and invest in its capacity to adapt to future circumstances. Reintroductions are part of this process but they must be justified, well planned and future-proofed to ensure viable population establishment and long-term persistence.

Reintroductions have a critical role as part of a wider process of improving ecosystem health and functioning, but these should be undertaken in an inclusive manner with human activities in mind. By comparison to other European countries, there seems to be a general reluctance towards the use of reintroductions as a valid conservation strategy in Britain[12]. Keystones species such as beavers can have significant impacts on human land use and activities, leading to greater human–wildlife conflicts. Therefore, the long-term tolerance of such species will only be achieved if accompanied by management strategies developed in collaboration with a range of stakeholders. ES

Róisín Campbell-Palmer has over 15 peer-reviewed scientific publications on beaver biology, a PhD from the University of Southeast Norway and is lead author on the recently published Eurasian beaver ecology and management book. She is also an independent beaver advisor for Scottish Natural Heritage and advises on beaver-related projects throughout Britain.

REFERENCES

1. Coles, B. (2006) *Beavers in Britain's Past*. Oxford: Oxbow Books.
2. Wilson, C. J. (2014) The establishment and distribution of feral wild boar (*Sus scrofa*) in England. *Wildlife Biology in Practice*, 10, pp.1–6.
3. Campbell-Palmer, R., Puttock, A., Graham, H., Wilson, K., Schwab, G., Gaywood, M.J. and Brazier, R.E. (2018) Survey of the Tayside area beaver population, 2017–2018. *Scottish Natural Heritage Commissioned Report No.* Submitted.
4. Sörhammar, M. (2015) GIS-based modelling to predict potential habitats for black stork (*Ciconia nigra*) in Sweden. Swedish University of Agricultural Sciences. ‹stud.epsilon.slu.se/7597/7/sorhammar_m_150205.pdf›
5. Puttock, A, Graham, H., Cunliffe, A M., Elliott, M. and Brazier, R. (2017) Eurasian beaver activity increases water storage, attenuates flow and mitigates diffuse pollution from intensively managed grasslands. *Science of the Total Environment*, 576, pp.430–443.
6. Barlow, A.M., Gottstein, B. and Mueller, N. (2011) *Echinococcus multilocularis* in an imported captive European beaver (*Castor fiber*) in Great Britain. *Veterinary Record*, doi:10.1136/vr.d4673. 169, p.339.
7. Goodman, G., Girling, S., Pizzi, R., Rosell, F. and Campbell-Palmer, R. (2012) Establishment of a health surveillance program for the reintroduction of the Eurasian beaver (*Castor fiber*) into Scotland. *Journal of Wildlife Disease*, 48, pp.971–978.
8. Leighton, F. A. (2002) Health risk assessment of the translocation of wild animals. *Revue scientifique et technique de l'office internationale des epizooties*, 21, pp.187–195.
9. Senn, H., Ogden, R., Frosch, C., Syrůčková, A., Campbell-Palmer, R., Munclinger, P., Durka, W., Kraus, R.H.S., Saveljev, A.P., Nowak, C., Stubbe, A., Stubbe, M., Michaux, J., Lavrov, V., Samiya, R., Ulevicius, A. and Frank Rosell, F. (2014) Nuclear and mitochondrial genetic structure in the Eurasian beaver (*Castor fiber*)–implications for future reintroductions. *Evolutionary Applications*, 7, pp.645–662. doi: 10.1111/eva.12162.
10. Weeks, A.R., Sgro, C.M., Young, A.G., Frankham, R., Mitchell, N.J., Miller, K.A., Byrne, M., Coates, D.J., Eldridge, M.D.B., Sunnucks, P., Breed, M.F., James, E.A. and Hoffmann, A.A. (2011) Assessing the benefits and risks of translocations in changing environments: a genetic perspective. *Evolutionary Applications*, 4, pp.709–725.
11. Parker, H., Nummi, P., Hartman, G. and Rosell, F (2012) Invasive North American beaver *Castor canadensis* in Eurasia: a review of potential consequences and a strategy for eradication. *Wildlife Biology*, 18, pp.354–365.
12. Arts, K., Fischer, A. and van der Wal, R. (2013) Political decision-making, governance shifts and Scottish animal reintroductions: are democratic principles at stake? *Journal of Environmental Planning and Management*, 57, pp.612–628.

New members and re-grades

Member

is for those individuals who have substantial academic and work experience within environmental science.

Khaldon Aldarraji – Environmental Studies Specialist
Matthew Baker – Environmental Consultant
Ann Barker – Lead Officer Contaminated Land
Shauna Barrett – Environmental Advisor
Justin Bishop – Senior Consultant
Rebecca Bragg – Wastewater Science & Optimisation
Andrew Bryan – Contaminated Land Officer
Ian Buchan – Principal Environmental Consultant
Anthony Bullen – Contaminated Land Officer
Corinne Burrows – Geo-Environmental Consultant
Samuel Butcher – Geo-Environmental Engineer
Dara Chadwick – Environmental Scientist
Jonathan Chenoweth – Lecturer & Programme Director
Daniel Clare – Director (Acoustics)
Jon Coates – Senior Consultant
Letizia Cocchiglia – Senior Ecologist
Carla Costelloe – EOC Project Manager
Ryan Cridlin – Consultant
Tim Croker – Environmentalist
Gail Currie – Senior Consultant
Marvin Danvers – Environment Manager
Sarah-Jane Davies – Senior Lecturer
Nicola Davies – ESG Specialist
Christopher Dennis – Senior Consultant Ecologist
Neil Dickson – Hydrogeologist
Mark Dodd – Remediation Manager
Douglas Dyche – Senior Environmental Scientist
Stewart Easton – Senior Environmental Scientist
Lisa Egan – Project Scientist
Martin Feery – Environment & Sustainability Manager
William Flynn – Ecologist
Alastair Forbes – Environment Advisor
David Green – Landscape Assessment Manager
Sarah Greenhough – Scientific Officer
Charlotte Handy – Consultant & Project Manager
Richard Hardeman – Environmental Manager
Jack Harper – Senior Geo-Environmental Engineer
Timothy Hill – Chief Scientist
Gareth Hodgkiss – Principle Air Quality Consultant
Christopher Holcroft – Environmental Technologist
Alex Hook – Director/Consultant
Stephen Howard – Geo-Environmental Engineer
Lois Hurst – PhD Student
Oliver Jensen – Environment Officer
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Mark Jessup – Environmental Advisor
Matthew John – Senior Environmental Scientist
Ghanim Kashwani – HSE Team Leader
Robert Kay – Environmental Consultant
Blaise Kelly – Lead Air Quality Engineer
David Kerr – Senior Environmental Consultant
Marina Kirkpatrick – Principal Engineer
Aine Kirrane – Environmental Scientist
Tin Yan Mona Lee – Project Executive
King Hang Leung – Environmental Protection Inspector
Fiona MacDonald – Project Environmentalist Scientist
Louise MacDonald – Environmental Advisor
Ross MacKenzie – Environmental Consultant
Gunnar Mallon – Project Manager
William Mankiewicz – Senior Project Engineer
Christine Mardle – Technical Director
Geoffrey Martin – Senior Environmental Consultant
Joao Martins – Scientist
Philip Mason – Environmental Consultant
Jessica McDermott – Senior Engineer
Joseph McGrath – Senior Scientist
David Mills – Environmental Consultant
Timothy Mitchell – Associate Director
Paloma Montes – Principal Risk Assessor
Charlotte Moore – Air Quality Consultant
Eilidh Morrison – Lead Environmental Consultant
Arun Mudiganti – Senior Environmental Manager
Mark Murphy – Senior Consultant (EIA)
Dhiren Naidoo – Senior Air Quality Scientist
Paul Neary – Director
Christopher Oates – Senior Geo-Environmental Engineer
Adobi Okam – Air Quality Enforcement Officer
Francis Okyere – Principal Consultant
Miriam Olivier – Environmental Assessment Graduate
Ian Packham – Principal Scientist
Christine Park – Senior Environmental Consultant
Shaun Pearce – Senior Consultant
Nicholas Pigula – Sustainability Manager
Patrick Pope – Associate
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Tom Reid – Sustainability Specialist
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Conrad Wilson – Senior Associate
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Wai Fung Yu – Assistant Consultant
Dace Zica – Environmental Consultant
Kali-Stella Zoannou – Water Quality Reporting Scientist

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Michael Bell – Assistant Air Quality Consultant
Jessica Breen – Administrator
James Brooks – PhD Student
Leanne Carr – Geo-Environmental Engineer
Bryan Cassidy – Environmental Consultant
Yohannah Caussyram – Graduate Air Quality Consultant
Natasha Caven – Graduate Environmental Consultant
Richard Chalkley – Volunteer Data Analyst
Andrew Curry – Graduate Consultant
Henry Davies – Account Development Rep
Rosemary Davies – Graduate Environmental Consultant
Adam Dawson – Air Quality Engineer
Andrew Denton – Geo-Environmental Consultant
Laurens Dominicus – Graduate Environmental Engineer
Aaron Drew – Assistant Environmental Consultant
Aamirah Essof – Graduate Air Quality Consultant
Naomi Gibson – Graduate
James Gooding – Geo-Environmental Consultant
Joseph Granelli – Graduate Air Quality Consultant
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Ryan Gunn – Geo-Environmental Scientist
Alexander Hargreaves – Search Advisor
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+44 (0)20 7601 1920
www.the-ies.org
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What's wrong with air pollution controls?

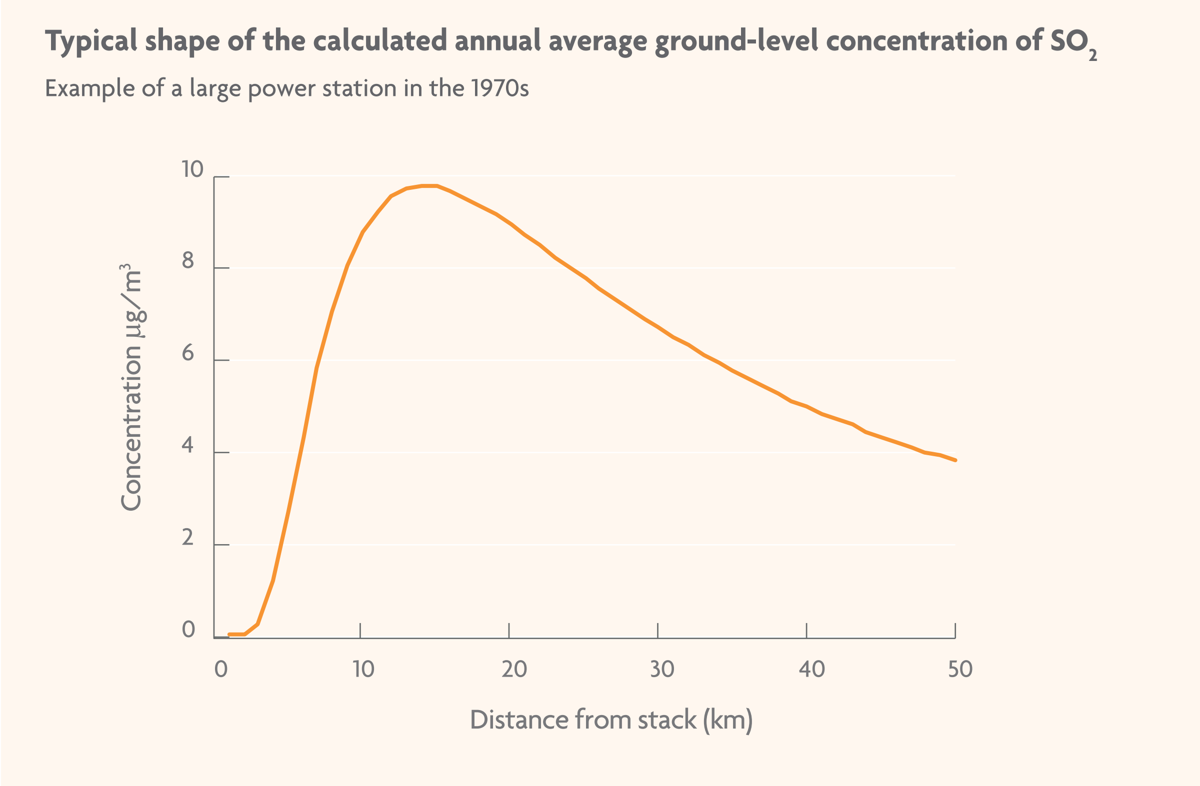
Bernard Fisher explores the unintended consequences of UK air quality policies.

In the early 1960s Britain needed to be supplied with electricity in a self-sufficient way. This need was satisfied by coal mined in the UK and burned in large power stations. Research was conducted to understand the dispersion of emissions from tall chimneys by the organisation responsible for supplying electricity, the Central Electricity Generating Board (CEGB). This led to the tall stack policy, which was the practice of building large power stations in rural areas, where the emissions would be carried away by air currents, leaving the maximum ground-level concentration acceptably low. The main airborne emission of concern was the gas sulphur dioxide (SO_2), although it and nitrogen oxides (NO_x, the sum of the two gases nitrogen oxide [NO] and nitrogen dioxide [NO_2]) were not controlled at source. Smoke from combustion in the form of small particles was very efficiently controlled using electrostatic precipitators, and measures to tackle smoke in cities had been under way for some years following the Clean Air Act 1956.

For the purpose for which they were designed, tall stacks were a good thing: the large stack height was sufficient to lead to substantial dispersion of the emitted plume before it reached ground level (see **Figure 1**).

COMPLAINTS ABOUT ACID RAIN

At the time most tall stacks were approved there was little awareness of where the effluent gases SO_2 and NO_x would end up. Perhaps there should have been, given the studies of radioactive releases into the atmosphere that took place after the Windscale accident in 1956. Acid rain became an international issue of high priority after the agricultural scientist Svante Odén wrote an article in a Swedish newspaper in 1967. Odén made people aware of the ongoing acidification of precipitation and surface waters and its consequences. He suggested that much of the acidifying pollutants that were deposited in Scandinavia originated from the UK and other countries on the European continent.



▲ **Figure 1. Typical shape of the calculated annual average ground-level concentration of SO_2 out to distance of 50 km from the chimney showing the location of the maximum ground-level concentration.**

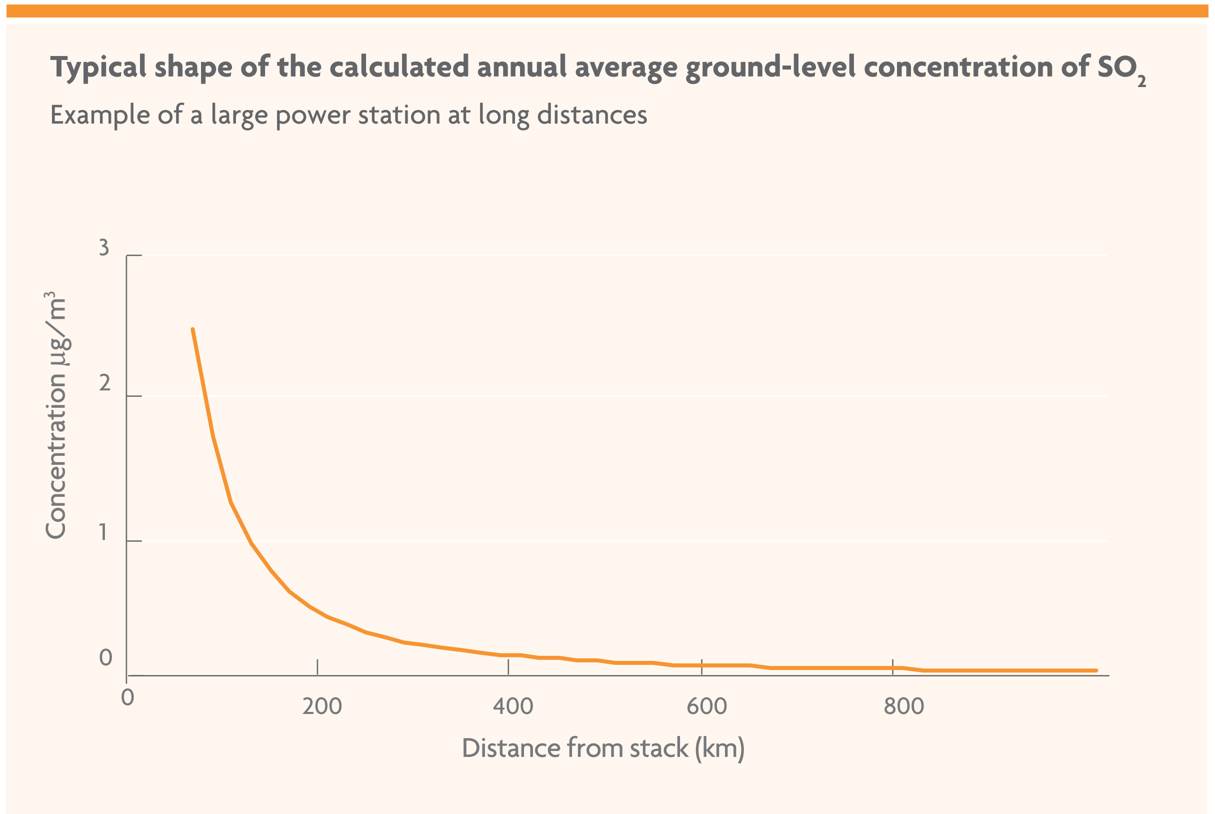
What had been neglected in the UK study of pollutant dispersion in the atmosphere was not just the need to estimate the maximum ground level concentration at distances of tens of kilometres but also the concentration at long distances of thousands of kilometres. This would be a small fraction of the maximum ground-level concentration (see **Figure 2**). However, when combined with the contributions from many sources in industrialised Europe and deposited by precipitation, it would provide air pollution derived input to remote lakes in Scandinavia larger than that from natural processes, with subsequent adverse biological effects.

Acid rain was a hotly contested international issue in the 1970s[1]. Much of the discussion of airborne processes (to determine how much of the SO_2 deposited over a receptor came from each country) relied on mathematical models, and was therefore subject to debate. About 6 million tonnes of SO_2 were emitted from the UK in 1970, of which about half was from power stations. Although tall chimneys disperse material further, dispersion occurs on time scales much faster than removal by wet and dry deposition, so material from a tall stack travels only slightly further on average compared with the equivalent amount of material released from a near-ground-level source, such as a chimney on a house[2]. Thus the culprit was not the tall stack, but the quantity of SO_2 released.

Acid rain is an example of not considering fully the consequences of releasing a substance into the atmosphere, even if to do so would involve a complex investigation.

NON-LINEARITY

One of the issues under discussion in the models was the question of non-linearity. SO_2 has to be oxidised to sulphate before it can be removed in precipitation and this requires chemical reactions in the atmosphere. This means that the amount of sulphate available to be deposited depends as much on the amount of oxidant as on the amount of SO_2. A simplified example illustrates the point: if a British power plant released 100 tonnes of SO_2 into the atmosphere in a typical day, but atmospheric oxidation only turned half of the SO_2 emitted into sulphate by the time it reached Scandinavia, then British power plants could halve their emissions without seeing any corresponding decrease in acid rain in Scandinavia[1].



▲ **Figure 2. Typical shape of the calculated annual average ground-level concentration of SO_2 from a large power station in the 1970s at distances beyond 50 km and up to 1,000 km from the chimney.**

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▼ **Table 1: Impact of UK SO_2 emissions on the UK and Norway.**

Year	Emissions of SO_2 in the UK (kt per annum)	Fraction deposited over the UK (%)	Fraction deposited over Norway (%)	Fraction deposited over the North Sea (%)
1978 – 1982	5120	31	2.1	N/A
2002	1002	25	2	30
2014	308	29	2	27

Questions of non-linearity led to enormous developments in atmospheric models involving all types of European atmospheric emissions, all known chemical reactions and all known atmospheric processes. Examples include the EMEP MSC-W model[3] and the CMAQ model[4]. These models must be regarded as one of the major scientific achievements of the last 40 years. For SO_2, but not for NO_2 and particles to be discussed later, the non-linearity effect is small and has been ignored in recent calculations of the impact of UK SO_2 emissions. These are shown in **Table 1** and emphasise the enormous reduction in SO_2 emissions over the years[5]. These data also emphasise that much of the emissions are deposited over the UK itself, and this should have alerted people to acid rain effects within the UK and the consequences of other types of air pollution within UK borders.

ACID RAIN EFFECTS AND RECOVERY

One should consider what the emission reductions (see **Table 1**) have achieved. Biological effects are difficult to evaluate quantitatively. Therefore to quote from a UNECE report[6], recovery is taking place but is not complete, and forest health is difficult to explain.

"In acid-sensitive lakes and streams in Europe and North America, sulphate concentrations have decreased on average 45–55 per cent since 1988 as a result of a decrease in sulphate deposition. This has led to a widespread chemical recovery of surface waters, i.e. pH and acid-neutralising capacity have increased. Biological recovery of acid-sensitive waters is also occurring, primarily as a result of improved water quality. However, aquatic systems that are under recovery from acidification still have lower species diversity than pristine aquatic ecosystems. Full biological recovery may not be possible in some ecosystems."

"In European forests, defoliation records reveal a slight, but significant, deterioration of crown condition, except for Scots pine. Reduced sulphur deposition, reflected in a decline in foliar sulphur concentrations, is expected to lead to reduced soil acidification and improved conditions for trees. Therefore, it seems unlikely that the reduced crown condition is directly linked to reduced sulphur deposition in forests. High nitrogen deposition, however, has been shown to be negatively correlated with crown condition in three common forest species in Europe. Ozone, drought [and] insect infestations ... also have potential adverse effects on needle and leaf biomass." de Wit, et al. (2015)[6].

As a consequence of SO_2 emission reductions over 45 years, ground-level concentrations in the UK are very much reduced by two orders of magnitude in some places and sulphur is no longer the main issue.

AIR-BOURNE PARTICLES AND HEALTH

The main issues now are particulate matter (PM) and NO_2 concentrations, because of health concerns. $PM_{2.5}$ denotes fine particulate matter defined as the mass of particles with diameters up to 2.5 µm. Particles not directly emitted from combustion sources, so-called secondary $PM_{2.5}$ particles, are formed in complex reactions from gaseous emissions of SO_2, NO_x and ammonia (which is largely from agricultural sources). They are present in greater concentrations than directly emitted primary $PM_{2.5}$ particles (such as from wood smoke or diesel vehicle exhausts). Changes in these particle concentrations are subject to considerable non-linearities because of the chemical reactions in the atmosphere. It is not straightforward to attach blame to sources. The concentration change from removing 100 tonnes of one source is not twice the concentration change of removing 50 tonnes of that source, so comparison of emission reduction scenarios gets very complicated. However, an indication of the six most important emitter countries in terms of their effect on concentrations in the UK has been calculated

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by the EMEP model. In 2014 the major contributors to a reduction in $PM_{2.5}$ from a moderate reduction in national emissions are: UK 55 per cent, France 7 per cent, North Sea 5 per cent, Germany 7 per cent, Atlantic 4 per cent, Netherlands 3 per cent, other countries 17 per cent. Note the role of marine emissions, which are due to be regulated by the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78).

BACK TO URBAN AIR POLLUTION

Primary $PM_{2.5}$ particles are those directly emitted from motor vehicles and wood burning. The former has received much attention, but the latter continues and is encouraged to combat climate change, despite the absence of controls on wood-burning stoves apart from design to ensure efficient combustion. $PM_{2.5}$ emitted from wood-burning stoves within domestic properties is likely to have a four orders of magnitude larger effect (10,000) on the maximum local ground level of concentrations than large-scale power generation from biomass sources on an equivalent energy input basis[7]. Moreover, national $PM_{2.5}$ emissions from wood burning are uncertain, which is worrying in itself.

Taking a low emission rate, one can estimate the fraction F of the $PM_{2.5}$ concentration in London from wood burning with the formula:

$$F = 28qd^{0.413}$$

where q is the emission density in kilotonnes per square kilometre and d is the diameter of the urban area in kilometres. For London, $F = 0.15$; in other words, 15 per cent of the $PM_{2.5}$ arises from domestic wood smoke. The rest comes from motor vehicles, mainly diesels and secondary $PM_{2.5}$ from sources outside London. Given the efforts to control $PM_{2.5}$ emissions from diesel vehicles, it seems counterproductive to permit unabated wood burning, accepting that it is burnt efficiently in advanced combustion wood stoves. One concludes that increased wood burning may offset reductions from road transport emissions. Surely this is not the intention.

LARGE-SCALE WOOD BURNING TO COMBAT CLIMATE CHANGE

Drax power station, which supplies 7 per cent of the country's electricity, has been converted to wood burning because of concerns over CO_2 emissions. All coal-fired power stations will close by 2025, because of concerns over climate change and coal's higher, uncontrollable emissions of CO_2. Drax is supplied by sustainable wood pellet from North America. One need not be concerned about air pollution emissions from the stack, which are strictly controlled. However one might be concerned about questions of resource management and self-sufficiency. Each year, Drax needs sustainable forest equivalent to 5 per cent of the land area of the UK. This clearly could not be supplied by the UK. Have all the consequences to the world's natural resources been considered?

RISING PRIMARY NO_2 EMISSIONS

In recent years urban NO_2 concentrations have been of concern, because of their health effects and because EU limit values are exceeded in many towns in the UK. These limit values were meant to have been met in 2010. The NO_2 limit value itself was set nearly 25 years ago and one might speculate on the reasoning behind and the current validity of the chosen levels, when at the time health effects from NO_2 were not recognised and the first vehicle emission controls were just starting to be introduced.

It is fortunate that NO_x emissions are primarily in the form of NO, so that roadside exposure to NO_2 is much less than it would be if all the NO_x emitted was NO_2. In addition, although NO can be oxidised to NO_2 by ozone, the quantity of ozone in the atmosphere limits this oxidation, representing another form of non-linearity. In 2004 the Air Quality Expert Group[8] warned there was evidence for significant amounts of NO_2 being emitted directly from the tailpipe of diesel vehicles, much higher than previously thought. These emissions have a significant impact on roadside NO_2 concentrations in areas where there is considerable diesel vehicle activity. Note diesel engines are more efficient than petrol engines and therefore better for managing climate change, but three-way catalysts do not work on diesel engines.

Attention was not paid to this warning and a further report[9] on vehicle NO_2 trends reiterated the same concerns. Exhaust treatment systems fitted to diesel vehicles, which filter particulate matter from exhaust gases, can increase the amount of NO_2 emitted from diesel engines, as will the increased number of diesel cars on the road. Policy regarding diesel vehicles has played a part in the current difficulties regarding EU Directive limit values. An unintended consequence of neglecting emerging new evidence.

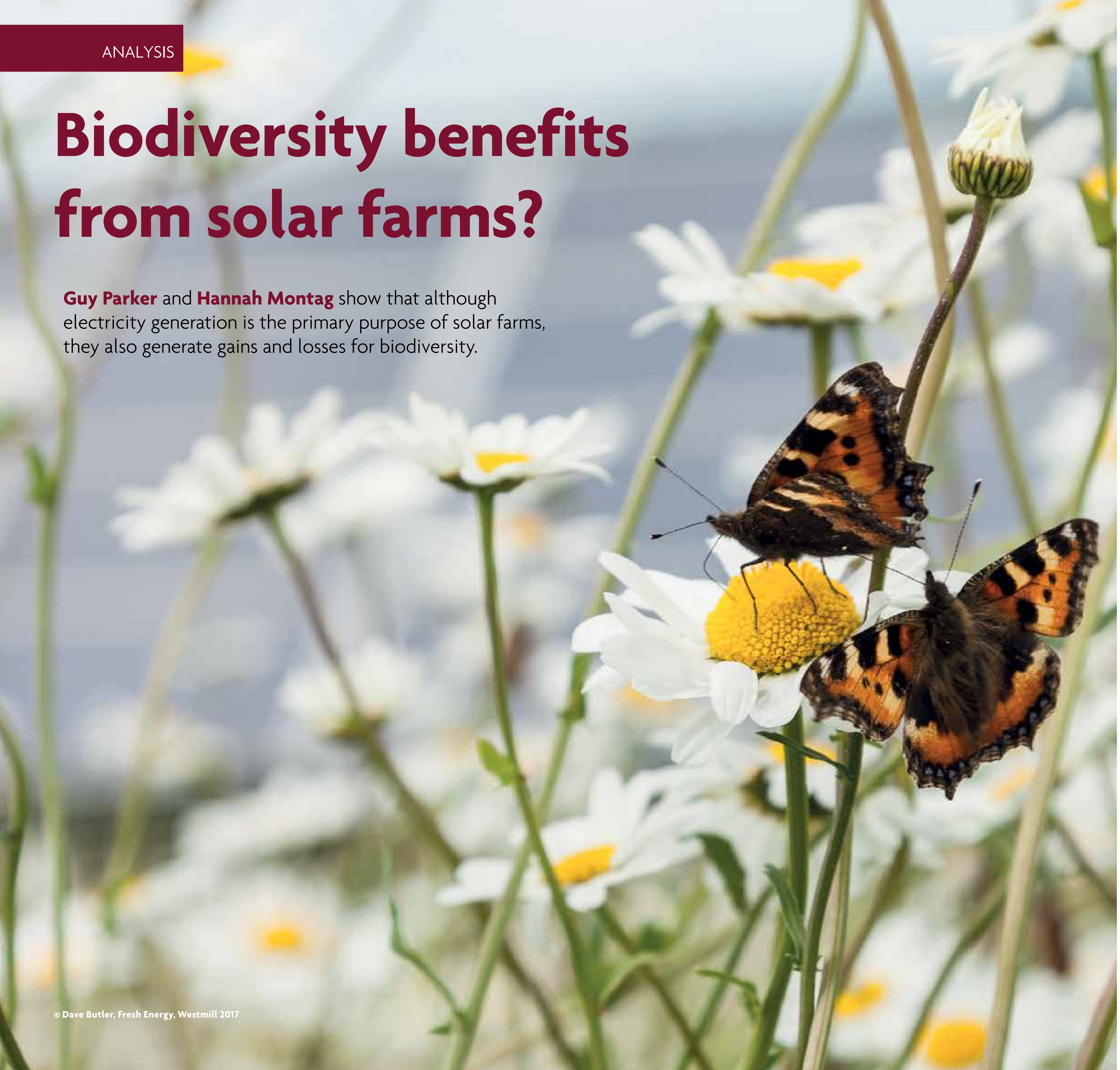
CLEAN AIR STRATEGY

The examples of wood burning and NO_2 pollution suggest that the consequences of policy decisions are not followed up promptly, even when evidence of ill effects becomes available. The Government is currently consulting on its draft Clean Air Strategy[10], published on 22 May 2018, in which the problems of wood burning and NO_2 pollution are addressed. However, a carefully considered strategy decision taking account of policy decisions over local, regional and global scales is preferable than having to reverse previous policy decisions. ES

Bernard Fisher researched acid rain at the Central Electricity Generating Board from 1971. After the privatisation of the power industry he became Professor of Environmental Modelling at the University of Greenwich. From 1990 he worked at the Environment Agency on advanced pollution models until his retirement, and remains a visiting professor at the University of Hertfordshire.

REFERENCES

1. Rothschild, R. (2015) A Poisonous Sky: Scientific Research and International Diplomacy on Acid Rain (PhD thesis, Yale University).
2. Fisher, B.E.A. (1986) The effects of tall stacks on the long-range transport of air pollutants. J *Air Pollution Control Association*, 36, pp.399–401.
3. List of publications available from the Meteorological Synthesizing Centre-West. ‹www.emep.int/mscw/mscw_publications.html›
4. CMAQ: The Community Multiscale Air Quality Modeling System. ‹www.epa.gov/cmaq›
5. Gauss, M., Nyíri, Á., Benedictow, A. and Klein, H. (2016) *Transboundary air pollution by main pollutants (S, N, O_3) and PM: The United Kingdom*. EMEP. ‹emep.int/publ/reports/2016/Country_Reports/report_GB.pdf›
6. de Wit, H.A. Hettelingh, J.-P.l. and Harmens, H. (2015) *Trends in ecosystem and health responses to long-range transported atmospheric pollutants*. 6946-2015. ‹www.unece.org/fileadmin/DAM/env/documents/2016/AIR/Publications/Trends_in_ecosystem_and_health_responses_to_long-range_transported_atmospheric_pollutants.pdf›
7. AQEG (2017) *The Potential Air Quality Impacts from Biomass Combustion*. ‹uk-air.defra.gov.uk/assets/documents/reports/cat11/1708081027_170807_AQEG_Biomass_report.pdf›
8. AQEG (2004) *Nitrogen Dioxide in the United Kingdom*. PB 9025. ‹uk-air.defra.gov.uk/assets/documents/reports/aqeg/nd-contents-chapter1.pdf›
9. AQEG (2007) *Trends in Primary Nitrogen Dioxide in the UK*. PB 12779. ‹uk-air.defra.gov.uk/assets/documents/reports/aqeg/primary-no-trends.pdf›
10. Defra (2018) *Air quality: draft Clean Air Strategy 2018*. ‹consult.defra.gov.uk/environmental-quality/clean-air-strategy-consultation›



Biodiversity benefits from solar farms?

Guy Parker and **Hannah Montag** show that although electricity generation is the primary purpose of solar farms, they also generate gains and losses for biodiversity.

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ANALYSIS

The push towards greener energy and the introduction of government subsidies in 2010 has resulted in the creation of more than 750 large-scale (>5 MW) operational solar farms across the UK. This equates to approximately 14,500 hectares of land under photovoltaic (PV) panels. Strictly speaking, since the purpose of solar farms is to generate electricity, any positive or negative impacts from them are unintended consequences. However, the UK solar industry has been encouraged to develop solar farms with ecological benefits in mind and national policy also states that development should seek to increase biodiversity[1]. Accordingly, guidance has been developed by the industry, in collaboration with conservation organisations, that outlines ways in which solar farms can be managed to benefit wildlife[2], although individual planning conditions and the corporate standards of solar companies have led to great variety in approaches.

WHAT OPPORTUNITIES DOES A SOLAR FARM OFFER?

There are several innate, unintended benefits that result from the construction of a solar farm. First, the intensity of land management is usually less than on equivalent farmland. Solar farms are typically sited on land under arable rotation or intensive pasture, which is then converted to permanent grassland following the installation of the solar array. From this point, farming operations such as ploughing, reseeding and fertiliser or pesticide application are greatly reduced, or indeed, cease completely. Intensive agriculture has been identified as a major driver of biodiversity decline in the UK[3], and therefore reducing these pressures is likely to benefit a range of species.

A solar farm is a fenced, secure site, which means there is very little disturbance from humans throughout its lifetime. Outside the security fencing a wide field margin is generally left unmanaged, thereby creating an important transitional habitat between the grassland and the field boundary, a habitat that is often lost in intensively managed farmland. Furthermore, there are often large areas of a solar farm that are not built on for reasons such as underground pipelines or overhead power lines, and these areas are often managed differently from the rest of the site. These areas may be fenced off and not subject to cutting, creating swathes of unmanaged, open habitat.

Other effects of this novel environment are currently unclear, but it is likely to exert an influence upon the patterns of plant and animal diversity. The physical presence of solar panels creates different microclimates, with the land directly beneath the panels being limited in the sunlight and rain it receives. The strip of land at the leading (lower) edge of the panel will experience higher levels of rainfall through runoff from the panel, whereas the area beneath the panel will be drier. The panel rows themselves lead to a variable regime of shading across the site, depending upon the time of day and time of year, with more shade beneath the panels and less between the rows. Does this shading mimic a woodland habitat? How do the species on a solar site differ from those found on the previously agricultural land? Do we find an increase or decrease in plants and animals on solar sites? These questions must be explored through further research.

SPECIES AND HABITAT ENHANCEMENTS

There are many measures that can be included in a solar development to enhance the site for wildlife. The degree to which biodiversity enhancement has been incorporated into a solar farm is usually a result of the planning process, company policy, the location of the site, public pressure, local planning policy or the agricultural grade of the land being used. Where solar farms may be contentious in terms of landscape impacts, this might be balanced by an increased focus on wildlife gains. Options for enhancing biodiversity on solar farms borrow heavily from agri-environment schemes and include:

- Wildflower meadows
- Tussocky grassland
- Ponds and scrapes
- Hedgerows, scrub and woodland
- Habitat boxes (for bats, birds and invertebrates)
- Log piles and hibernacula

Recent research has shown that solar farms that have a management regime favourable to biodiversity can yield benefits for a variety of species[4].

WHICH SPECIES MIGHT BENEFIT?

Unsurprisingly, solar farms can increase the botanical diversity of a site when they are constructed on previously arable land, as they replace a monoculture crop with grassland that usually contains at least five to six species. However, they can also offer a higher diversity of plants when sited on pasture sites. This is likely due to the reduction of agricultural inputs and intensity of grazing, the cessation of ploughing or disturbance, and the provision of a more heterogeneous environment (varying microclimates beneath and between panels, unmanaged areas or areas that are managed in different ways). Where a solar site is sown with a wildflower seed mix, it can provide a species-rich habitat that is considerably more diverse than the agricultural habitat it replaces. Wildflower meadows are hugely important habitats; since the 1940s the UK has lost more than 97 per cent of its meadows and there have been dramatic declines in the species that rely on them. There exist very few opportunities to provide and manage this habitat, due to the pressure for agricultural land within the UK, but solar farms are unique in that they provide a 'crop' for harvest (electricity), whilst leaving the land area relatively untouched for other uses.

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The increase in floral diversity and establishment of permanent grassland in turn benefits other species. Research has shown that butterfly and bumblebee numbers are significantly higher on solar farms compared to the surrounding farmland, and where the site is managed as a wildflower meadow, still more species are found. A solar farm can also offer a year-round resource for invertebrates, in contrast to agricultural monocultures, where the flowering season tends to be short lived (with rapeseed or clover ley, for example). The same research[4] shows that solar farms can also support a greater diversity of birds than similar agricultural land, with a higher abundance of species of conservation concern. This has implications for bird conservation, particularly for species that are being affected by changes in farming practices. Other studies have similarly shown that solar farms can support a variety of bird species[5].

POSSIBLE DETRIMENTAL IMPACTS

There have been concerns regarding the detrimental impact of solar farms on wildlife, in particular on birds, although no detailed research on this issue has been completed in the UK. It is generally accepted that the installation of ground-mounted solar panels will displace ground-nesting birds such as skylarks and lapwings (both Red-Listed Birds of Conservation Concern), as they rely on far-ranging, unbroken sightlines associated with their nesting sites. Research has shown that skylarks do use solar farms for foraging and singing, although nesting within an array has not been confirmed and it seems likely that any breeding activity would be confined to wide field margins or adjacent land[4]. It is possible that the increase in foraging opportunities within a solar farm may boost productivity, even if potential nesting sites are lost, so the overall impacts on ground-nesting birds remains unclear. The idea that solar panels may pose a collision risk for birds has also been put forward but there is very little research to support this[5,6].

The polarised surface of solar panels can attract species seeking water, such as insects looking for a water surface on which to lay eggs[7]. This can result in reproductive failure and thus can have detrimental impacts on certain species, although more research is required to fully understand these. It has also been shown that bats can confuse smooth surfaces for water and there are cases of bats colliding with such surfaces due to an inability to detect them using echolocation[8]. Research[4] indicates that lower numbers of bats may be found within solar farm environments than adjoining land, although this result was not statistically significant and may have been a product of the survey methodology. Again, more research is needed.

▲ **Figure 1. The distribution of operational solar farms (>5MW) in the UK. (© March 2018 Renewable Energy Planning Database: Department of Business, Energy & Industrial Strategy)**

THE FUTURE FOR WILDLIFE ON SOLAR FARMS

Recent research[4] shows that solar farms have the potential to offer wide-ranging benefits for wildlife where management is conservation focused and especially where new wildlife habitats are created.

Solar farms that are managed for biodiversity are likely to deliver broader benefits to society. These natural values are often termed ecosystem services and include pollination, water cycling and erosion control. A solar farm with a permanent wildflower meadow within a landscape of intensive agriculture should act as a reserve for invertebrates, increasing their numbers and helping with the pollination of surrounding crops and, possibly, pest control.

However, while solar farms have the potential to deliver on biodiversity, the reality of the situation often does not reflect this. Even where the planning process has secured an ecologically driven management plan for a site, there are few mechanisms to ensure that this management plan is followed. So what has potential to benefit our declining biodiversity often remains unrealised.

Nevertheless, a number of successful partnerships have developed between conservation bodies and solar asset managers, including the RSPB and Anesco, who are working to provide habitat for skylarks, turtle doves and tree sparrows, and Wychwood Biodiversity and NextEnergy, who are rolling out a programme of grassland habitat creation on a number of solar sites.

These partnerships, while encouraging, are currently limited in scale. To maximise the benefits of the solar sector for biodiversity, there is a need for policy-driven incentives for wildlife management on solar farms, with the post-Brexit agri-environment subsidy offering a great opportunity. Further, innovative new businesses such as Wild Power aim to supply renewable electricity and biodiversity gains to customers for a small premium, which is then invested in biodiversity on solar farms. This financial model is scalable and could incentivise the sector into biodiversity management at the national scale.

Looking forward, it is important that we improve our understanding of the impact that solar farms have on our native and declining flora and fauna, and the opportunities they present to protect them. Post-subsidy it is becoming apparent that new schemes may be larger in size in order to benefit from economies of scale, thus presenting more significant opportunities for losses or gains. We need a firmer evidence base to fully understand the impact that this relatively new technology has on our wildlife and we need to implement mechanisms to guarantee that sites are constructed and managed to optimise ecological benefits. This will ensure that this great opportunity to boost our currently declining ecosystems is achieved. **ES**

Guy Parker is an ecologist and director of Wychwood Biodiversity. He has been working with the solar industry for the past 8 years on managing solar farms for biodiversity gain.

Hannah Montag is an ecological consultant at Clarkson and Woods and specialises in solar energy projects; encompassing both ecological impact assessment and management plan design and implementation.

REFERENCES

1. Ministry of Housing, Communities and Local Government (2012) National Planning Policy Framework. ‹www.gov.uk/guidance/national-planning-policy-framework›
2. BRE (2014) Biodiversity Guidance for Solar Developments. Eds Parker, G.E. and Greene, L.
3. Hayhow, D.B., Burns, F., Eaton, M.A., Al Fulaij, N., August, T.A., Babey, L., Bacon, L., Bingham, C., Boswell, J., Boughey, K.L., Brereton, T., Brookman, E., Brooks, D.R., Bullock, D.J., Burke, O., Collis, M., Corbet, L., Cornish, N., De Massimi, S., Densham, J., Dunn, E., Elliott, S., Gent, T., Godber, J., Hamilton, S., Havery, S., Hawkins, S., Henney, J., Holmes, K., Hutchinson, N., Isaac, N.J.B., Johns, D., Macadam, C.R., Mathews, F., Nicolet, P., Noble, D.G., Outhwaite, C.L., Powney, G.D., Richardson, P., Roy, D.B., Sims, D., Smart, S., Stevenson, K., Stroud, R.A., Walker, K.J., Webb, J.R., Webb, T.J., Wynde, R. and Gregory, R.D. (2016) *State of Nature 2016*. The State of Nature partnership.
4. Montag, H., Parker, G, and Clarkson, T. (2016) The Effects of Solar Farms on Local Biodiversity: A Comparative Study. Clarkson & Woods and Wychwood Biodiversity.
5. Feltwell, J. (2013) Are photovoltaic solar arrays an influencing factor in avian mortality? *The Newsletter of the Kent Field Club*, 77, pp.18–27.
6. Harrison, C., Lloyd H. and Field, C. (2017) Evidence review of the impact of solar farms on birds, bats and general ecology (NEER012). Natural England.
7. Horváth, G. Blahó, M., Egri, A, Kriska, G, Seres, I. and Robertson, B. (2010) Reducing the maladaptive attractiveness of solar panels to polarotactic insects. *Conservation Biology*, 24 (6) pp.1644–1653.
8. Greif, S., Zsebők, S., Schmieder, D. and Siemers, B.M. (2017) Acoustic mirrors as sensory traps for bats. *Science*, 357 (6355), pp.1045–1047.

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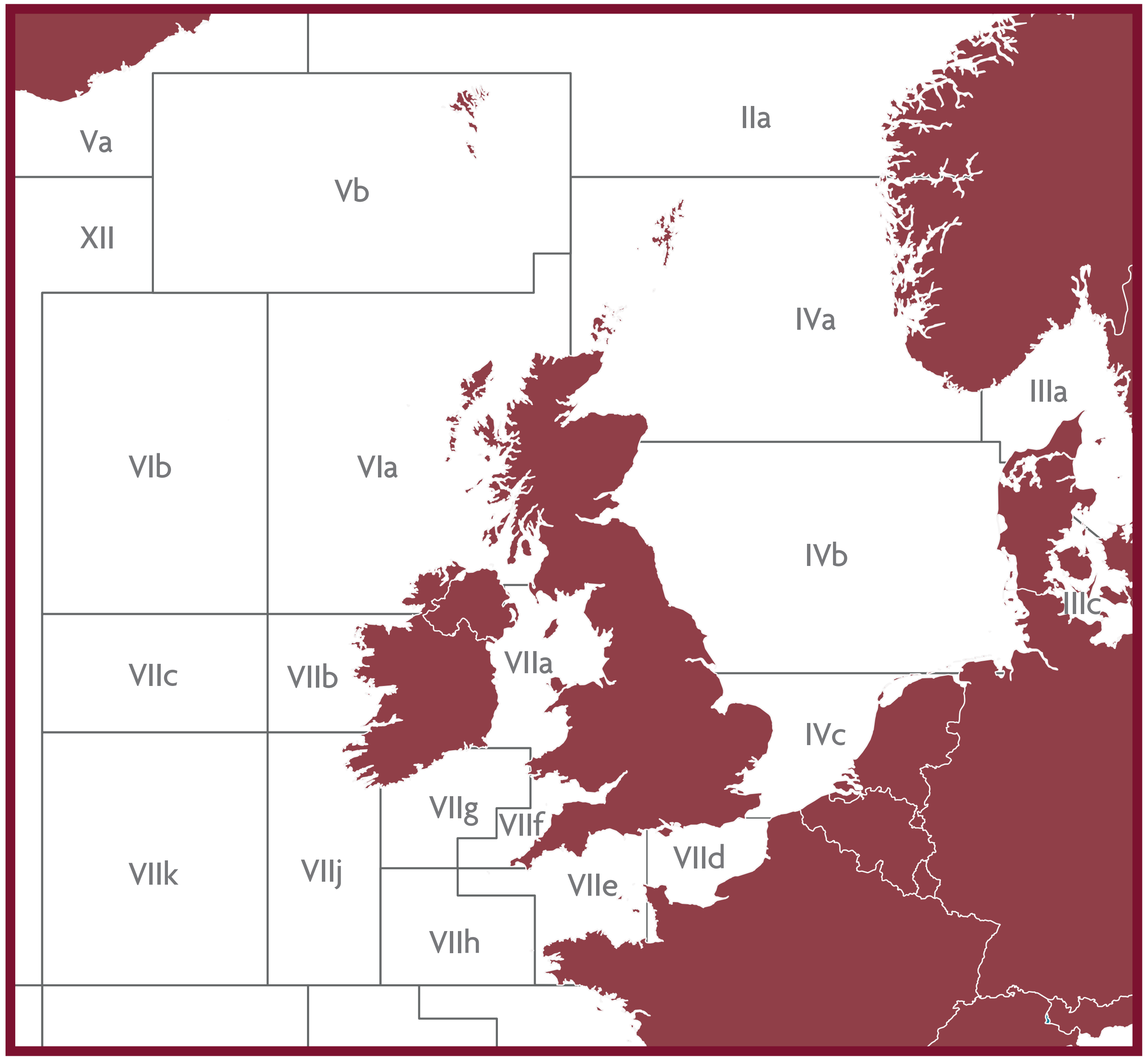
UK fishing quotas and unintended environmental consequences

Chris Williams shows that progress on limiting the catch sizes of some species has been undermined by other species being overfished.

European, and therefore UK, fishing quotas are successfully limiting fishing pressure on key quota stocks[1]. However, fishing quotas have also had the unintended consequence of shifting fishing effort towards non-quota species: as a result of excluding small-scale fishers from the quota system, their effort has been redirected to non-quota species, which often do not have management plans (or other restrictions) and therefore many are overfished or remain unassessed. These issues have largely been overlooked, as the attention of managers, policymakers and politicians has mainly been focused on quota species.



▲ **Figure 1. International Council of the Sea (ICES) UK sea areas for EU TAC allocation. (Adapted from the European Commission Names of Sub-areas and Division of FAO fishing areas 27 and 37[3])**

SHARING THE FISH STOCKS

The shared access to European Union (EU) fishing waters and resources is governed by the Common Fisheries Policy (CFP). Total allowable catches (TACs) are the quantified fishing opportunities for each stock in each sea area (see **Figure 1**), and they were first introduced in the UK in 1974, with further species[2] added when the CFP began in 1983. TACs are agreed at the EU level, and fisheries ministers are provided with scientific advice from the International Council for the Exploration of the Sea (ICES) on which to base their negotiations to set them.

One of the main objectives of the CFP was to ensure the maximum sustainable yield was not exceeded (MSY; the largest amount that can be harvested without jeopardising the future of the stock) for all stocks by 2015 where possible, and by 2020 at the latest. In December 2016, 44 (of around 200) stocks were fished at MSY levels. Following the 2017 December Council, fish stocks managed at MSY levels will increase to 53 stocks in 2018[4]. While progress has been slow, there is no doubt, especially for the North East Atlantic stocks (as shown in **Figure 2**), that quotas are reducing fishing pressure and increasing fish biomass.

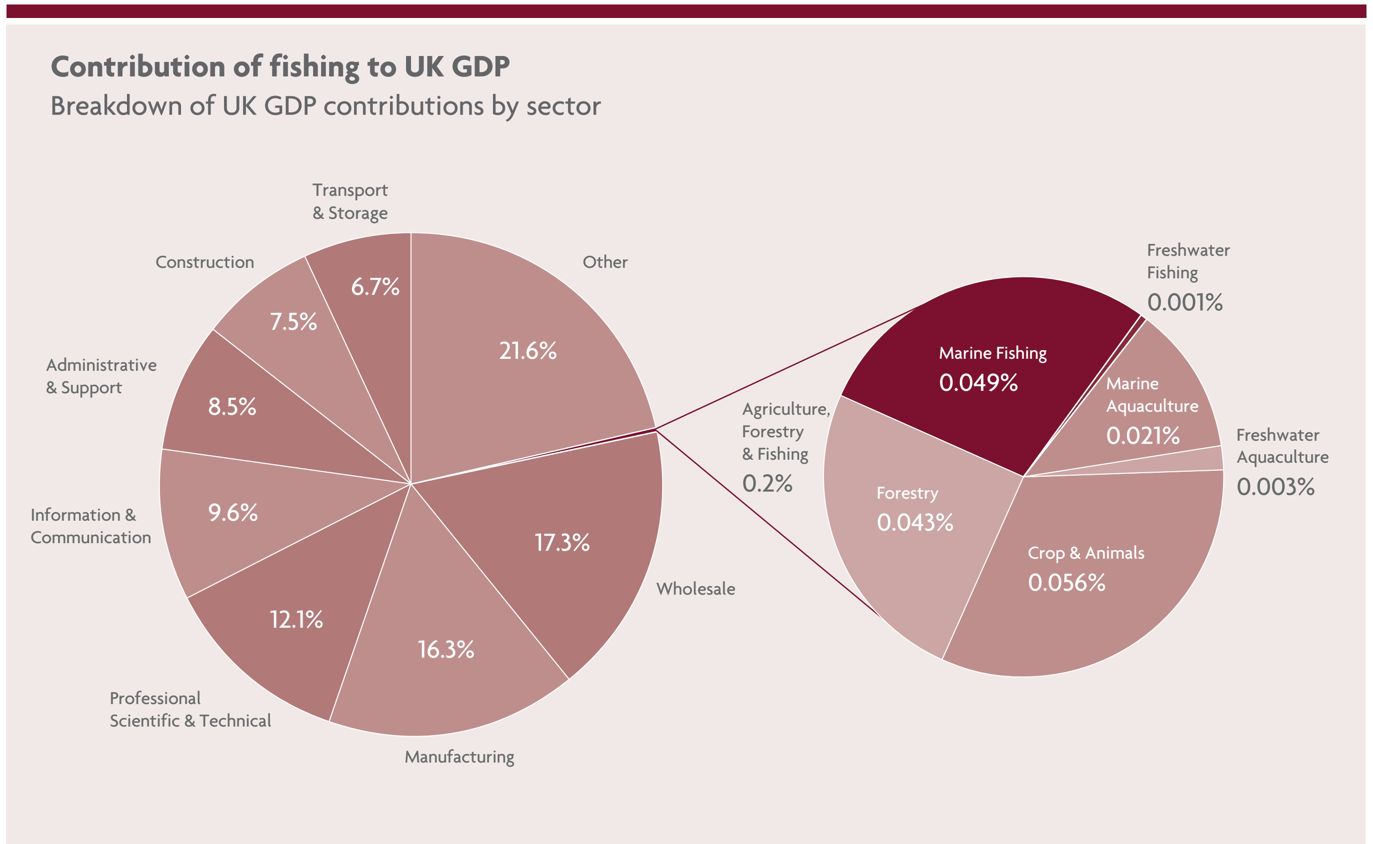
▲ **Figure 2. The impact of the EU quota system on fishing pressure and fish stock biomass for 85 major commercial fish species in the North East Atlantic. Data is scaled to the mean, ie. if the y-axis value is 1 in a given year then this year's value is equal to the mean over the time series; if it is 0.5 it is half the mean value; etc. (Source: Review of the 2014 ICES' advice[5])**

SHARING OUT THE QUOTA IN THE UK

Each member state receives a set amount of the TAC, which is their quota. These quotas are agreed every year at the December Council (at which the fisheries ministers of each member state meet to agree quotas for the year ahead). The quota is divided between member states following the principle of 'relative stability' which keeps the percentage entitlement the same year on year[6], which each member state then distributes to its own national fishing businesses using its own domestic laws[7]. In the UK the quota is mainly allocated to the fishing industry's 24 producer organisations (POs) known as 'the sector'. The UK fishing industry is divided between members of the POs and non-members. There are two kind of non-member: the 'under 10s' (small coastal boats that are less than 10 m in length, also called the 'inshore fleet') and non-sector vessels (those that are more than 10 m in length but not PO members, who generally do not fish for quota species)[8].

The allocation of the UK quota (as fixed quota allocations – FQAs) since 1999 has developed in a way that means the majority of working fishers in the UK, who are not PO members, have little access to the quota and face high costs to lease quota for the species they catch in mixed inshore fisheries (where the variety of species caught is greater than offshore, which tends to have larger shoals of single species). This impacts the number of active fishers as well as recruitment into the industry[9,10]. The allocation of quota was originally based on vessel track records, which were attached to a vessel's previous landings; because under 10s did not have to retain these records and therefore had no evidence upon which to base a historic track record, they were excluded from quota allocations. Once these fishing rights were obtained by the POs they could trade them, thus creating an informal market[7].

This transferability has further implications for the concentration of fishing rights, and rights being held by companies or individuals based outside the UK, which are now coming to the fore in the Brexit debate. The inshore fleet currently fish from a shared pool of quota, administered by the UK Government's Marine Management Organisation (MMO), giving them access to 2–4 per cent of the total UK FQAs[11]. As an example, the concentration of fishing rights for the large-scale fleet had reached such an extent that by 2015, 98.55 per cent of all the UK quota was allocated to the 814 over-10-m vessels in POs, which represent only about 15 per cent of the total fleet. This left 85 per cent of the fleet, nearly 5,000 vessels, to share the remaining 1.45 per cent, which



▲ **Figure 3. Breakdown of UK GDP showing proportional contribution of fishing. (Source: Fishing and the UK GDP[15])**

they have access to through the pool. Furthermore, until 2014, when an FQA register was finally published, there was no official or public record of quota holdings in the UK, hampering attempts to see who the ultimate beneficiaries of UK quota were.

The theory of why tradable quotas are used in fisheries management relates mainly to the economic concept of efficiency. A rights-based management (RBM) or quota system that is designed with only this theoretical concept in mind may have negative social consequences and is not in itself a conservation tool, nor in many cases is it even efficient[12,13]. The result of the FQA system for the UK fishing industry has also been called the legal squatting of access to the public fishery by quota holders[14].

INSHORE FISHERIES AND COASTAL ECONOMIES

While the fishing industry is a relatively small sector of the economy (0.05 per cent of GDP, as shown in **Figure 3**), its indirect economic contribution is much greater through the supply chain, with this impact focused in coastal communities. Many of these are highly dependent on the fishing sector to support local economic activity. There are also harder-to-measure impacts from having a fishing presence in coastal communities – from attracting tourists to providing a sense of identity to the people living there. It is also important to note that the distribution of the fishing fleet across coastal communities is highly uneven.

Despite little quota, under 10s are the primary source of landings for half of the coastal communities[16], and small-scale fishers in England in particular have diversified into targeting non-quota species, including shellfish species such as crab, lobster, whelk and cuttlefish along with finfish species such as sea bass[17]. The percentage of shellfish caught by the small-scale fleet increased from around 6 per cent in 2000 to 30 per cent by 2016[18]. Quota shortages appear to be an important factor, but other factors such as EU and global export markets and high prices have likely contributed as well (this is certainly true for the booming whelk market in South Korea, for instance)[19].

ASSESSING INSHORE FISHERIES

Up until recently there was no way of knowing what impact the inshore fleet was having on the species it had diversified into. However, Project Inshore[20] was a ground-breaking partnership that assessed many of the stocks being fished by the inshore fleet and rated them against the Marine Stewardship Council (MSC) sustainability criteria[21]. As shown in **Figure 4**, the reports revealed that many key stocks fished by inshore vessels in England were overexploited, while others lacked assessment or sufficient data to make that assessment. This led to fisheries regulators bringing in byelaws to combat the declines or improve data.

According to Project Inshore assessments in 2014, the vast majority of the 15 highest-value fisheries that under 10s vessels are engaged in in England (see **Figure 4**) would face challenges towards achieving MSC certification. Only cod and sole would be recommended for certification by Project Inshore.

In the case of sea bass in particular, the exclusion of small-scale vessels from the quota system (and the viable economic opportunity from plentiful sea bass stocks and good markets at the time) meant that this fishery became the fishery of choice for many on the South Coast. In particular, high-capacity 'super under 10s' (under 10s with a higher fishing capacity than traditional under 10s) using drift nets began fishing there in the mid-1990s, which coincides with the start of the rapid decline in the stock

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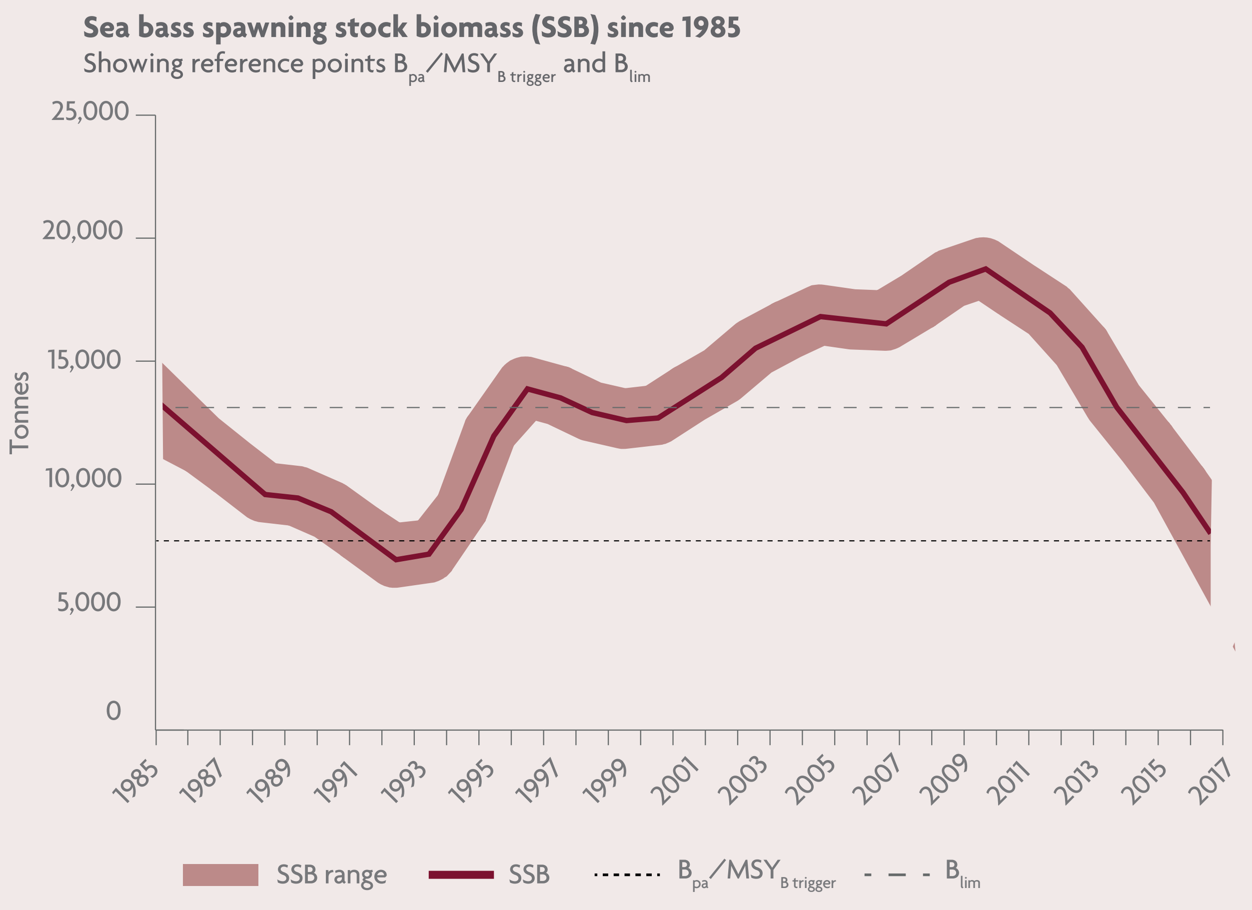
▲ **Figure 4. Proportion recommended (green), likely to be facing conditions (yellow) and significant challenges (red) to full MSC certification, based on the Project Inshore database (2014). (Source: Does size matter? Assessing the use of length-based fisheries management in England[22])**



▲ **Figure 5. Detail of sea bass spawning stock biomass (SSB) decline in recent years, in part as a result of increased fishing pressure by English under 10s showing the precautionary reference point for SSB (B_{pa}) and biomass reference point triggering a cautious response ($MSY_{B\ trigger}$), as well as the limit reference point for SSB (B_{lim}). (Source: Who gets to fish for sea bass?[23])**

(see **Figure 5**). (A large-scale French offshore fishery had the main impact on the stock, but the under-10 English drift-net fishery was the second most significant in scale.)

While the overall purpose of introducing quotas was to limit fish mortality and thereby increase sustainability, adopting an approach to UK allocation that was akin to privatisation left the majority of the fishing fleet without access to that common resource, which in turn led to the overexploitation of non-quota species. This situation has demonstrated that there are risks that are often not considered when policy is adopted, especially in the haphazard and legally dubious manner in which the FQA system came about in the UK. Although more an accident of history than a deliberate plan, it is a useful reminder that natural resource management and regulation requires more focus on the bigger picture than is provided by developing a rights-based approach to the resource and assuming this will resolve current and future sustainability issues. Equity impacts sustainability, and following the departure from the CFP in 2020 the UK Government urgently needs to address these issues if fishing communities and the marine resources they rely on are to have a viable future. **ES**

Chris Williams joined the New Economics Foundation (NEF) in 2011 as the Marine Socio-economics Coordinator, building marine conservation NGO capacity around socio-economics. Since 2015 Chris has been working on fisheries management problems and coastal community economic development issues. He holds a BSc in Biology (and North American History and Politics) from the University of Sussex and a Masters degree from Kings College London in Environment and Development (with Spanish).

ANALYSIS

REFERENCES

1. European Commission (2017) Council agreement on 2018 fishing quotas in the Atlantic and North Sea. ‹www.consilium.europa.eu/en/press/press-releases/2017/12/13/council-agreement-on-2018-fishing-quotas-in-the-atlantic-and-north-sea/› [Accessed: 2nd July 2018]
2. European Commission (2015) Fishing TACs and Quotas ‹ec.europa.eu/fisheries/sites/fisheries/files/docs/body/poster_tac2015_en.pdf›
3. European Commission (2014) Names of Sub-areas and Division of FAO fishing areas 27 and 37. ‹ec.europa.eu/fisheries/sites/fisheries/files/docs/body/fishing_areas_en.pdf›
4. European Commission (2017) Council agreement on 2018 fishing quotas in the Atlantic and North Sea. ‹www.consilium.europa.eu/en/press/press-releases/2017/12/13/council-agreement-on-2018-fishing-quotas-in-the-atlantic-and-north-sea/› [Accessed: 2nd July 2018]
5. O'Brien, C. (2016) Review of the 2014 ICES' advice. Cefas ‹www.seafish.org/media/1327189/clg_nov2014_cefas_stockstatus2.pdf›
6. European Commission Fishing quotas. ‹ec.europa.eu/fisheries/cfp/fishing_rules/tacs/index_en.htm› [Accessed 2nd May 2018]
7. Appleby, T., Cardwell, E. and Pettipher, J. (2018) Fishing rights, property rights, human rights: the problem of legal lock-in in UK fisheries. *Elem Sci Anth*, 6: 40. Available at: ‹www.elementascience.org/articles/10.1525/elementa.295/›
8. Williams. C. (2014) MSEP Facts and figures on capture fisheries. Marine Socio-Economics Project/New Economics Foundation (NEF). Available at: ‹www.mseproject.net/capture-fisheries›
9. Defra/MMO (2016) Allocation of additional quota in England. ‹www.gov.uk/government/publications/allocation-of-additional-quota-in-england/allocation-of-additional-quota-in-england› [Accessed: 2nd July 2018]
10. MMO (2014) Fixed quota allocation units. ‹www.gov.uk/government/publications/fixed-quota-allocation-units› [Accessed: 2nd July 2018]
11. Defra (2015) Current catch limits: 10 metres and under pool. ‹www.gov.uk/government/publications/current-catch-limits-10-metres-and-under-pool› [Accessed: 2nd July 2018]
12. Cardwell, E. (2015) Power and Performativity in the Creation of the UK Fishing-Rights Market. *Journal of Cultural Economy*, 8 (6), pp.705–720. ‹www.tandfonline.com/doi/abs/10.1080/17530350.2015.1050441›
13. Bromley, D.W. (2009) Abdicating Responsibility: The Deceits of *Fisheries* Policy. Fisheries, 34 (6), pp.280–302.
14. Appleby, T., van der Werf, Y. and Williams, C. (2016) *The management of the UK's public fishery: A large squatting claim?* Working Paper. University of the West of England. Available from: ‹eprints.uwe.ac.uk/28855›
15. Williams, C. (2012) Fishing and UK GDP. Marine Socio-Economics Project/New Economics Foundation (NEF) Available from: ‹www.mseproject.net/capture-fisheries›
16. New Economics Foundation calculations; Marine Management Organisation – UK Sea Fisheries Annual Statistics (2014). ‹www.gov.uk/government/collections/uk-sea-fisheries-annual-statistics› [Accessed: 2nd July 2018]
17. Association of Inshore Fisheries and Conservation Authorities (2013) New Whelk Byelaw embodies the IFCA vision ‹www.association-ifca.org.uk/Upload/K%20and%20E%20IFCA%20Whelk%20story%20.pdf›
18. Mason, C. (undated) Defra Shellfish Policy Presentation. ‹www.shellfish.org.uk/files/PDF/17003Mason.pdf›
19. Bannister, C. (2006) Towards a national development strategy for shellfish in England: Executive Report. Sea Fish Industry Authority, Grimsby, UK. ‹www.shellfish.org.uk/files/Literature/Projects-Reports/0605-National-Shellfish-Strategy-Bannister.pdf›
20. Seafish. About the project ‹www.seafish.org/industry-support/fishing/project-inshore/about-the-project› [Accessed: 2nd May 2018]
21. Marine Stewardship Council (MSC) ‹www.msc.org/about-us/standards/fisheries-standard/msc-environmental-standard-for-sustainable-fishing› [Accessed: 2nd May 2018]
22. Davies, P., Williams, C., Carpenter, G and Beukers-Stewart, B. (2018) Does size matter? Assessing the use of length-based fisheries management in England. *Marine Policy* (Accepted).
23. Williams, C., Carpenter, G., Clarke, R. and O'Leary, B.C. (2018) Who gets to fish for sea bass? Using social, economic, and environmental criteria to determine access to the English sea bass fishery. *Marine Policy*, doi.org/10.1016/j.marpol.2018.02.011

A perfect storm: The 1980s farming crisis of the American midwest

Joseph Martin dives into the environmental impacts of the crisis and asks what is to be learnt from the mistakes of the past.

ANALYSIS

"For the true measure of agriculture is not the sophistication of its equipment, the size of its income or even the statistics of its productivity but the good health of the land."

Wendell Berry, *The Unsettling of America: Culture and Agriculture*[1]

Rural America in the early 1980s changed forever. The boom in agriculture of the 1970s was most definitely over and farmers in the midwestern states of Iowa, Kansas and Indiana were left to sell up or survive the harsh realities of modern agriculture in the 1980s. This left rural America facing economic ruin, but there were other effects that went largely ignored, such as the environmental impact of large-scale agricultural production. The farming crisis of the 1980s was something that was unexpected and its after-effects would have far-reaching consequences and some unexpected outcomes.

A DUST BOWL REBORN

After the Second World War, agriculture in the United States of America (USA) soared. Technical innovation in the form of larger, more powerful machines started to do the work that once was done by local farm labourers. The boom in the 1950s and 1960s was swiftly followed in the 1970s by an extremely favourable economic agricultural climate for rural America. The increase in wealth also meant a decrease in the subsistence, agrarian way of life – the lifeblood of American rural farming communities. Agribusiness became the new model for agriculture in the midwest with signifcant consequences for the land. The land changed from making a living for families and communities to providing food for global corporations around the world. As a result, the overall ecosystem of each farm was neglected as the personal, cultural and environmental connection to the land was severed and mostly lost.

ANALYSIS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As the 1980s progressed, the banks started to call in loans and new farming families and those with large debts were in a serious economic tailspin. This meant eviction notices, and rural America was struggling to cope. Abandoned farms littered the landscape. Droughts in 1983 and 1988 only added to the ongoing crisis.

AGRICULTURAL OVERPRODUCTION & THE HIGH PLAINS AQUIFER

The origin of the rural collapse of the 1980s in the USA was sown in the push for large-scale unregulated agricultural production in the 1960s and 1970s. The problems were not only economic, but also environmental. One of the most prominent unseen problems was the drain on the key underground water resource of the midwest.

The High Plains Aquifer (also called the Ogallala Aquifer) underlies parts of eight states, stretching from South Dakota to Texas. In the 1980s, water levels had dropped by an average of nearly 3 m throughout the region. In some central and southern parts of the High Plains water level decreases exceeded 30 m. In some places farmers were owering water levels at about 1.5 m a year, while natural restoration was occuring at 1 cm per annum[2]. One of the main crops grown in the midwest, corn, requires more water than traditional crops such as wheat and barley:

"Corn is a really thirsty crop, so in parts of the country where we don't have ample rain, we're irrigating it, usually with groundwater, like from the aquifer that we have in the middle of the country called the High Plains Aquifer, which is a tremendous groundwater resource. It really is the lifeblood of states like Nebraska and Kansas."[3]

The other main threat to the aquifer in the 1980s was the use of fertilisers and pesticides throughout the midwestern states. According to a report by the United States Geological Survey in 2009, 90 per cent of samples taken from shallow groundwater in the Nebraska portions of the High Plains Aquifer contained nitrate from fertilisers. Pollutant levels within the aquifer had no doubt been growing for several decades in parallel with modern technological changes in farming practices. Chemicals trickle downward with each rainfall or application of irrigation water. The Geological Survey has warned that over the coming decades, contaminants will continue to leach down into the aquifer, and more wells will exceed federal safety levels. Already, 14 per cent of all High Plains Aquifer irrigation wells tested contained one pesticide or more. There is a dangerous effect on human health when crops are irrigated and the contaminants are ultimately ingested. The problem is that states such as Nebraska are corn-producing states that rely on federal subsidy payments to keep on producing more and more of this thirsty crop for cultivation[4].

Perhaps more worryingly, a recent study concluded that the High Plains and Central Valley aquifers exceed the uranium contamination guidelines set by the United States Environmental Protection Agency and endanger roughly two million people who live above or near these water sources. The most significant part of the research was not necessarily finding high levels of uranium in some places, "but rather the observation that nitrate can lead to contamination on a widespread level of naturally occurring uranium, this is the first instance of this"[5]. Also of concern is the recently approved Keystone XL Pipeline, which will be laid in close proximity to the High Plains Aquifer.

It is highly likely that the problems of the High Plains Aquifer began in the years after the Second World War and were driven by the agribusiness model in the American midwest that still exists today. As shown in **Figure 1**, levels of fertiliser use increased throughout the second half of the 20th century.

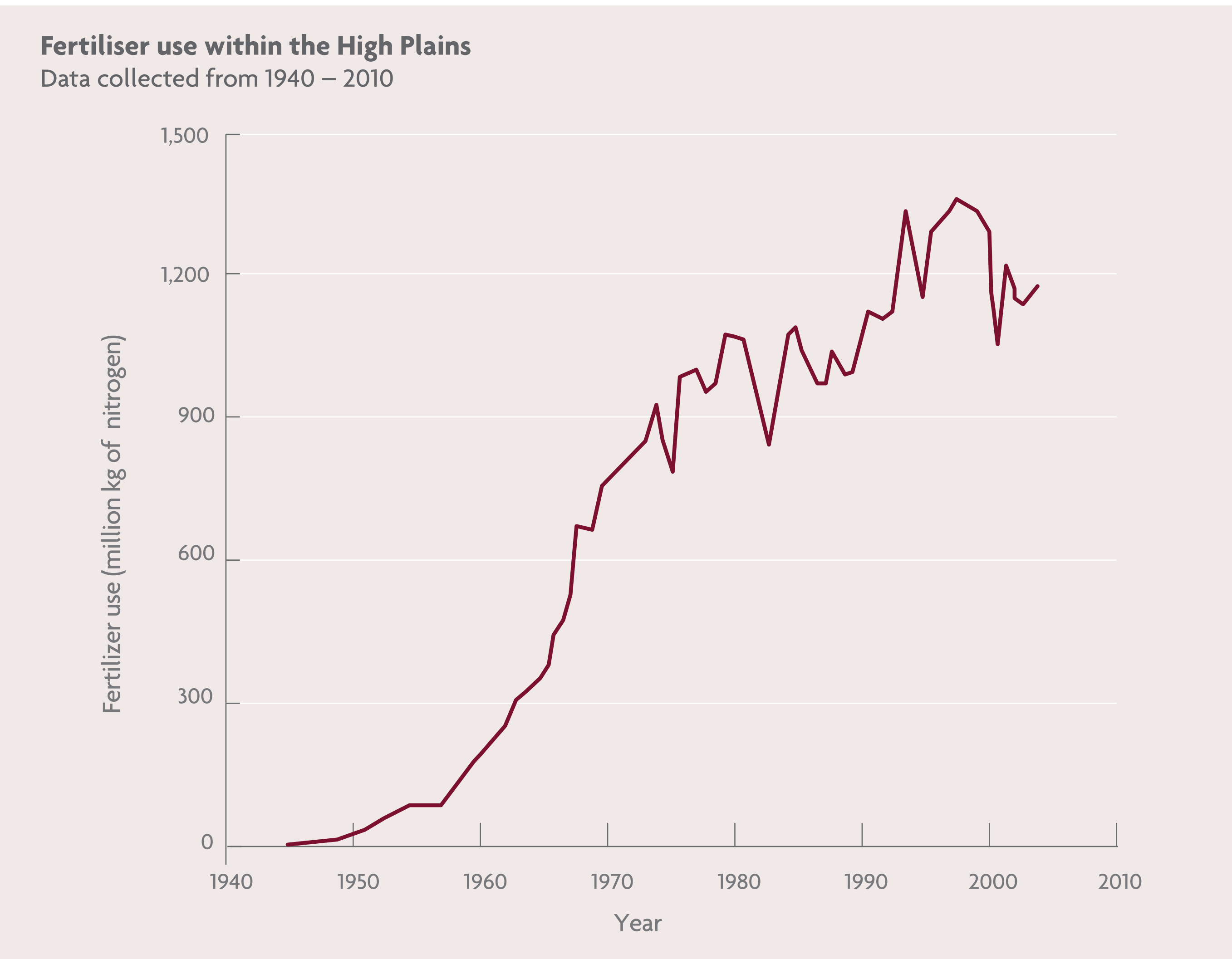
SOIL DEGRADATION AND BIODIVERSITY LOSS

One the main unforeseen impacts of the 1980s farming debt crisis was the pressure being put on the land to cope with international demand. The growth of agribusiness meant that super-farms were becoming normal for rural America as the 1970s came to a close.

"True agripower... generates agridollars through agricultural exports." (Assistant Secretary Richard E. Bell in Wendell Berry, *The Unsettling of America: Culture and Agriculture*[1])

Commercial farming had removed small-scale farmers and with them the sensibilities and attachment to the land, which large-scale commercialisation cannot replicate. As the banks called in their loans and farms went under, the land that was already devoid of organic nutrients after years of intensive production was now choked with weeds and had poorly structured irrigation systems. The banks owned the land but no one could afford to buy it or tend to it as they had previously done.

As the land quality degraded, so too did the levels of biodiversity. Large-scale farms in the midwest had already changed the ecological profile of the Great Plains beyond recognition before the 1980s farming



▲ **Figure 1. Fertiliser use within the High Plains 1940–2010. (© National Geographic 2016)**

crisis. Before European settlers arrived, the billion acres of grassland that blanketed the High Plains were home to pronghorn antelopes, swift foxes, lesser prairie chickens and burrowing owls as well as bison. Blue grama, green needle grass and other drought-resistant plants thrived in the short growing season. More than half these native grasslands have now been converted to crops, including nearly over 10 million hectares since 1982, according to a 2007 General Accounting Office study[2].

TALLGRASS PRAIRIE NATIONAL PRESERVE – SEEDS OF HOPE

One of the surprising aspects of the 1980s farming crisis was that innovative ecological ideas were still being planned and implemented throughout the midwest from the early 1980s onwards. One of the most successful projects was the Tallgrass Prairie National Preserve. The Tallgrass Prairie originally covered 57 million acres over portions of 14 states, and was one of North America's largest ecosystems. It exists now only in the Flint Hills of Oklahoma and Kansas. The Tallgrass Prairie Preserve was purchased in 1989 by the Nature Conservancy and consists of the 12,000 hectare Barnard Ranch, and approximately 3,500 more hectares[6]. Today you can find over 500 species of plant, nearly 150 species of bird, 39 species of reptile and amphibian, and 31 species of mammal.

The Nature Conservancy is also putting bison back on the prairie to restore its ecological role on select preserves in the Great Plains (see **Figure 2**). The research on bison–tallgrass prairie interaction is limited, but just as fire is now recognised as an essential component of tallgrass prairie management, the need to reintroduce grazing by large unregulated herbivores such as bison to this grassland is evident. The research suggests that the interaction of grazing and fire, operating in a shifting mosaic across the landscape, is key to conserving and restoring the biotic integrity of the remaining tracts of tallgrass prairie[7].

ANALYSIS

A MORE RESILIENT FARMING FUTURE

The 1980s farming crisis in the midwest remodelled the rural landscape as farming families abandoned their livelihoods, unable to survive and adapt to the prevailing wave of agribusiness and large-scale super-farms that began to dominate the midwest. Farmers are now more receptive and adaptive to new farming practices such as organic food production. Global manufacturing giants such as John Deere are funding the production of 'super seeds' that are drought resistant, low in cost and widely available. However, even in 2018 threats remain, such as those in the dairy sector, with their close-knit farming cooperatives where memberships are highly selective and farming families are once again being pushed to the periphery. The 1980s debt crisis showed that midwestern farming families must adapt to new technologies and more creative, diversified farming practices to ensure their continuing survival.

"The way of industrialism is the way of the machine... Industrialism prescribes an economy that is placeless and displacing. It does not distinguish one place from another. It applies its methods and technologies indiscriminately in the American East and the American West… But agrarianism begins with givens: land, plants, animals, weather, hunger, and the birthright of knowledge of agriculture… Agrarian farmers use responsibility and hand down intact an inheritance, both natural and cultural, from the past." (Wendell Berry, 'The Agrarian Standard' in *The World-Ending Fire*[8]). **ES**

Joseph Martin is a Chartered Environmentalist at AECOM in Belfast. He works primarily on environmental impact assessments, air quality monitoring and CEEQUAL assessments. Joseph also has a background in renewable energy technologies and has contributed to the environmental SCIENTIST since 2014.

▲ **Figure 2. Bison are returning to the Great American prairies. (© Markus Spiske 2017)**

REFERENCES

1. Berry, W. (1977, 2015) *The Unsettling of America: Culture and Agriculture.* Berkeley, CA: Counterpoint Press.
2. Braxton Little, J. (2009) The Ogallala Aquifer: Saving a Vital U.S. Water Source. *Scientific American.* ‹www.scientificamerican.com/article/the-ogallala-aquifer/›
3. Barton, B. (2014) The Environmental Risks of Corn Production. WBUR Radio ‹www.wbur.org/hereandnow/2014/06/11/corn-environmental-risks›
4. Blair, J. (2011) Running Dry on the Great Plains. New York Times, 11 November. ‹www.nytimes.com/2011/12/01/opinion/polluting-the-ogallala-aquifer.html›
5. Goard, A. (2018) Researchers say High Plains Aquifer Contaminated with Uranium, TTU Researchers Weigh In. Nexstar Broadcasting, Inc. ‹www.everythinglubbock.com/news/kamc-news/researchers-say-high-plains-aquifer-contaminated-with-uranium-ttu-researchers-weigh-in/208509028›
6. The Nature Conservancy (2018) Oklahoma. Joseph H. Williams Tallgrass Prairie Preserve. ‹www.nature.org/ourinitiatives/regions/northamerica/unitedstates/oklahoma/placesweprotect/tallgrass-prairie-preserve.xml› [Accessed 13th June 2018]
7. Knapp, A.K. Blair, J.M., Briggs, J.M., Collins, S.L., Hartnett, D.C., Johnson, L.C., and Towne, E.G. (1999) The Keystone Role of Bison in North American Tallgrass Prairie. *BioScience* 49 (1), pp.39–50.
8. Berry, W. (2018) 'The Agrarian Standard' in *The World-Ending Fire*, London: Penguin Books.

Alien versus predator: The grey squirrel and the pine marten

OPINION

Paddy Fowler talks to **Emma Sheehy** about the unintended consequences of a resurgence in pine marten numbers in Ireland and Scotland.

Emma Sheehy is an ecologist currently investigating the role of the European pine marten on red and grey squirrel population dynamics in Scotland and Ireland.

We spoke to Emma about her past and current research on the relationship and the history of pine martens and squirrels in Ireland and the UK, and how the results of her work could have impacts on future reintroductions and species recovery.

Could you give us a little background on both pine marten and squirrel populations in Ireland and the UK?

Historically pine martens were widespread in Ireland and the UK, but as a result of large-scale deforestation, by the turn of this century they had been reduced to a couple of relic populations in the north and north-west of Scotland and in the west and midlands of Ireland. They were functionally extinct in England and Wales and really rare if present at all in the rest of Ireland. Change only became apparent as they became protected by law in the 1970s in Ireland and 1980s in the UK, and as forest cover increased over the last few decades.

Red squirrels were also widespread throughout the UK and Ireland, and they suffered similarly from the widespread deforestation. It was also legal to hunt red squirrels as they were considered a pest because of their bark stripping. Another threat came from grey squirrels, first introduced into the UK roughly 150 years ago and into Ireland in 1911. For quite a long time it was anecdotal reports rather than scientific studies that indicated that grey squirrels had a detrimental impact on red squirrels. We now know that grey squirrels compete with reds both for space and food, and they also carry the squirrel pox virus. It is incredibly rare for the virus to be symptomatic in greys, but it is deadly for red squirrels as they have not evolved any immunity and therefore, once the virus enters a population it can have dramatic effects, especially as it is density dependent.

So what is happening now?

In around 2008, we received the first anecdotal reports of red squirrels returning to land previously inhabited by grey squirrels, areas they hadn't been seen in for many decades. At the same time, pine martens were also being noticed in the same areas. These reports were coming from foresters and gamekeepers, people who were spending a lot of time in the woodland and could see the changes day to day. Reports were emerging both in Ireland and Scotland.

In 2009, I was completing my undergraduate Zoology degree at NUI Galway. It was here that the anecdotal reports were coming in as part of the Irish Squirrel Survey, more and more frequently from unconnected sources. I applied for a PhD to see if pine martens were playing a role in squirrel distribution. Quite honestly, we did not expect to find that the pine martens would be having a positive effect on red squirrels. Up until this point, anyone who had done any research on the relationships between red and grey squirrels could only find negative impacts of greys on reds. We were going very much against the literature and wisdom to suggest that red squirrels would be doing better than greys under any circumstance.

I was focusing my research in the east and midlands of Ireland and working on two projects in parallel. The first of these was a large-scale citizen science survey where people were invited to submit sightings; this was highly successful and I received well over a thousand valid entries. We could see that in terms of distribution, the density of sightings of pine martens and red squirrels overlapped more or less completely, whereas there was a negative correlation between pine martens and grey squirrels. Grey squirrels had all but disappeared from parts of the country where there were records of them being very well established.

The second element of the project involved live trapping in a perfect habitat in the midlands that had a very well-established grey squirrel population and where red squirrels had been absent for more than 30 years. We had heard from the landowner that they had spotted pine martens and red squirrels returning and fewer grey squirrels about. Lo and behold, we were trapping five pine martens repeatedly in around 100 hectares of woodland, a large number for the area, with a really healthy population of red squirrels throughout. The site's population of grey squirrels was found to have shrunk considerably, and after a series of week-long tracking sessions over a period of two years, only three adults and three juveniles were recorded throughout the entirety of the study. We were also trapping in the east of Ireland, in an area that had recently seen one adult pine marten return to a specific section of woodland. The grey squirrel population was still very healthy and that single pine marten had yet to make a large impact on the population, but this may be explained by the fact that the trapping period here was significantly shorter and therefore the impact a single animal may have made could not have been picked up.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Comparing these two datasets indicated correlation, but causation could not be justified at this stage. The same can be said about the anecdotal sightings and reports: although there was a strong correlation between pine marten and red squirrel populations there was not enough data to imply causation. Although this was evidence enough to convince a great number of people that the pine martens were the driving force, for me, as a scientist, this was something I felt I needed to study further.

So you had to go back and find out more – you were left with unanswered questions.

That's how science works: you form a hypothesis, you test it and you form more detailed hypotheses. I finished my PhD in 2013 and in the resulting paper, published in 2014, we basically said that there was a population crash in grey squirrels. It was regional and specific, and it correlated with pine marten distribution, but we didn't know for sure if it was directly related.

For my post-doctoral studies, I wanted to see if the same thing was happening in Scotland. Also, I wanted to investigate causation, either on a landscape level, i.e. are pine martens suppressing the grey squirrel population? Or by looking at the mechanism of the interaction between pine martens and grey squirrels at the woodland level. These were two different questions on two different scales, and looking at the woodland level in Scotland would have been putting the cart before the horse, so we had to look at causation in populations first.

Because with any PhD or post-doctoral study you have funding for a specific time frame, you have to ensure that you get both high-quality data and a lot of data within that timeframe. You have to think about how your study can represent a long timeframe when you only have a few years to carry out your work. So I substituted space for time: I sampled areas where pine martens were fully established and had been for some time, areas where pine martens had taken up residency more recently, and areas where they were only just appearing. This offered three timepoints laterally so a timeline could be established for long, medium and short residency. In order to gather a large amount of data, we used non-invasive techniques: detection/non-detection data from squirrels, and DNA from pine marten hair samples to identify individual martens, from 223 multi-species feeders and 19 trail cameras. It worked really well, and we were able to look in the three regions at the scale of the squirrels' home range and the intensity of the space used by pine martens, allowing us to see if that was having any effect on red or grey squirrels.

I should probably talk a little about the models as some of the key findings are a result of how the models work. We used occupancy models for squirrels; for pine martens, we used spatial capture-recapture techniques with DNA sampling. We didn't actually capture any animals but getting the DNA of one animal from the hair samples was marked as a capture. Using the spatial capture-recapture models we were able to look at how the intensity of space used by pine martens was affecting squirrel occupancy at the scale of their home range. To look at occupancy you have to calculate two things: the probability of detecting a species given that they are there and the probability of occupancy.

What we found was that pine martens had a strong effect on the probability of detection, differing between the two squirrel species. For red squirrels, given that they were present, they were far less likely to be detected as pine marten activity increased. Their presence was not being affected by pine martens but their behaviour was: they were more cautious and harder to detect when pine martens were present. Conversely, grey squirrels showed no caution at all and in fact, the probability of detection rose. This indicated that they were naïve to the threat of a tree-climbing predator, whereas red squirrels weren't. This makes sense when you think of red squirrels and pine martens overlapping throughout their home ranges for millennia, in contrast to grey squirrels, which are from the east coast of North America where they don't overlap with American martens, fishers (which are related to American martens) or any other tree-climbing predator.

The probability of occupancy for red squirrels was higher with an increase in pine marten activity. In fact, red squirrel occupancy was highest in the areas where pine martens had been established longest. Grey squirrel probability of occupancy was really strongly negatively affected by exposure to pine martens. There were only two regions to compare (where pine martens had recolonised 5–15 years ago versus 0–5 years ago) but there was a very similar relationship. Where pine martens had been established for longer, the baseline for grey squirrel


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occupancy in the region was quite a bit lower, and in the region where pine martens had been present for a shorter amount of time, we could see the same relationship more dramatically, as we started with no pine martens and a large number of grey squirrels – the population of greys dropped dramatically as pine marten activity increased. As far as we are concerned you can't really get any more conclusive: the more pine marten activity the less likely greys occupy an area.

So what is actually happening between the species?

I personally do not know if pine martens are eating grey squirrels or if they are pushing them out of the habitats. However, I would be very surprised if direct predation wasn't the main cause. You would think that it would be, as we have seen from our detection models that greys aren't cautious, making them more susceptible, but we don't actually know for sure, so that is the next step.

There are a couple of PhDs going on at the moment, one in Exeter and one in Queen's University Belfast, that are looking at that element, so with a bit of luck they will be able to shed some light on it. I have a feeling it is going to have to be a longitudinal study and will have to focus on populations where for a reasonable period of time there is an overlap of pine martens and grey squirrels. The ideal would be to work out an area that has a healthy grey squirrel population and is just about to see pine martens return so that you could collect data throughout the entire process of pine marten arrival and their establishment to the kind of numbers that would impact on grey squirrels (e.g. a minimum of 10 years), rather than a short-term study such as a PhD or a post-doc where data is typically collected for around two years. That would be the way to find out; I don't know if that will or can ever happen though.

Is there something to learn in relation to reintroductions and alien invasive species?

Very much so: firstly, it is a very tricky thing to study. Species interactions are naturally difficult as there are many connections, especially in predator–prey relationships. The best examples I could give are similar concepts in the literature on the impact novel predators can have on prey, usually in the instances where a predator has been introduced and become invasive and the native prey are detrimentally impacted. For example, American minks wiping out UK water vole populations, or cats and foxes introduced into Australia killing marsupials, or mammals being introduced into New Zealand and killing ground-nesting birds. Novel predators can have a really strong and quick effect on prey that have not evolved alongside them, and this effect is often seen in real time. In this instance, the pine marten is a novel predator from the point of view of a non-native prey species – the relationship of novel predator–naïve prey turned on its head.

So do you think we will ever see pine martens in the rest of the UK?

They are now present throughout much of Scotland but are still functionally extinct in England and Wales. There is, however, a reintroduction project underway by the Vincent Wildlife Trust in mid-Wales, where they took 51 animals from Scotland and introduced them over three years. The scheme has gone well so far and they now have their first Welsh born-and-bred kits. One day these could spread into England – there is no reason why they wouldn't. As for official reintroductions in Ireland, there has been one project in Killarney National Park, but this is nowhere near the scale of the Welsh project. There have been unofficial movements, though, where people have given animals a helping hand, but it is unclear to what extent this has occurred.

It is unlikely that pine martens will be able to live everywhere in England: they need areas of habitat that aren't too heavily urbanised, so not too many massive roads and they are certainly not going to be finding habitats everywhere. They don't need huge areas of woodland but they do need smaller areas connected by hedgerows or other natural linkages. So don't expect them to be turning up behind the bins in your town any time soon! But over time, pine martens should have a very positive impact on the red squirrel populations in those locations where it is suitable for them to thrive. **ES**

Paddy Fowler is the Publications Officer at the Institution of Environmental Sciences. He studied for an MSc in Science Communication before joining the IES in 2017. Paddy has a keen interest in aquatic conservation and an enthusiasm for communicating interesting sustainability innovations across the environmental sciences.

REFERENCES

1. Sheehy, E., Sutherland, C., O'Reilly, C. and Lambin, X. (2018) The enemy of my enemy is my friend: native pine marten recovery reverses the decline of the red squirrel by suppressing grey squirrel populations. *Proceedings of the Royal Society B: Biological Sciences*, 285. doi:10.1098/rspb.2017.2603.
2. Sheehy, E. and Lawton, C. (2014) Population crash in an invasive species following the recovery of a native predator: the case of the American grey squirrel and the European pine marten in Ireland. *Biodiversity and Conservation*, 23 (3), pp.753–774.

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