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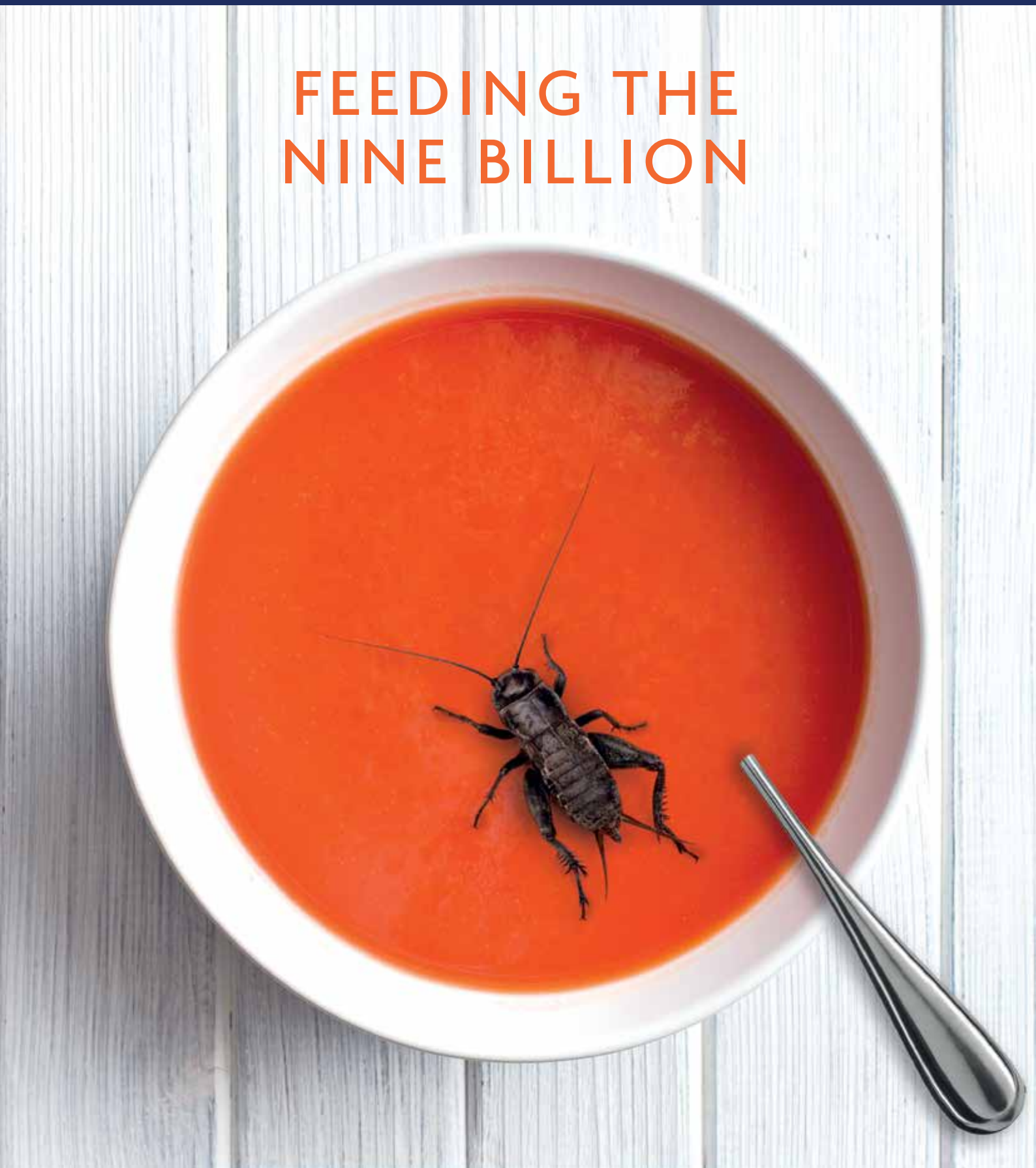
FEEDING THE NINE BILLION



Food waste and food scarcity – why is it so hard for us to get right?

Global food production has increased dramatically in the last 50 years, yet large numbers of people remain malnourished worldwide. This is compounded by the ever-increasing threats from climate change and resource scarcity. Extensive and coordinated action is required to tackle these huge challenges, on many fronts. One area in which we could make significant difference is by reducing food waste.

This is a unique time for the UK when it comes to food waste: we are more aware than ever of this urgent problem, yet despite many efforts and interventions it's not going away.

In fact, the Waste and Resources Action Programme's (WRAP's) most recent research has shown that household food waste has risen from 2012 to 2015, after years of steady decline. As distribution of surplus food increases, we must accept that this urgent effort is not a long-term solution to food waste or food poverty. So what are the solutions available to us, and who should drive these changes?

The oft-quoted statistic is that one-third of the food we produce is wasted. Another way to read it is that we have enough food to feed everyone on Earth, plus another 1.3 billion. In order to feed a growing global population, tackling food waste must be at the top of the agenda. The United Nations' Sustainable Development Goals and the EU Parliament's vote to halve food waste by 2030 are promising steps in the right direction, but voluntary targets are not enough. We need political courage to drive decisive action. Our dwindling natural resources and rising carbon emissions require it.

Projects using surplus food to support people in need are growing in Brighton & Hove where I am based and elsewhere, including surplus food cafes, redistribution networks and social enterprises upcycling rejected ingredients into gourmet foods. These projects offer an alternative to dumping perfectly good food, a chance for the public to get involved in community action, and most importantly a nutritious meal for someone struggling to get by. But too often they become dumping grounds for low quality food, and have to rely on volunteers working overtime and using their personal resources. As surplus food donation increases, donors must prioritise high quality nutritious food, because everyone deserves to eat healthily. They need to make sure projects are adequately resourced to do their work. Meanwhile food surplus projects should find ways to contribute towards action on food waste and social inequality. The volunteers, beneficiaries and supporters who make up our surplus food networks can be the voices for the change we need to tackle these salient issues.

On the home front, the Love Food Hate Waste campaign and celebrity chefs like Hugh Fearnley-Whittingstall have championed the changes we can make as individuals. An initiative run by the University of Leeds and Asda found customers need routine reminders to stick to good habits, and they look to retailers for help and advice on food[1]. This echoes the sentiments of countless people I've listened to in my work. Retailers must use their ample resources and influence to take greater responsibility in tackling household and farm-level food waste. They should publish their entire supply chain food waste, as Tesco and Sainsbury's have done, if they are to make lasting changes.

But more broadly, we need culture change, not just behaviour change. Valuing food as a key part of our lives, not just as fuel, should be intrinsic to our food experience wherever food happens - at home, work, school or restaurant. We need education and nudges towards sustainable behaviour in every setting. We need more research into deeper engagement on food waste. We need more initiatives connecting people over food, such as food-sharing apps and surplus food feasts, where the guilt of food waste can be reframed as a celebration of food sharing. And we need our public and business leaders to model the necessary culture change to tackle food waste.

Vera Zakharov is the Love Food Hate Waste Project Coordinator at the Brighton & Hove Food Partnership, supporting individuals and food businesses to reduce food waste, and developing the Surplus Food Network to better support and resource surplus food use in the city. She is also the Sussex Gleaning Coordinator and a food-sharing volunteer.

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INTRODUCTION

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Feeding the nine billion: population growth and the challenge of food security

Robert Ashcroft explores what population projections mean for global food security.

It is estimated that world population is currently increasing by an average of over 220,000 people every day, or 83 million per year[1]. In mid-2015 the United Nations estimated that world population had reached 7.3 billion. Although the current rate of increase is slower than that recorded a decade ago, projections still indicate that by 2050 the population could reach 9.7 billion, and will continue growing (see **Figure 1**). This increase will of course not be spread evenly across the planet, but in an increasingly globalised world these projections raise challenges which all countries and societies must seek to address, including how to feed nine billion people.

FOOD SECURITY

The term 'food security' is now in common use in public forums as well as in research and policy, but what does it actually mean? Food security is a flexible concept, and many different definitions have been proposed. However, the following contribution, from the United Nations Committee on World Food Security, is a helpful attempt to capture the complexity of this topic:

> "Food and nutrition security exists when all people at all times have physical, social and economic access to food, which is safe and consumed in sufficient quantity and quality to meet their dietary needs and food preferences, and is supported by an environment of adequate sanitation, health services and care, allowing for a healthy and active life."[2]

This definition demonstrates the range of interconnected factors which contribute to whether a person, group or population are considered food secure. Access to food resources is as important as its production. The World Food Programme break the concept down further into three main elements – food availability, food access, and food utilisation – which must combine for people to be considered food secure (see **Box 1**)[3].

Important progress on food security has been made in recent decades. Increasing food production has led to a significant decrease in the proportion of the global population who are hungry, despite massive population growth. In fact, studies show that in terms of production,

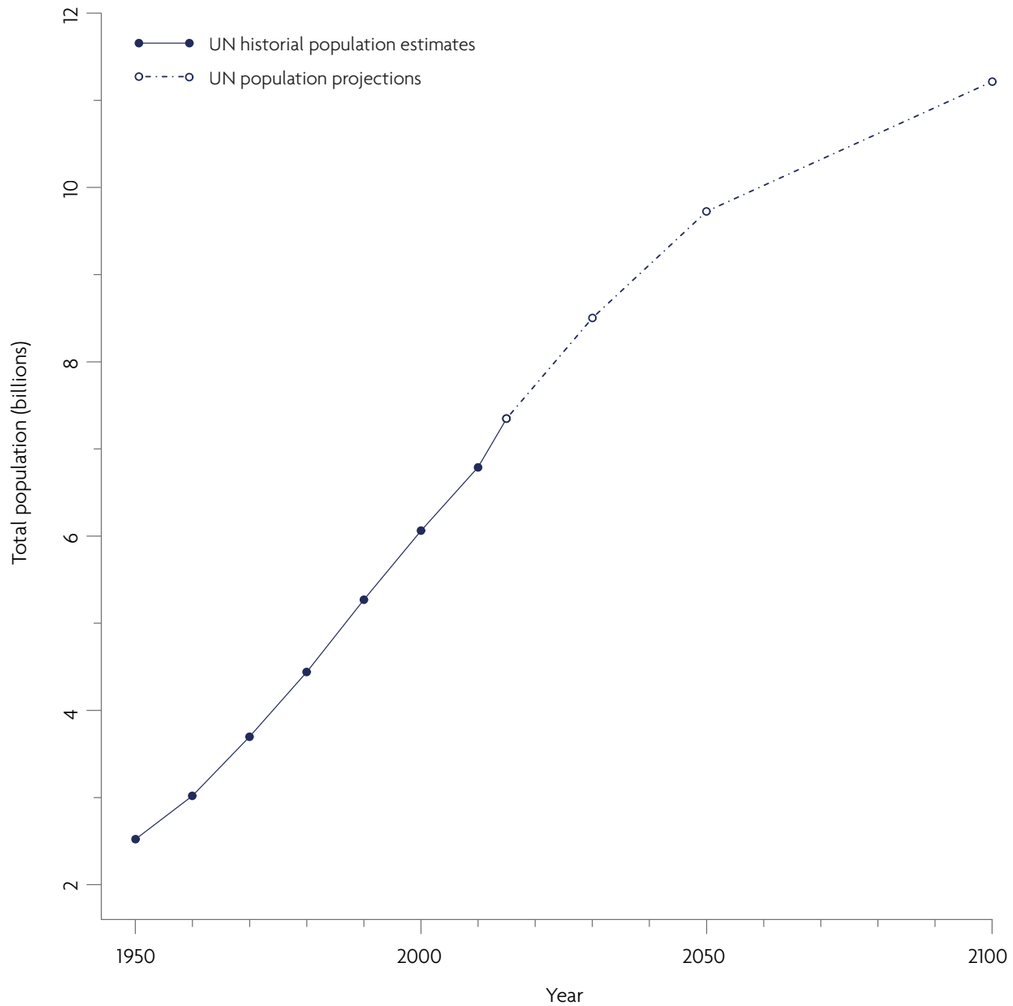
BOX 1. THREE PILLARS OF FOOD SECURITY

Food availability: Food must be consistently available in sufficient quantities. It considers stock and production in a given area and the capacity to bring in food from elsewhere, through trade or aid.

Food access: People must be able to regularly acquire adequate quantities of food, through purchase, home production, barter, gifts, borrowing or food aid.

Food utilisation: Consumed food must have a positive nutritional impact on people. It entails cooking, storage and hygiene practices, individuals' health, water and sanitations, feeding and sharing practices within the household.

As defined by the Word Food Programme[3].



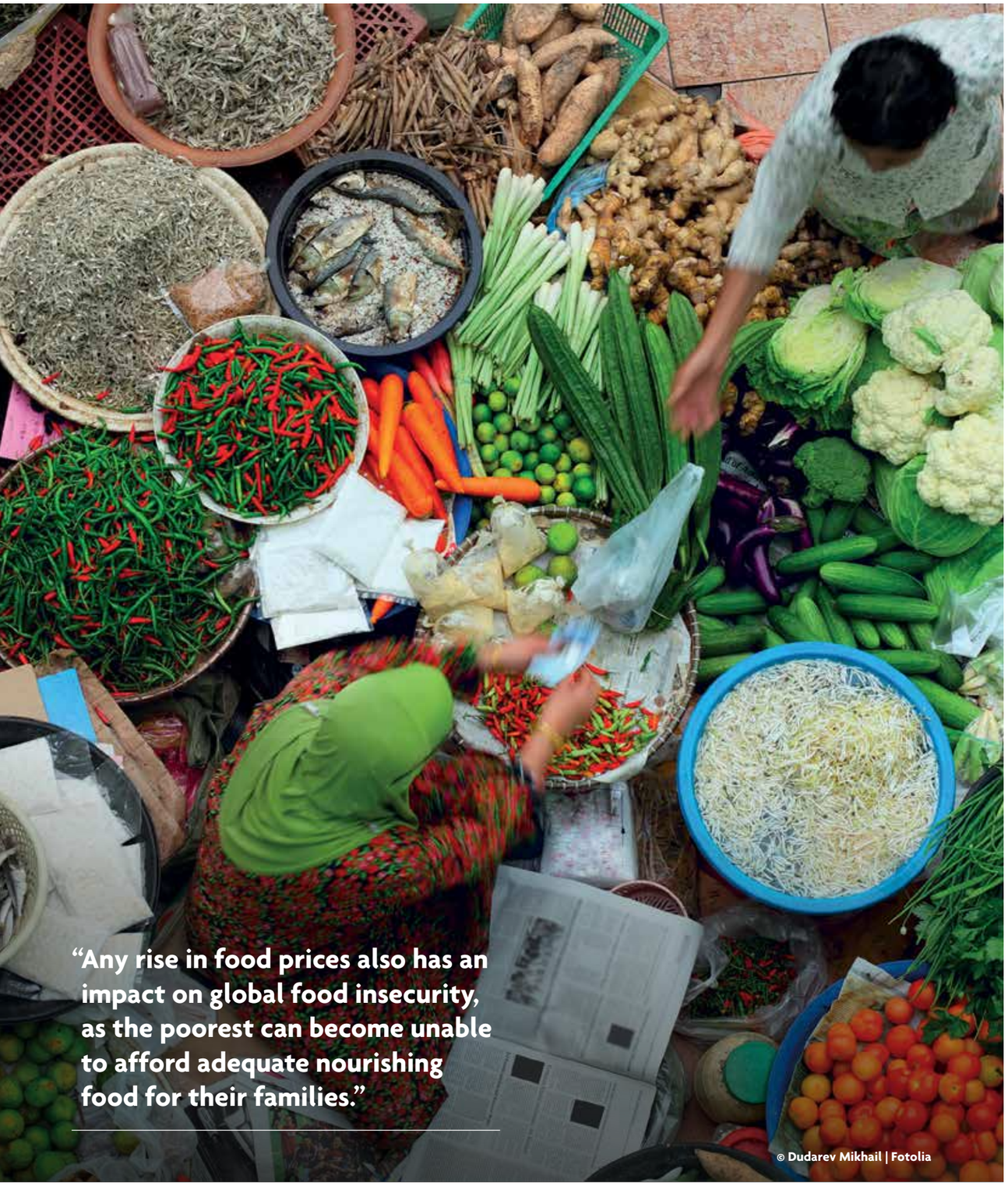
▲ **Figure 1. Graph showing historical global population and projections to 2100. Historical data is based on United Nations Population Division estimates[8]. Future figures are based on the medium variant projections published in the UN report, World Population Prospects: The 2015 Revision[1].**

the world does produce more than enough food to feed everyone[4]. Despite this, in 2015 the Food and Agriculture Organisation (FAO) estimated that approximately 793 million people were undernourished globally[5]. In a seminal paper published in 2010, born out of a UK Government Foresight project, Godfray et al. explored the causes of and a potential strategy for addressing this problem, and made the observation that "The world is now facing a new set of intersecting challenges"[6].

INTERSECTING CHALLENGES

Godfray et al.[6] explained that although projections show population growth will continue to slow during this century, this is unlikely to mean an end to food security challenges. They note that this deceleration in population growth is correlated with increased wealth, which brings higher consumption, and a greater demand for food products which put pressure on the supply systems, such as processed foods, meat, dairy and fish. Meanwhile, they also note that producers are facing increasing competition for land, water and energy, and evidence continues to demonstrate that action must quickly be taken to mitigate the negative environmental impacts of intensive food production if these systems are to remain sustainable. Furthermore, climate change presents an overarching threat to food systems; the Intergovernmental Panel on Climate Change predicts that climate change will result in an additional 40-170 million undernourished people worldwide[7].

Although food production has continued to increase, given the resource scarcity trends noted above and the likely increase in demand which is being predicted, future production should not be taken for granted[7]. Climate change and increasing temperatures may bring more frequent extreme weather events, and have negative impacts on yields at lower latitudes, where the majority of developing countries are located. Climate change is also likely to compound problems of water scarcity. Agriculture currently accounts for 70 per cent of global fresh water use, so will be particularly vulnerable to shortages[7]. These issues could threaten supply, and drive food price fluctuations.



“Any rise in food prices also has an impact on global food insecurity, as the poorest can become unable to afford adequate nourishing food for their families.”

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Any rise in food prices also has an impact on global food insecurity, as the poorest can become unable to afford adequate nourishing food for their families. Food prices are driven by a range of factors, which include the cost of inputs to the system, such as fertiliser, fuel and equipment. As such, energy prices can have a major impact on food security. To tackle food insecurity around the world, resilience needs to be built into the food system. In an increasingly unpredictable period for global economics, resilience to price changes is now of significant importance.

SEEKING INTEGRATED SOLUTIONS

Clearly, food security is an issue which requires holistic thinking. So many systems – economic, physical and social – have an interconnected impact on the ability of communities around the world to access sufficient nourishing food, that no one factor should be considered in isolation. To tackle these complex challenges, a global, and multifaceted approach will be necessary[6].

In the coming years producers will have to cope with increasing resource scarcity and extreme weather events, whilst competition for land grows more intense. A food security strategy must focus on how resilience can be built into production systems, so that producers are able to adapt to these challenges.

The social and economic factors which mean some groups and communities cannot access the food they need must be addressed through a combination of regional and national policy measures, and small-scale, context-specific local measures. Meanwhile, the huge global problem of food waste must be tackled, to ease pressure on producers and struggling communities.

It will also be vital to recognise the economic, social and cultural changes taking place, which is resulting in a greater number of people adopting more traditionally ‘Western’ diets, consuming more meat, fish and dairy than ever before. The greater resources required to produce these nutritionally-rich products is putting increasing stress on global food production. Measures must be put in place to prepare producers for this change, and ensure increasing intensification does not have damaging environmental consequences. However, thought must also be given to how these resource intensive diets may be adapted or changed, to make them more sustainable. Education will be important in informing people of the impacts of their dietary choices. New or unfamiliar products and processes, such as insects as an alternative source of protein, may play a role in this transition, and their relative merits and costs should be debated.

FOOD FOR THOUGHT

This journal seeks to explore some of the interconnected food security challenges identified in this brief summary, and introduces some of the innovative work being undertaken to address them in the UK and around the world. The articles in this issue are broadly broken down into three strands: those addressing food production methods and sustainability, those addressing food waste, and those considering diet and the role of behaviour change in tackling food security challenges. Innovation in thought, technology, policy and practice will play a crucial role in tackling food security in the coming decades, and we hope the case studies presented here will provoke further thought and discussion.

The second Sustainable Development Goal commits us to an aim of ‘Zero hunger’ by 2030. If global food insecurity is to be eliminated, and these intersecting challenges tackled, a massive worldwide effort will need to be underpinned by interconnected thinking and analysis about the systems and processes involved. Environmental scientists, as champions of interdisciplinarity, should be at the heart of this effort.

ES

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Smart cities need smart farms

Dr Stephen Hallett describes how the relationship between Cranfield University, industry and the farming community is helping to work towards sustainable food production to meet increasing urban demand.

Take a look at your average shopping trolley and it's likely that more than half of the food within will have been imported. As a country with a rising population, our demands for food outpace our ability to grow it. Internationally, the latest estimates suggest the world's population is likely to hit nine billion by 2050. Added to this, the UN estimates that some 54 per cent of the world's population now live in urban areas, with a predicted increase to 66 per cent by 2050, and for this population in particular, there are fewer opportunities to become self-sufficient for food. With this, we will see further draining of our natural resources and increasing tensions around them, together with rising numbers of people abandoning the countryside and moving to the cities for work, as well as diets worsening, resulting in a myriad of health implications. Added to this mix, the effects of climate change are hard to predict and plan for. And of course here in the UK, Brexit has resulted in a falling pound, with import prices likely to increase, exacerbating the situation. Taken together, this paints an unsettling geo-political picture for future food security.

FEATURE

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It is no less comforting when one thinks about this in terms of land management, with one question standing out: how to achieve increased food production given the finite amount of land, and indeed how much land is that? It is when we consider the Earth as a whole that the scale of this challenge becomes painfully clear. Imagine for a moment that the Earth is an apple; 74 per cent of that apple is water, and of the remaining 26 per cent land, some 13 per cent is already inhabited, leaving 13 per cent for agriculture. However, of this, 10 per cent is suitable only for non-arable land, leaving just 3 per cent of usable land for arable farming. And just as an apple has a peel, so too does the world have a fragile layer – soil. This precious resource, less than 3.1 per cent of the Earth, has to support a population that took hundreds of thousands of years to reach one billion, and then only a further 200 years to reach more than seven billion. The situation appears increasingly unsustainable, especially when we may have as few as 60 harvests worth of topsoil remaining, as has been bleakly warned by the UN Food and Agriculture Organization (FAO)[1].

We must also contend with living with environmental change. The impacts of our changing climate will affect how we can use land and what crops can be grown; the UK is no different from anywhere else, and will be affected by these changes. In some cases these changes may have positive effects such as reported in a Cranfield study which noted how changing temporal soil wetting patterns can benefit autumn-sown crops[2], but in many cases it is likely to be negative as droughtiness increases.

What is needed for tomorrow, to meet the food security challenges of today, is a new approach to farming; and not just technical improvements on existing approaches. Researchers at Cranfield University are working on a number of novel initiatives to support the farming community and to help deliver the sustainable intensification that is required if we are to improve yields, reduce demand on imports, and protect the fragile environment. It is the blend of innovative scientific methods and techniques, the co-development of approaches drawing across different academic disciplines, the active collaborative engagement with industry, and the harnessing of new and promising technological development (such as big data approaches) that will drive the new agri-technological revolution.

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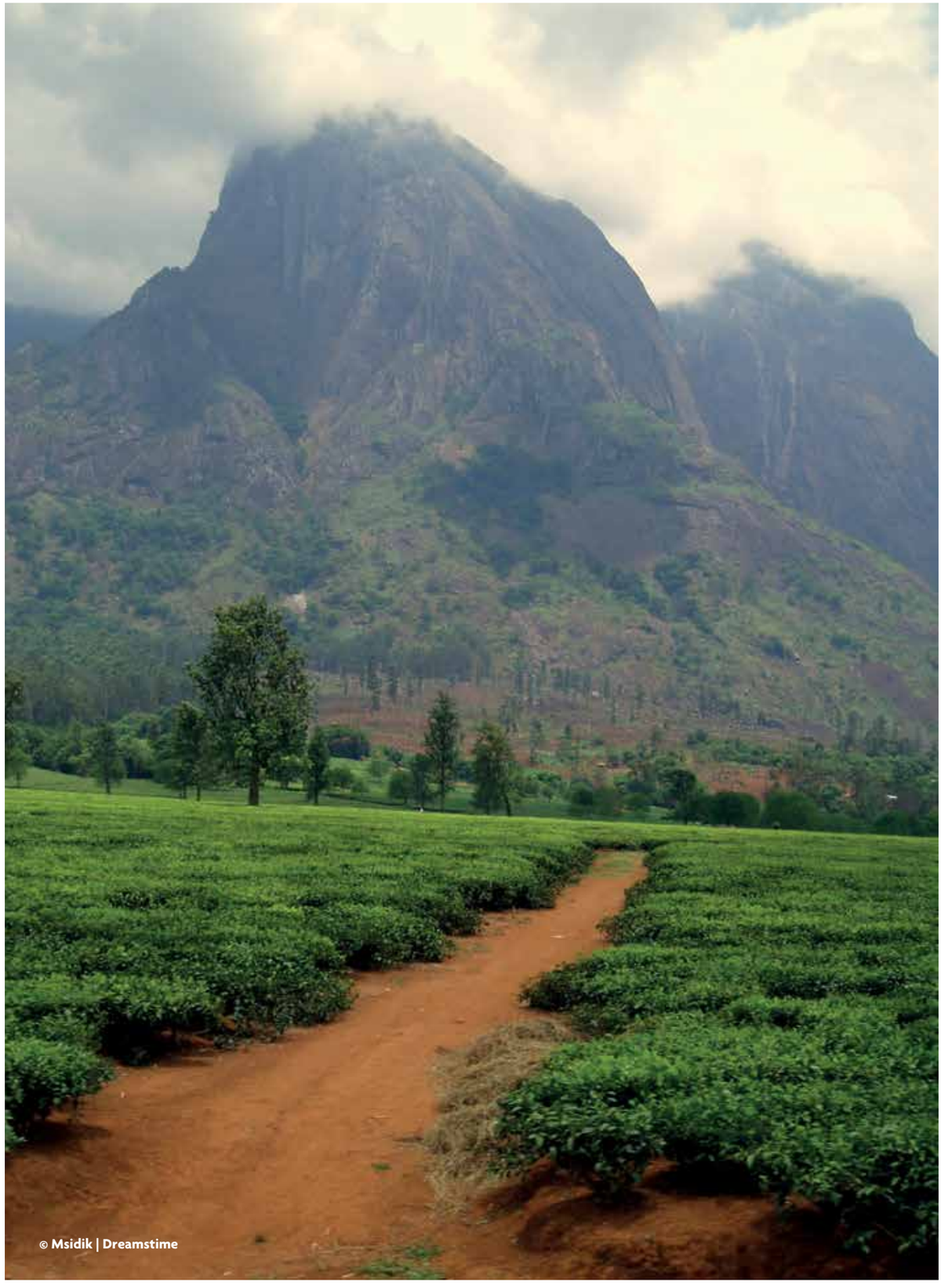
BIG FARMING DATA AND PRECISION FARMING

Developing scientific approaches to maximise on-farm production efficiencies is essential. Cranfield scientists are fortunate in being able to draw on huge environmental data resources, having the responsibility for managing the soils data and national soil maps for England and Wales. Cranfield's National Soil Collection and Archive today contains hundreds of thousands of observations and records of soil properties and characteristics, recorded alongside the geographic location of different soil types (in the form of maps and point observations). It has been said that "What the Natural History Museum does for dinosaurs, we do for soil!" A huge task over the previous three decades has been the computerisation of these unique land and environmental records, which have been used to form LandIS, the Land Information System[3]. Cranfield University's LandIS team maintain and provide expert analysis on this resource for many groups of users of soil information, used then to inform, enrich and improve wider technical advances in remote and proximal soil observation.

Government reports have highlighted how "Eight great technologies" will propel the UK to future growth. These technologies include Big Data, Space, Robotics and Agri-Science – all of which have a direct relevance to the future farm. The adoption of 'Big Data, agri-informatic' approaches is today becoming more prevalent, in ways that were just not possible, even a few years ago. Technological advances are being implemented now in the land-based sector that have been in use in other industrial sectors for some time. One advantage of this is that lessons learned elsewhere can be taken on board. There is a wealth of information on soil and land types, meteorology, engineering, agronomic options and practices, and farm level outcomes that, when used collectively, can enhance farming efficiency, increase yield and reduce inputs to help feed our rapidly growing global population.

Drawing together existing data is only half the picture. Alongside our ability to develop novel means to collect and represent land-soil characteristics, we are also able to fuse together traditional, or legacy, datasets and present-day data sources. This includes traditional soil survey assessments and meteorological, agronomic and soil management activities, analysed alongside contemporary sources of on-farm data collected by farm machinery, in-field investigation and proximal sensing, plus advanced satellite and airborne Earth observation (planes and Unmanned Aerial Vehicles [UAVs] remote sensing investigations.)

Cranfield's work with AgSpace Agriculture Ltd. (AgSpace) is one such example – a collaborative industrial project aiming to help arable farmers and landowners from all over the UK make a more affordable entry into the world of precision farming[4]. Employing high resolution satellite data processed using a soil brightness algorithm to show where variation in soil characteristics vary 'within field', this data is being analysed and modelled alongside LandIS to produce, for the first time in the UK, a new precision soil map. This approach presents an economically viable alternative to



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the current labour-intensive method of field soil survey, with growers able to increase yields with lower input costs and reduced environmental impact.

Precision farming involves dividing farmed land into management zones where each possesses specific characteristics – soil related ones being the most important. Using such 'within field' precision data has been proven to lead to better yields across all crops, when compared with conventional 'whole field' farming. However, to date, the high costs of entry have proved a barrier for many small-scale farmers.

Another exciting project example is Cranfield's Soil for Life initiative[5], a collaboration with Produce World Group TM, one of the largest expert growers and suppliers of high quality fresh vegetables in Europe, which seeks to use big data techniques to provide a toolkit for farmers to drive continuous improvements in soil health, marketable yield and agricultural sustainability. Soil for Life aims to allow an in-depth analysis and exploration of the big data supplied by leading farmers, providing robust scientific evidence to support and underpin sustainable, profitable agriculture through improvement in soil health at the field, farm and enterprise scale.

INTERNATIONAL COLLABORATION

Similarly to LandIS, Cranfield University also holds a unique worldwide soil and land archive, the Worldwide Soil Survey Archive and Catalogue (WOSSAC)[6]; a unique body of data and records collected over the past 60 years from over 300 territories around the world, with a strong African representation, providing a unique insight into soil resources globally.

But how do we use this wealth of information in a way that helps people on the ground, often in less developed countries than our own? One recent example of how this information can help has been its incorporation within the world's first *Soil Atlas of Africa*[7]. In this seminal European initiative, leading soil scientists from across Europe and Africa collaborated to develop this atlas using state-of-the-art computer mapping techniques to reveal the changing nature of soil across the continent, helping to explain the origin and functions of soil, and describing the different soil types that can be found and their relevance to both local and global issues. The atlas also discusses the principal threats to soil and the steps being taken to protect soil resources.

All well and good. We have WOSSAC, we have a Soil Atlas, but how does that help people on the ground and improve yields? Let's look to Malawi, where agriculture is a key activity and farmers are being challenged to produce more cash crops (tobacco, tea, coffee, etc.) against a background of increasing resource limitations, such as a lack of water, fertilisers and energy. Smallholder farmers, growing such staple crops as maize and vegetables, often cannot afford commercial mineral fertilisers. One means to address this is to use locally produced, renewable sources of soil improvement. Several Malawian farmers have been applying a specialist type of compost known as *Bokashi*, made from a mixture of charcoal/ash, maize bran, top soil, dung and water. The application of Bokashi has been shown to improve soil fertility considerably when used alone or as a supplement to other fertilisers. This is a great example of how big farming data, new technologies, and international collaboration together can bring about more food to feed more mouths.

Thinking back to the apple analogy; just 3 per cent of the Earth's surface is suitable for arable crops. Strikingly, it is estimated that the global extent of agricultural land in 2011 was approximately 49 million km^2, of which some 11 million km^2 (approximately 24 per cent) are found in Africa[7]. However, Africa only accounts for 16 per cent of the world's arable land (just over 2.2 million km^2). We need to work proactively with partners in Africa to shift these figures, delivering much needed food to the region and beyond.

Unfortunately, the history of large scale commercial agri-business operations in Africa is disappointing, with a history of failures that occurred primarily due to mismatching enterprises with their physical environments. These stretch back to the now infamous post-war Groundnut Scheme in the then Tanganyika, and more recently to centre pivot irrigated schemes in West Africa. However, there have been successes where large scale cultivation of new crops has flourished and has been sustainable for decades in suitable conditions, such as cotton in the Gezira of Sudan and sugar cane in the eastern Swaziland Lowveld.

If we can combine soil resources and agri-technological advances, and promote collaboration (as we are doing, by example with organisations such as AgSpace, and Produce World), we can help improve farming management methods and consequent crop yields. Lessons learnt from this can be applied beyond our borders, helping farmers around the world to better understand the soil below their feet and the crops that would best suit them.

Strong academia-industry collaborations are essential and we are fortunate at Cranfield to possess fantastic facilities to put collaborative thinking to the test. For instance, we are key partners in the Innovate UK initiative which supported a £17.5 million Agri-EPI Centre[8], which will provide a well timed focus to help develop these exciting developments and aid the drive towards a future of sustainable intensification at the farm. The Centre, which brings together expertise from academia and industry, aims to drive growth and support innovative ideas to help farmers and business

owners become more profitable and sustainable, in part by giving industry access to top academic minds and facilities. Data and smart engineering driven approaches are needed to support the farmer to reduce inputs, and increase efficiencies and yields. Academic institutions partnering with companies, such as AgSpace Limited, permit the fusion of innovative engineering with big data informatics techniques, which ultimately helps to provide the food requirements needed in the coming decades to feed the nine billion. The smart cities of the future need smart farms to sustain them.

There is also the Centre for Applied Crop Science (ACS), a £21.3 million government investment seeking to revolutionise how farmers manage crop threats including pests and disease, both in the UK and overseas. Giving farmers access to the best and most sustainable technologies, strategies and protocols to improve crop performance will make a real difference at the farm gate. Cranfield's involvement in ACS focuses on soil health – healthy soils underpin most agricultural businesses, as they support crop production by providing vital nutrients and water. However, soil properties also influence the viability and distribution of soil-borne pests, weeds and diseases. Soil management can influence these relationships, but there are significant gaps in our understanding of how different practices affect the persistence and transmission of biotic threats, and cost-effective guidance needs to be developed on how to manipulate the physical, chemical and biological properties of varied soils to optimise crop health and protection.

There is still much to learn, but by working together across continents, countries, institutions and businesses, and by testing new ideas and methods in modern facilities, we can make sure the impact we have on the field is significant and long lasting, helping to feed our rising population.

SMARTER FARMS FOR THE FUTURE

Equipping the farmer with the skills and knowledge to deliver appropriate outcomes is paramount. Providing a synoptic overview of farm operations, agronomic scenario planning, soil management interventions, problem hotspots and in-field variation, yield optimisation, input minimisation, and better investment outcomes, will help deliver the sustainable intensification required.

Where these approaches have already had measurable successes in the UK arable farming sector, there is now great hope that similar approaches can be adopted and be used similarly to drive efficiencies in other key regions such as Africa, where soil conservation and land degradation pose real concerns. Integrated and sound land resource management approaches are needed.

And these advances will lead to others, such as with the new generation of high resolution multispectral satellite platforms, whose data is now being employed alongside other datasets, or the new generations of UAV and drones that can be used together in concert. Innovation, knowledge-sharing, industrial and academic collaboration, and multinational co-operation are needed to ensure we can feed the nine billion.

There is no underestimating the challenges that face us, and food security in the face of finite resources ranks high amongst them. Thankfully, there are many scientists, agronomists and practitioners from the land-based industries who are dedicating their efforts to the applied research and application required, working with growers in East Anglia to deliver these improvements.

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Dr Stephen Hallett is a Principal Research Fellow at Cranfield University with interests in soils information in environmental decision making. His research interests examine the role of soil in agri-infomatics; land resource management; geohazards and urban infrastructure; and environmental risk mitigation and soil-related impacts of climate change.


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CASE STUDY

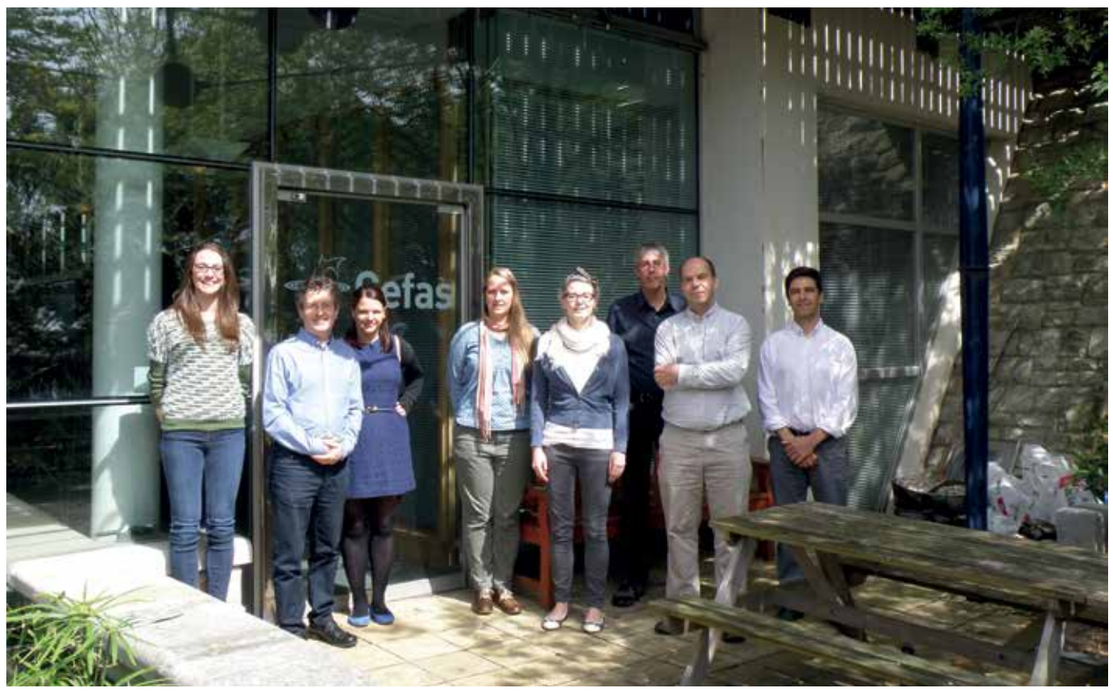
ShellEye in the sky

Kelly-Marie Davidson describes how a team of UK scientists are working with shellfish industry partners to explore the use of satellites, meteorological data and modelling to monitor and forecast water quality events that may negatively impact shellfish farms and their stock.

The ShellEye project[1], funded by the Biotechnology and Biological Science Research Council (BBSRC) and the Natural Environment Research Council (NERC), is using state-of-the-art satellite technology, and research to develop an easy to use and cost effective water quality bulletin service, specifically for UK shellfish farms. This project combines the expertise of four research organisations (Plymouth Marine Laboratory, Scottish Association for Marine Science, University of Exeter and the Centre for Environment Fisheries and Aquaculture Science) and partner shellfish farms in Scotland and the south west of England.

AQUACULTURE WITHIN THE UK ECONOMY

Aquaculture is an important worldwide source of protein and production has been increasing at an average rate of 5.8 per cent per year from 2005-2014[2]. As global populations continue to rise at approximately 1.13 per cent a year[3], the expansion of aquaculture, including shellfish farming, is considered key to helping provide food security for future generations. This expected growth provides a clear business opportunity for the UK shellfish industry, which in 2012 had an estimated value of £33.2 million each year[4]. The rise of aquaculture has also been backed by the Department of Environment,



▲ **Figure 1. ShellEye team at their first annual science meeting at the Centre for Environment Fisheries and Aquaculture Science.**

BOX 1: RICHARD BENYON MP

Richard Benyon MP, the Parliamentary Under-Secretary of State at the Department for the Environment, Food and Rural Affairs until 2013, stated in the report 'Planning for sustainable growth in the English aquaculture industry':

"The UK Government considers that aquaculture has a vital role to play in meeting the needs of consumers for a sustainable supply of fish and seafood... We want to enable the industry to fully develop its potential to become an efficient, competitive and sustainable provider of high quality seafood"[5].

Food and Rural Affairs (Defra), particularly in their 2013 report "Planning for sustainable growth in the English aquaculture industry"[5] (see **Box 1**).

WATER QUALITY THREATS TO THE SHELLFISH INDUSTRY

However, without effective strategies and new technologies in place to enable the industry to grow sustainably, safely and economically, it will be challenging to realise this potential. One such threat to the expansion of the shellfish industry is that of detrimental water quality events, for example, harmful algal blooms and microbiological pollutants.

Algal blooms occur when environmental conditions, such as temperature, nutrients, plenty of sunlight and a stable water column, are favourable for the algae to thrive. They can occur naturally or can be caused by human activities such as agricultural run-off. Blooms are harmful only occasionally and the development of a harmful algal bloom very much depends on the intensity of the bloom and the species forming it.

Subsequently, harmful algal blooms can be hard to detect and occur with very little warning, having a significant impact upon industries that rely on good water quality. Aquaculture industries are vulnerable to such biological events and, in particular, the shellfish industry is especially susceptible to harmful algal blooms, as many shellfish species intended for our plates are filter feeders and can accumulate harmful algal toxins in their tissue. In the US, harmful algal blooms are considered to be a major environmental problem in all 50 states, occurring in fresh water and sea water alike.

Research suggests that Earth's changing climate is increasing the frequency, intensity and species composition of harmful algal blooms[6]. Observations also indicate that there is an expansion in the distribution of harmful algal blooms across the globe, as waters warm and species move to higher latitudes, and seasonal windows for harmful algal bloom development are widening; a recipe for earlier, longer and unexpected harmful algal bloom events.

In fact, last year saw the largest bloom ever recorded that stretched for an estimated 40 miles along the Californian coast and to depths of 650 feet[7]. Across the Atlantic in the summer of 2013, a large bloom led to a voluntary ban on harvesting from all 20 mussel sites around Shetland; an area that produces approximately 77 per cent of rope-grown mussels in Scotland and is worth nearly £350 million a year[8]. A shellfish farmer involved with the ShellEye project concurred that these types of closures have a huge economic impact on their business as well as the industry, with closures estimated to cost him around £25,000 - £30,000 a week; significant costs that cannot be sustained.

MANAGING POOR WATER QUALITY EVENTS

Limited scientific understanding of harmful algal blooms is hindering the development of effective monitoring and forecasting capabilities, to better prepare society for future harmful algal bloom scenarios. Currently, monitoring of water quality surrounding shellfisheries in UK and European waters usually involves a series of direct samples and measurements by government agencies, which can be expensive and slower than what is needed to allow protective measures such as early harvesting. In situ monitoring equipment is being developed and deployed to enhance monitoring capabilities, but with the marine environment being so vast, this could be equated to sampling an area the size of a pin head on a football pitch. Consequently scientists are looking to space for further help.

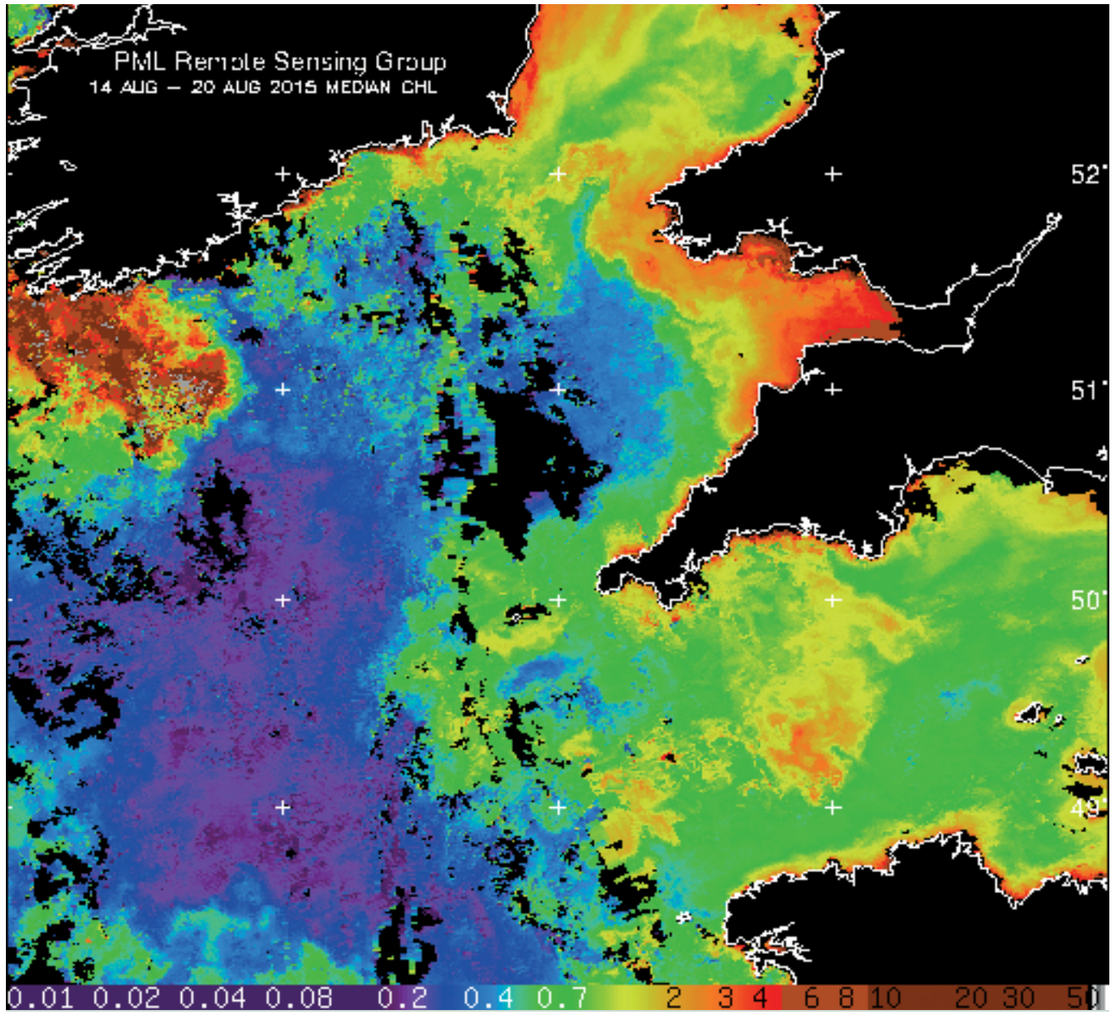
The successes seen in other related industries using satellite observations, to help monitor local water quality and identify harmful algal blooms around the UK in recent years, have been highly encouraging. Plymouth Marine Laboratory's satellite monitoring around salmon farms in Scotland has proven to provide timely information to salmon farmers, allowing proactive stock management, and in many cases, this has reduced the risk of significant economic implications to farms. As yet, however, these services have not been tailored for shellfish farms and their specific needs and risks.

▲ **Figure 2. ShellEye scientist, Carlos Campos from the Centre for Environment Fisheries and Aquaculture Science, showing his project mussels.**

▲ **Figure 3. Mussel rope: photograph taken during a BBSRC filming day.**

The main challenge of using satellite imagery to monitor water quality issues, specifically harmful algal blooms, is identification of the algal species. Satellite ocean colour sensors are already used to estimate chlorophyll concentration; the green pigment found in all plants such as algae. However, there is additional colour information that can be analysed and by comparing these data against the characteristics of known species, scientists can deduce the likely culprit forming a bloom.

As part of the ShellEye project, scientists have been 'training' a harmful algal bloom classifier to automatically identify specific species of algae, which are known to be hazardous to shellfish and consumers, so that the potential risk to the local environment can be estimated. By comparing multispectral measurements, provided by satellite ocean colour sensors, with case studies and historical records of harmful algal bloom events, the classifier has been trained to differentiate between target harmful algal blooms species, such as *Karenia mikimotoi*, *Phaeocystis globosa* and *Pseudo-nitzschia*. This method of detection, developed by Plymouth Marine Laboratory, identifies the specific characteristics of water-leaving radiances to measure quantities of particular algal species for automatic detection of harmful algal bloom events. This method can be easily adapted to identify other algal species that form dense blooms and has been developed to work with different



▲ **Figure 4. Satellite image by Plymouth Marine Laboratory of a large algal bloom off the south coast of Ireland and a small bloom developing in the English Channel (shown in red).**

BOX 2: DR PETER MILLER

ShellEye project leader and Senior Scientist at Plymouth Marine Laboratory, Dr Peter Miller:

"Our team have been working closely with colleagues in aquaculture companies to extend and adapt approaches, which have been successfully developed for salmon farmers, so that they can also benefit shellfish farmers. This new approach to monitoring water quality around aquaculture sites, coupled with recent advances in satellite imagery and observations, will help build a multidisciplinary approach and tools to support the expansion of the UK's shellfish aquaculture industry".

satellite ocean colour sensors, such as MODIS or VIIRS, and in future OLCI, which was recently launched on the European Space Agency's Sentinel-3 satellite.

Alongside satellite information, ShellEye scientists at the University of Exeter have also incorporated biotoxin and microbacteria modelling forecasts into the bulletin service. By using meteorological data, and validated by direct sampling, the model can perform short-term predictions of microbiological activity in the water. The forecasts include *E. coli*, and algal toxins okadaic acid, pectenotoxins and dinophysistoxins; all of which have been linked to being hazardous to shellfish and often humans. ShellEye will combine these techniques to develop an alert capability expressly for algae that is potentially dangerous to UK shellfish and provide an enhanced, predictive approach to assist the local farmers in their stock management strategies.

THE FUTURE USE OF SHELLEYE

The leaders of this project are clear that the overall aim is to use the results of this research to develop a user-friendly service, providing farmers with helpful and timely bulletins on water conditions and potential risks (see **Box 2**). Importantly, all of this work has been carried out in consultation with partner shellfish farmers in pilot locations, allowing them to provide valuable knowledge and feedback on products to ensure these tools meet their needs.

To extend this user consultation further, the first interactive Stakeholder Webinar was held in November 2016 to present the project's progress and glean valuable feedback on the accessibility and usefulness of the developing bulletin service. The webinar was extremely useful for the project, with participating stakeholders providing important information on preferred format and frequency of bulletins, additional sensitivities and industry issues as well as highlighting future opportunities.

The recently funded second phase of the project will explore options for the long-term delivery of the service. To help achieve this expansion and service provision, a number of new partner stakeholders have been welcomed to the project, having held the first project meeting in March 2017. Through this co-development approach, ShellEye aims to be piloting a useful and usable alert service by the end of the second phase that will help improve the economic mobility of farms and increase consumer confidence in UK shellfish into the future.

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The project, ShellEye, would value feedback, comments and suggestions during this development phase and this can be done through shelleye@pml.ac.uk. To be kept up-to-date with the progress of ShellEye and the development of the novel water quality bulletin service, interest can be registered at www.shelleye.org.

Kelly-Marie Davidson is the Senior Communications Officer at Plymouth Marine Laboratory and Knowledge Exchange Co-ordinator for the ShellEye project. Kelly-Marie has an MSc in Science Communication with a focus on the impact of social media on science reporting.
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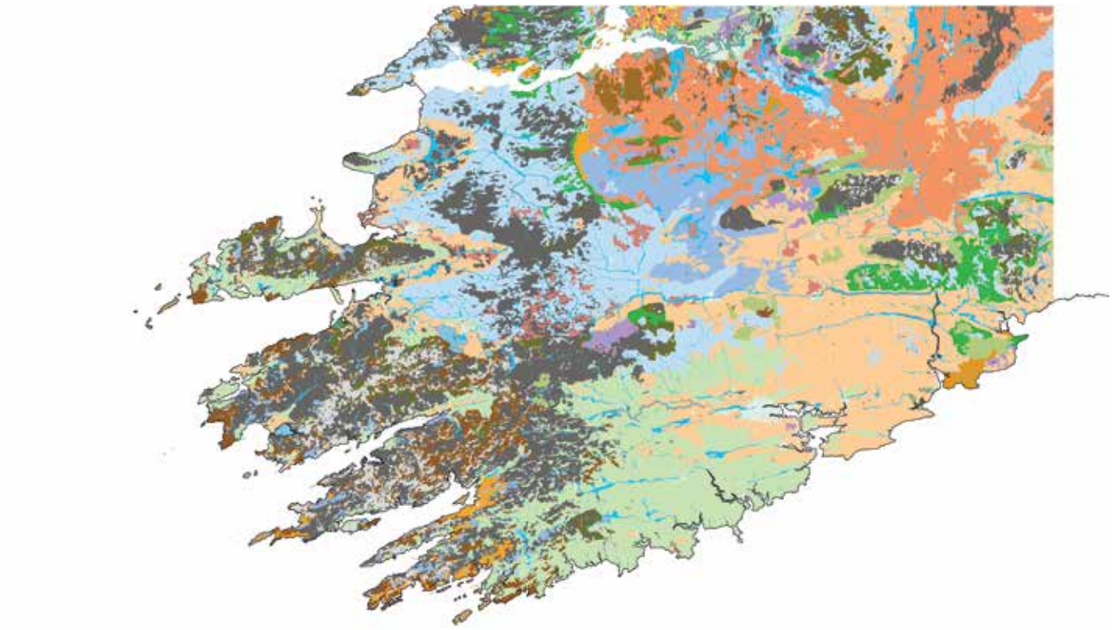
S.O.S. - Save our soil today to meet the food challenges of tomorrow

Dr Jacqueline Hannam analyses how soil research and disruptive innovation in farming techniques are contributing to meeting the food challenges of a growing global population.

It may be stating the obvious, but soil is where food begins. Around 95 per cent of our food comes from soil. But what if more food is needed, as is the situation today with a booming global population? Why not just increase the amount of agricultural land? The problem is there isn't actually much viable land left. In the UK, 70 per cent of the land area is already under productive agriculture[1] and globally this figure is around 40 per cent. Given many countries have significant natural constraints to agriculture (such as deserts, mountains and polar regions), or natural areas that society wishes to protect, the reality is that we have essentially run out of available land resources for growing food.

The only option is to grow more on the same (or less) land. It should be simple, after all there have been significant increases in crop yields over the last 50 years. This has been achieved by increased use of artificial fertilisers, better crop breeding programmes and crop protection – but all this has been to the detriment of soil quality.

▲ **Figure 1. Soils of England and Wales. (© Cranfield University) ‹www.landis.org.uk›**



▲ **Figure 2. Detail of the Irish Soil Map part produced using machine learning. Irish National Soils Map, 1:250,000, V1b(2014). Teagasc, Cranfield University. Jointly funded by the EPA STRIVE Research Programme 2007-2013 and Teagasc. ‹http://gis.teagasc.ie/soils›**

It is estimated that most of the worlds soil resources are now only in fair, poor or very poor condition[2]. And in Africa (home to nearly a quarter of the worlds agricultural land), 40 per cent of soils are considered degraded, meaning they are less effective at supporting plant growth, resulting in lower crop productivity and crucially less food. It also means they have reduced capacity for other important environmental functions, such as water filtration and storage, biodiversity and carbon storage.

Soils are endangered through degradation. As soil forms very slowly (500-1000 years to produce a few centimetres), it is essentially a non-renewable resource. Degradation takes many forms; soil erosion, excess salts, nutrient loss, loss of organic matter and contamination. Agricultural practices can accelerate soil erosion, removing 25-40 billion tonnes of topsoil every year[2]. Soil erosion results in 15-30 per cent reduction in crop yields globally[3]. In England and Wales there has been a reduction in the organic carbon content of soils under arable agriculture over a period of 30 years (1978-2007)[4], although any potential effects on crop yields are likely to have been masked by fertiliser inputs. Nutrient depletion is limiting crop productivity in many other countries, particularly in Africa where effective application rates of artificial fertiliser are limited by economic viability. Altogether, this paints a gloomy picture when trying to deliver the food requirements for a predicted nine billion people by 2050. But unlike some past civilisations that collapsed as a result of resource degradation, we are at least aware of the problem and have a knowledge of potential soil management interventions that can help to stop and reverse this degradation.

UNDERSTANDING SOIL IN ALL ITS RICH COMPLEXITY

Assessing the current and future status and condition of soil resources is imperative to be able to make effective decisions on soil use and management. This requires a good handle on the spatial (and temporal) variability of soils and their properties, especially when considering in England and Wales alone there are over 700 soil types **(Figure 1)**. The assessments in a recent report on the status of the world's soil resources[2], were based on expert interpretation of primarily historical data collected decades ago during national soil surveys. Whilst there are efforts to update soil data, for example in Europe the LUCAS survey collected and analysed 20,000 soil samples across the EU-27, we cannot sample everywhere and often data is at a resolution that is not compatible for soil management decisions needed at the farm level.

Gaps in soil property mapping can be filled using machine learning methods to produce new soil information and maps (known as digital soil mapping). Machine learning is a technique that helps computers learn from existing data to predict new data, forecasts or trends. It is everywhere; embedded in voice recognition software like Siri and used to recommend products you might like to buy based on what you've already purchased online. Machine learning in digital soil mapping uses similar algorithms to identify patterns between ubiquitous spatial environmental data, such as satellite data and digital elevation models, and the resulting distribution of soils or soil properties in the landscape. The outputs can increase the resolution of already existing soil data or predict into areas where there is data scarcity (**Figure 2**). Although like the online pop up predictions of "what you might like to buy", machine learning doesn't always get it right as it still relies on enough relevant data to train the models effectively.

BETTER MANAGEMENT AND POLICY

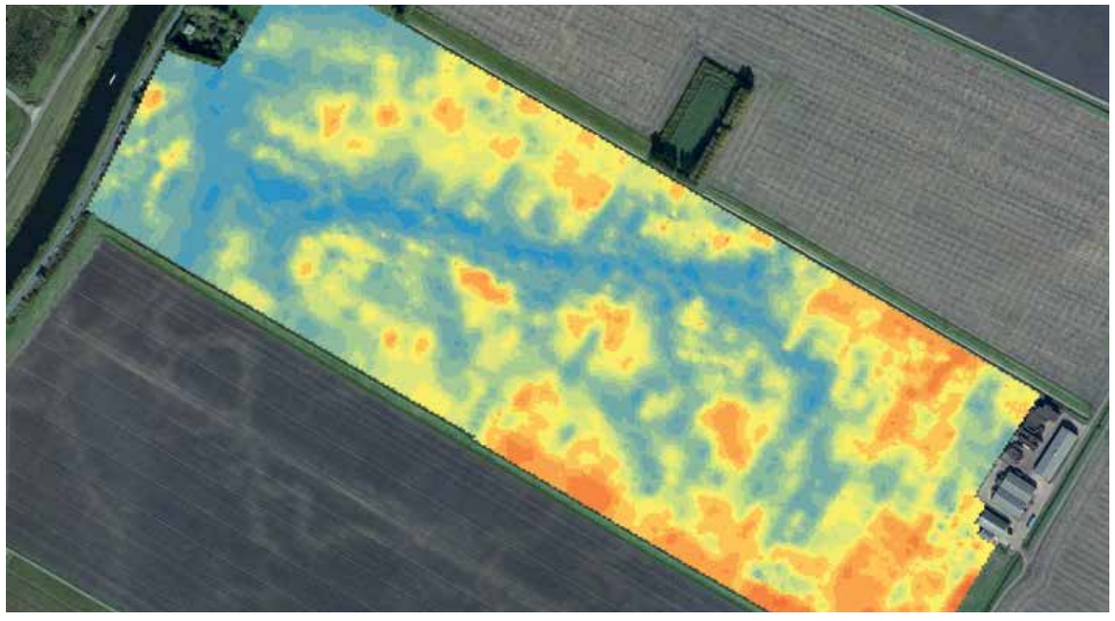
Once we have a better idea of how the soil resource is changing spatially, the question looms; how do we grow more food on the same amount of land but without damaging the soil further? There is no magic bullet, but it can be achieved through a variety of soil management interventions under sustainable intensification. These approaches focus on improving the soil condition, such as increasing organic matter, reducing erosion and targeting nutrient use and efficiency. Examples include:

1. Applying organic amendments (manure, crop residues, etc.) to increase soil organic matter.
2. Implementing cover crops (such as green manures) to reduce bare soil, while returning more organic matter and nutrients to the soil system and reducing erosion.
3. Minimising tillage to maximise organic matter and soil biology.
4. Reintroducing mixed farming and rotational grassland within arable systems.
5. Using precision agriculture for smart targeting of inputs (**Figures 3a & 3b**).

These approaches are already being implemented and empirical evidence shows improvement in both soil conditions and crop yields, but the effects can be inconsistent, variable or uncertain.

The variability in the effects of soil management interventions on crop yields is due to the local variation in soil type, climate and crop type. Thus soil management approaches need to be flexible and targeted to account for this spatial and temporal variability, but they also need to respond to policy requirements. The efficacy of these interventions should be monitored to:

▲ **Figure 3a. Google Earth image showing old drainage network (imagery © Getmapping plc © 2017 GeoEye © 2017 Intermap Earthstar Geographics Sl O © 2017 Microsoft Corporation)**



▲ **Figure 3b. Variability in soil type within a field highlighted by electrical conductivity measurements (EC mapping © Gs Growers and Cranfield University Imagery © 2016 Getmapping plc).**

ANALYSIS

"The challenge of feeding nine billion people by 2050 is immense, but so is our capacity to challenge and innovate."

© Jacqueline Hannam

1. ensure the soil system is not degraded further;
2. detect recovery from previous agricultural shocks;
3. adjust management practices accordingly; and
4. ascertain yield improvements.

FUTURE FARMING NEEDS TO BE COMPLEX

Soil is a complex system and some components respond rapidly to change (for example nutrient levels) whilst others are slower to show any effect (for example soil carbon). However, at present we are still largely limited to taking samples to measure soil parameters or using proxy measurements (for example near infrared spectroscopy) that also require calibration or large reference libraries with soil parameters.

The Holy Grail is real-time monitoring and direct measurement of soil conditions (nutrient levels, soil moisture, biological activity, carbon content, etc.) so that management practices can be tweaked to optimise the soil system. This will undoubtedly result in greater efficiency and increased crop yields. Considering that today's fields are already monitored for some soil parameters and farming with robots is on the horizon, current sensor technologies do not measure everything, some are expensive and others are at low technological readiness levels. However, future progress in sensor development could mean that small, cheap devices can be buried in the soil to collect continuous measurements. These in situ measurements can also be integrated with other remotely collected datasets from satellites or drones. The future farm would be able connect data to decision support systems that translate the data into soil management options for the farmer. For example, a machine learning algorithm would be able to utilise all this available data and could predict which cover crops to implement for enhanced yields for the next crop in the rotation, based on the soil and crop requirements.

Innovative thinking and new approaches are needed because if we continue with the status quo, it has been estimated that soils will only support 60 more harvests[5]. To avoid this catastrophe we need to understand our soils better, and support farmers to try new approaches, many of which will be radically different to their current practice. Agriculture needs disruptive innovation to increase yields sustainably, and this can start with farming for soil. This requires a combination of new technologies and changing farming practices. These should be underpinned by effective knowledge exchange and collaboration between research, industry and agricultural practitioners, and crucially, be supported by agricultural policy that is flexible enough to encourage implementation of the adaptive approaches that are necessary to protect our soil resources. Most farmers recognise the fundamental value of their soil, but the numbers of practising 'soil farmers' needs to swell to ensure soils are able to effectively support sustainable increases in food production. This requires investing in soil for the benefit of the farmers and the population of the future. The challenge of feeding nine billion people by 2050 is immense, but so is our capacity to challenge and innovate. And remember, we need to save our soil now to save our future planet!

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OPINION

Neonicotinoids – friend or foe?

Dave Goulson debates the impact of neonicotinoids used in current crop farming practices on the UK and international ecosystem health, and in particular, the humble bee.

The impacts that neonicotinoids may or may not be having on bees, wildlife and ecosystem health has become one of the most hotly contested areas of environmental research and policy in recent years. Neonicotinoids are neurotoxins, synthetic variants of nicotine, and they have become the most widely used insecticides in the world since their introduction just over 20 years ago. Being insecticides they are of course highly toxic to insects, with the LD50 (the dose that kills 50 per cent of test organisms) being just 4 billionths of a gram for honeybees; meaning that 1 teaspoon would be sufficient to give an LD50 to 1.25 billion bees. They are systemic, water-soluble chemicals that are most commonly used as a seed dressing; farmers buy pre-dressed seeds and simply sow them. The pesticide is soluble within soil water and is taken up by the roots of the crop, spreading through the tissues and protecting all parts of the crop from insect pests. This all sounds like an efficient and effective means of pest control, but there are problems.

OPINION

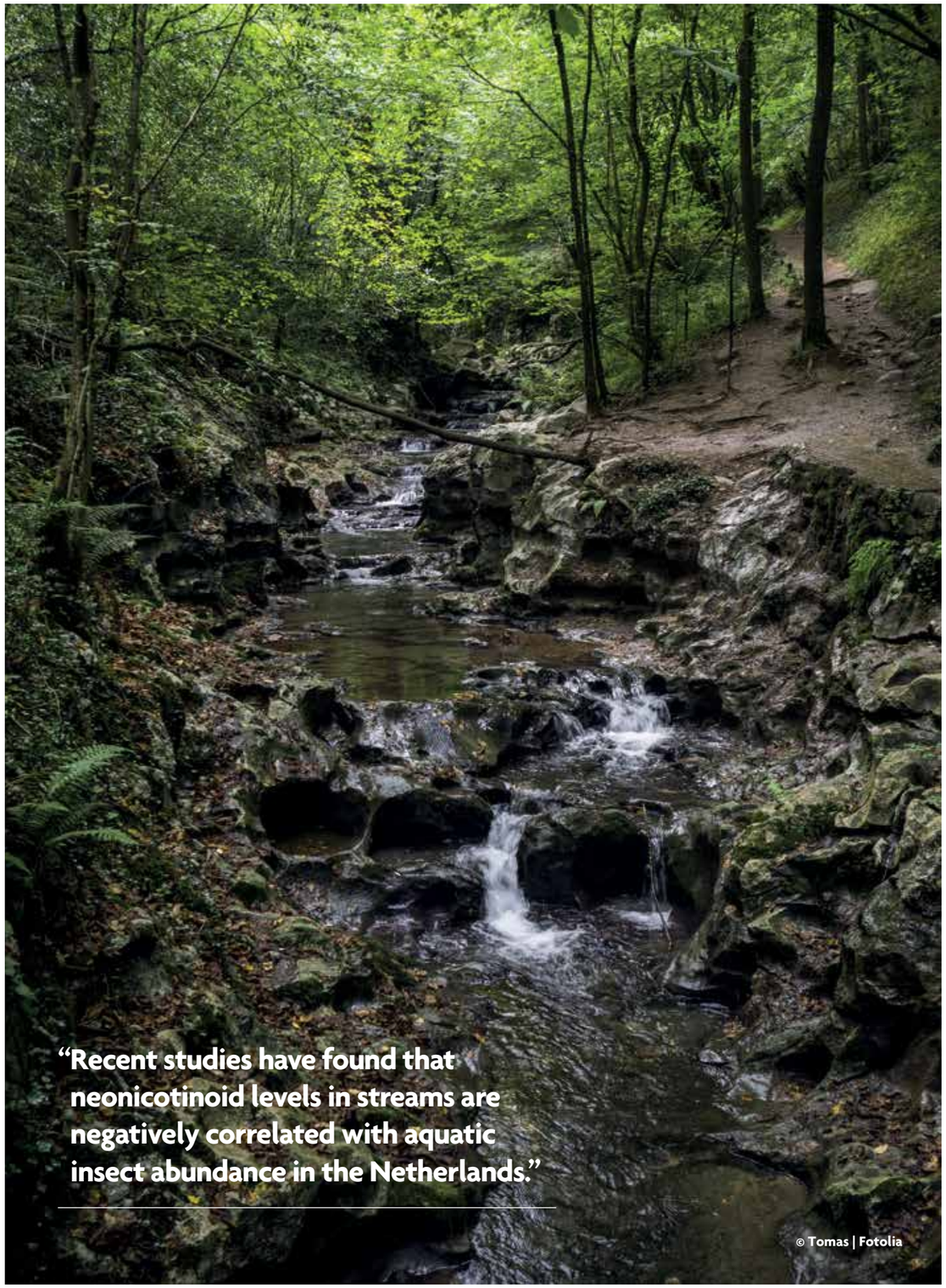
BEES AND NEONICOTINOIDS – WHAT'S THE PROBLEM?

The first to emerge was that, being systemic, the neonicotinoids are absorbed into the pollen and nectar of flowering crops such as oilseed rape and sunflowers, and thus are consumed by bees and other pollinators. French beekeepers raised the alarm as long ago as 1996 when they found that their honeybee hives were dying when near treated fields of sunflowers. This sparked considerable research, and it has since become clear that the doses that bees receive from exposure to a treated crop are not enough to kill them swiftly, but impairs their navigation, learning, memory, egg laying and fertility, and their immune systems.

Large-scale field trials have found that this translates into a major impact on the colony health for wild bumblebees and reduced breeding and abundance of solitary bees. Evidence for impacts on honeybee colonies is mixed, and much debated. The agrochemical industry have funded and/or conducted several large field trials on the impacts on honeybee colonies, and found no adverse effects. However, these trials have been widely criticised on numerous grounds including whether it is appropriate for companies that make billions of dollars from the sales of a chemical to be the ones evaluating their safety.

IS THE DAMAGE GREATER THAN FIRST THOUGHT?

Although much of the focus of this debate has been on bees, it has begun to emerge that there are broader problems associated with neonicotinoids. When introduced, they were regarded as providing an excellent targeting tool for crop management and a big improvement on the mass spraying of pesticides from a tractor, but this proved to be incorrect. On average only about 5 per cent of the pesticide is taken up by the crop (much less than can be achieved with a foliar spray). The remainder goes into the soil and consequently soil water, where it can persist for many years, and may accumulate if treated crops are sown every year. Neonicotinoids leach into streams and ponds; water samples collected from locations as diverse as the Netherlands, Canada and California reveal that the majority of waterways in arable areas contain them, often at concentrations exceeding recommended levels and also exceeding levels known to cause mortality in aquatic insects such as mayflies[1]. Neonicotinoids are intended to be taken up by the roots of the target crop, but of course they are just as readily taken up by the field margin and hedgerow plants that have their roots in the same soil. Recent studies have demonstrated that common field margin wildflowers, such as hawthorn, poppy and thistle commonly have neonicotinoids in their leaf tissues and in their pollen and nectar, sometimes at levels exceeding those in the crop[2]. This means that pollinators aren't just threatened by exposure to the crop; they are being exposed all season



long if they visit almost any flowers in conventional arable farmland. Of course this also means that other insects that live in our hedgerows: grasshoppers, frog hoppers, the caterpillars of butterflies and moths and so on, are all exposed since their food sources are contaminated with these potent neurotoxins.

Recent studies have found that neonicotinoid levels in streams are negatively correlated with aquatic insect abundance in the Netherlands[3], honeybee colony deaths and rates of local extinction of wild bees correlate with neonicotinoid use in the UK[4,5], rates of decline of insect-eating birds are highest in areas of the Netherlands that have higher levels of neonicotinoid pollution[6] and UK farmland butterfly declines are neatly predicted by annual rates of application of neonicotinoids[7]. These are all sophisticated analyses that attempt to take into account other factors that might affect insect and bird populations, such as changing weather and land use. Yet all are dismissed by the pro-pesticide lobby as mere correlations. Through repetition they have created a myth that correlations are not a valid tool of statistical inference. Of course correlation is not proof of causation, but when one repeatedly finds a strong correlation between insect declines and insecticide use, it seems reasonable to infer that causation is the most likely explanation.

DO NEONICOTINOIDS HAVE A FUTURE?

The pro-pesticide lobby states that highly potent and persistent neurotoxic pesticides effectively control and target farm pest insects while having no effect on non-target bees, butterflies or other insects living on those farms. In previous decades they made the same claims for previously used pesticides, such as the organochlorides (e.g. DDT) and organophosphates, which are now largely banned.

Interestingly, politicians in different countries have drawn markedly different conclusions as to where the balance of evidence lies. The European Food Standards Agency (EFSA) published reports in 2013 reviewing the evidence to date which concluded that the three most commonly used neonicotinoids pose “an unacceptable risk to bees”. As a result, the European Parliament proposed a moratorium on their use on flowering crops, which was passed and came into effect in December 2013. This continues to the present, and is currently being reviewed. Since 2013, the evidence that neonicotinoids harm the environment has become much stronger, as highlighted in a recent review by the European Academy of Sciences in 2015[8].

It seems reasonable to conclude that the moratorium will remain or be extended in the EU, and both France and Germany are unilaterally moving towards total bans on neonicotinoids. However, the UK government (and a small number of other countries) opposed the moratorium in 2013, and has not since indicated that it has changed its mind.

Outside of Europe, no national government has taken steps to limit or ban neonicotinoid use in response to the growing evidence of environmental harm (though Ontario is legislating to greatly decrease use). The UK’s National Farmers Union and the agrochemical industry continue to lobby for the moratorium to be rescinded, and with Brexit the UK government will be free to do so. At a time when Britain’s farmland wildlife continues to decline, with farmland bird populations down 54 per cent since 1970 and farmland butterflies down 40 per cent since 1990, this might well be the final nail in the coffin for many UK species.

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Dave Goulson is Professor of biology at the University of Sussex. He has published over 270 scientific articles on bumblebees and other insects, and is author of the Sunday Times bestseller *A Sting in the Tale* (2013), a popular science book about bumble bees, *A Buzz in the Meadow* (2014), and *Bee Quest* (2017). He found the Bumblebee Conservation Trust in 2006, a charity which has grown to 9,000 members.

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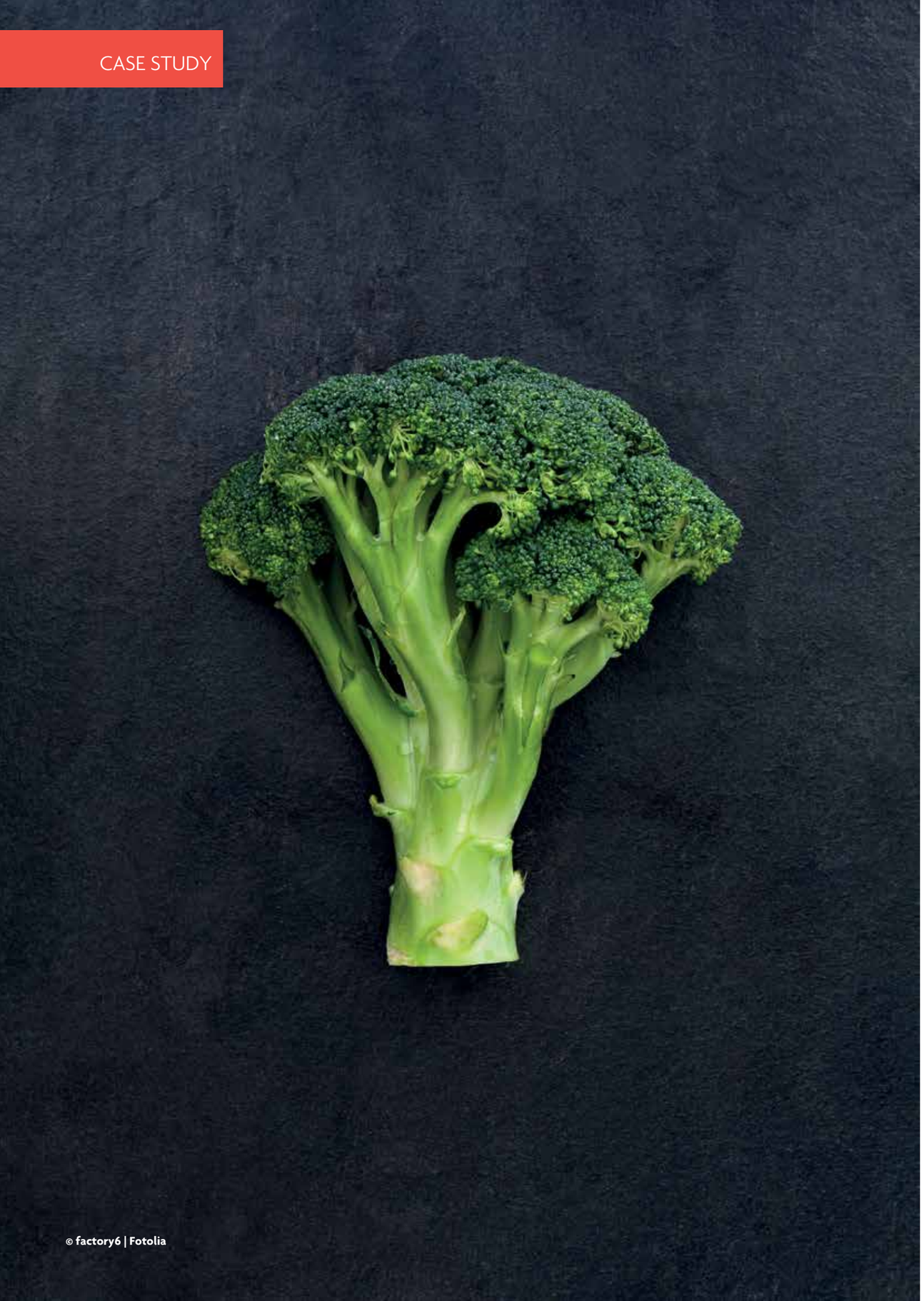

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CASE STUDY

Increasing global food security: nutrition and the case of the 'Super Broccoli'

Andrew Chapple introduces the 'Super Broccoli' – Beneforté – and discusses why the nutritional content of food is vital to global food security.

An often overlooked aspect of the challenge of ensuring food security is ensuring that the food we do receive is sufficiently nutritious to support good health. Threats to food security, such as climate change, dwindling resources and emerging diseases pose serious challenges, and often the response to those challenges is to look for ways of producing more food.

But are there other solutions that could also help us address some of the world's other global challenges? Instead of making even more of the same, could we make the food we are growing heathier, more nutritious, and able to deliver more 'bang for the buck' than our current diet? Food insecurity is usually portrayed as leading in malnutrition, even starvation, and there is no doubt that this is a growing crisis in the world's poorest countries. But at the same time, especially in the western world, we are seeing a boom in health problems associated with overconsumption. Shockingly, as reported in The Lancet[1] recently, there are more obese people in the world than there are people underweight. What's more, many of those classed as obese regularly fail to meet the minimum recommended levels of nutrition advised by government to maintain health. In the UK, the five-a-day message has become well ingrained into the nation's psyche, yet we collectively have barely managed to reach three. And it is the poorest in society, the most at risk from food insecurity, where obesity is coupled with insufficient nutrition.

So could a focus on the nutritional aspects of food security help improve the situation? Scientists at the Institute of Food Research (IFR) think so, and have been leading the way in efforts to improve diet by increasing the nutritional value of specific foods. In 2011, a new variety of broccoli, Beneforté®, was launched onto supermarket shelves. This broccoli has been bred to contain two to three times more of a naturally occurring chemical called glucoraphanin; one of a group of compounds called glucosinolates that are produced naturally by many brassica vegetables, they have been of great interest to scientists because many studies have pointed to the potential health benefits from diets rich in these vegetables. The concept is that increasing the amount of glucoraphanin raises these health benefits – addressing that nutritional aspect of food security. It is thought that Beneforté is the first variety to be specifically bred to increase the levels of a nutrient, but in principle the same could be applied to other vegetables, fruits or even cereal crops, thus delivering greater nutrition for the same yield.

But delivering a new variety isn't trivial, especially where the trait being bred for is difficult to assess, as in this case. It is relatively easy to measure an increase in yield, changes in flavour, or to measure disease resistance, but how do you show something is healthier? Addressing this has been critical to the commercialisation of Beneforté, and has called on the

CASE STUDY

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application of excellent, long-term bioscience, backed by the UK's Biotechnology and Biological Sciences Research Council.

THE RISE OF BENEFORTÉ – A 'SUPER BROCCOLI'

The story of Beneforté begins around thirty years ago, when PhD student Richard Mithen joined a field trip to Sicily to collect seeds from brassica plants for preservation in seed banks. Mithen's PhD, at the University of East Anglia, involved studying the glucosinolates in brassicas and their role in defending the plants against insect attack. Brassica plants accumulate glucosinolates in compartments within their cells and separate cellular compartments contain an enzyme called myrosinase. When the tissues are damaged, the myrosinase comes into contact with the glucosinolate, converting it into an active form called an isothiocyanate, which acts as a repellent. At the time, it was postulated that these may be toxic to humans, but little was known about their chemistry or genetics, which led to the collection of different varieties and Mithen's studies.

Back in the UK, Mithen worked with Professor Roger Fenwick, an expert in these compounds at the IFR in Norwich. Professor Fenwick developed the first methods for accurately measuring glucosinolates. The analysis identified certain wild brassicas with elevated levels of glucoraphanin that grew as weeds on the cliffs of the Mediterranean.

At around the same time, a role for these compounds in protecting health was being suggested from other studies being conducted around the world. Large studies, involving many thousands of people, suggested that people who reported including several portions of brassica vegetables in their diets, had a lower risk of chronic diseases, such as cancer and heart disease. These epidemiological studies do not imply a causative link, and other socio-economic factors may be at work, although most of the studies tried to eliminate these. Other, more controlled studies, followed cohorts of people over long periods, who recorded their diets; this was then correlated with their long term health. The gold standard of these studies is the double blinded placebo controlled dietary intervention, where people were given something to include in their diet, or a placebo, and outcomes related to health were measured. Neither the participant nor the scientists knew whether an individual had been given the placebo. Very careful study design is needed for these, and it's very hard to run these experiments over the long periods of time needed, making intervention trials very expensive; consequently few have been carried out to date, and again, they can only provide clues to possible mechanisms. Mechanistic studies have focused on the glucosinolates because they are enriched in brassicas; these have shown positive results in isolated laboratory studies on cells. Further research is ongoing to confirm whether these in-vitro studies are mimicked in the body, but together with the epidemiological studies, there is an ever-growing body of evidence linking brassicas and the glucosinolates they contain, with a reduced risk of chronic diseases. It is on the back of this evidence that scientists have been looking at how to improve nutritional content of foods – confidence in a positive effect is needed in order to avoid wasting effort and valuable resources for research.

In the 1990s, Mithen began a breeding programme to transfer the high glucoraphanin from the wild brassica into a regular variety of broccoli; not a trivial undertaking as little was known about the genetics that controlled this. A series of crosses and backcrosses began to untangle the complex genetics, and produce an edible broccoli with more glucoraphanin. This work was started at the John Innes Centre, a leading institute for plant genetics, also based on the Norwich Research Park.

Whilst these crossed varieties were useful for research, it was apparent that if they were ever going to be taken to the consumer, a more targeted commercial breeding programme would be needed to make this broccoli at least as good as other commercial varieties. This would need greater investment and a commercial partner, and to protect the investment made so far, Plant Bioscience Limited (PBL) were brought in to secure the intellectual property and apply the relevant patents. Without this, it would have been harder to convince a commercial breeder to become involved in this pioneering project, but it did ensure that a proportion of any eventual profit would flow back into publicly funded science.

In 2000, PBL partnered with Seminis, one of the world's leading vegetable breeders, to take on the commercial breeding programme. This continued for the next decade, during which Seminis was taken over by Monsanto. As experts in vegetable breeding, including broccoli, they were able to ensure that the new variety would be acceptable to consumers as well as to growers. There was no point developing a high glucoraphanin variety that was unpalatable, had severely reduced yield, or was susceptible to disease. It is a slow process of creating crosses and picking the best of the next generation on the basis of genotype or phenotype, and it took many more years until the field trials were finally carried out in different countries, to show that this broccoli would reliably have two to three times more glucoraphanin[2].

During this time, Mithen joined the IFR, setting up a research group to look at the health benefits of brassica vegetables. The new variety was a useful tool in this research, especially in dietary intervention trials because it overcame one of the main issues they faced: how to design a suitable control. With most experiments, the design needs a suitable control to compare against. A food type can be eliminated, but the participant then

easily perceives the reason for the change and so the experiment is no longer blinded. Broccoli is full of many different compounds and having varieties with different levels of glucoraphanin means that any differences in observations can be specifically put down to the effect of glucoraphanin. One such study, published in 2015[3], showed that the high glucoraphanin broccoli could reduce low-density lipoprotein (LDL) cholesterol.

THE GLOBAL LAUNCH OF BENEFORTÉ

The high glucoraphanin broccoli was launched in 2011 under the brand name Beneforté, initially in the United States and Canada, and later in the UK's Marks and Spencer stores, becoming what's thought to be the first nutritionally-enhanced vegetable to go on sale. Research is still ongoing to determine more about how glucoraphanin works, and also to build on the existing evidence base. No health claims can be used for EU products until a dossier of evidence has been produced and approved, in order to protect the consumer from poorly researched claims.

So, can this broccoli really help improve food security, through improving nutrition? It isn't a magic bullet, and was never meant to be so. The intention was to help consumers obtain the maximum benefit from their food. The epidemiological studies have shown that the people who get the most benefit from brassicas are those who consume them daily; something that most people wouldn't naturally do. However, the advantage of Beneforté broccoli is that it allows people to consume it a few times a week and still receive the same benefits. Throughout the development process, the driver was always making it easier for the consumer to get the maximum benefit in a way that could easily be incorporated into everyday diets. This is seen as a better way of improving nutritional food security, rather than relying on consumers to add expensive, exotic or unfamiliar foods to their diet.

IS THE FUTURE BRIGHT FOR 'SUPER BROCCOLI'?

The Institutes on the Norwich Research Park that collaborated on the Beneforté broccoli have formed a unique focus for research into food and health, and are able to not only understand and explore the fundamental science linking what we eat with health, but to translate this into new varieties. There are already a number of programmes looking at other plant-derived compounds, particularly the polyphenols that give fruits and vegetables their bright colours. Whilst Beneforté was bred through conventional breeding, could genetic modification take bigger, faster steps to nutritionally enhanced products such as the anthocyanin-rich purple tomatoes developed at the John Innes Centre? Tomatoes are a staple food and used as an ingredient in many different products, but will consumers accept genetically modified food for nutritionally enhanced products. If so, it could be another staple food that will help boost nutritional food security.

But it is the biggest food staple of all that is at the centre of a new research effort. Wheat is the most widely grown crop in the world, providing a fifth of the global population's protein and calories. A number of global initiatives are focused on boosting wheat yield to help feed an anticipated nine billion extra people expected to make up the global population in 2050. Could food security be improved by making wheat more nutritious? This a goal of the Quadram Institute, a new research centre currently under construction on the Norwich Research Park. A partnership between IFR, the University of East Anglia, and the Norfolk and Norwich University Hospital, will work at the forefront of where food and health combine; one programme will look at different wheat breeds to determine if nutrition can be improved further. Using the same approach pioneered with broccoli, nutritional food security could really come with our daily bread.

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▲ **Figure 1. Institute of Food Research, Norwich Research Park. © Institute of Food Research**

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FEATURE

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Food loss and waste: A key issue for our generation

Barbara Leach and **Richard Swannell** discuss the challenges society faces in quantifying food waste, and describes the steps the UK and international governments are taking to manage food waste and surplus food for economic, social and environmental benefits.

Around a third of all food produced for human consumption is lost or wasted from the farm to the fork. This huge level of inefficiency has economic, social, and environmental impacts. Food loss and waste causes about $940 billion per year in economic losses, it exacerbates food insecurity and malnutrition, and food that is ultimately lost or wasted consumes about a quarter of all water used by agriculture, requires cropland area the size of China and is responsible for an estimated 8 per cent of global greenhouse gas emissions[1]. The emissions from food production alone, if left unchecked to 2050, would be enough to increase global temperatures by 2 °C[2]. Therefore, it is important for future generations to find solutions now, particularly to help feed nine billion people in 2050 without undue environmental implications for water, land and fishery resources.

WHAT IS FOOD LOSS AND WASTE?

The Food and Agriculture Organization of the UN (FAO) defines food loss as any decrease in mass or nutritional value of food that was originally intended for human consumption, normally caused by deficiencies in the supply chain or the impact of natural factors. Food 'waste' is a sub-set of loss and refers to food appropriate for human consumption being deliberately discarded[3]. The FAO definition includes only edible items thereby excluding skins, stones and rinds. FUSIONS, the 2014-16 European project aimed at reducing food waste, include "associated inedible parts of food" to the definition of food loss and waste, to enable a wider approach to tackling the problem to be adopted[4]. Given that what is regarded as edible food varies around the world (for example chicken feet are eaten in China, but are not widely eaten in the UK), the latter definition has some advantages and helps provides details on the full scale of the issue. The international Food Waste and Loss Standard provides an approach to measuring all food waste, both edible and inedible parts, although it does not define food waste specifically[5].

UNDERSTANDING THE SCALE OF THE PROBLEM

The old adage "If you can't measure it, you can't manage it" applies especially to food waste. Globally there is very limited data on food loss and waste, partly due to a historic lack of interest and more recently due to the very real difficulties in measuring it. The World Resources Institute (WRI) recognised this in its paper outlining the problem, commenting, "If one does not know how much or where food loss and waste is occurring, how can one be expected to do something about it? Experts interviewed for this working paper agreed that across the food value chain, better measurement and monitoring of food loss and waste is needed"[6].

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Take the UK as an example. Because most food discarded by households is part of general mixed waste, prior to 2008 no one had much idea how much food households were wasting. There was a view that most of it was likely to be unavoidable (peelings, cores and skins) and so not much could be done to prevent it. Waste and Resources Action Programme's (WRAP) study, *The Food We Waste*[7], clearly showed not only was the scale of waste large, but the vast majority of the food discarded was edible. WRAP updated the figures in 2012[8] and more recently in 2017[9]. The latest estimates are that 7.3 million tonnes (Mt) was produced of which 4.4 Mt was avoidable (60 per cent), which was worth a staggering £13 billion.

Although waste in food manufacturing and retail is significant, it is not at the same scale as household food waste. In the UK, for example, 2.0 Mt arises from retail and manufacturing and a further 0.92 Mt from the hospitality sector; less than half of the amount produced by households[10]. Data on food loss and waste in primary production is much harder to obtain, with no reliable UK estimate available. WRAP is currently working with Trade Associations, food producers and retailers to improve this situation.

The need to quantify food waste has recently gained profile around the world, with the UN Environmental Programme (UNEP) and the FAO partnering to produce guidance[11], and the World Resources Institute (WRI) leading a global effort to produce a quantification and reporting standard[5]. The European project, FUSIONS, has provided an estimate of 88 Mt for the 28 Member States of the EU, while noting that this estimate is based on data from relatively few countries[12]. They also supplied a manual on measuring food waste which is consistent with the Food Waste and Loss protocol[12].

TACKLING THE ISSUE

There have been pockets of activity around the world to prevent food waste, with activities ramping up recently in the light of UN Sustainable Development Goal (SDG) 12.3 on tackling food waste. Some of these are outlined in WRI's working paper[6] and covers initiatives right across the supply chain.

Often businesses and other organisations can tackle food waste themselves through adaptations to processes or practices. UNEP provides a general step-by-step guide in their 2014 publication[11], with more detailed guidance widely available for localities, such as the Greater London Authority[13], and for sectors[14].

Other initiatives are consumer-facing. In the UK, the *Love Food Hate Waste* campaign aims to raise awareness of the need to reduce food waste and help everyone to take action, showing that by doing some easy practical everyday things in the home, everyone can all waste less

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▲ **Figure 1. Studies by WRAP have shown that 60 per cent of food waste generated in the UK was avoidable.**

food, and this together with other initiatives in the UK, has helped people reduce food waste by around 1 Mt per year[9]. Love Food Hate Waste also operates in parts of Canada, Australia and New Zealand[15]. Sainsburys, one the UK's major grocery retailers, runs *Waste Less Save More* which aims to change the way we think about food - what we buy, how we cook, how we eat - and what we throw away[16]. In Denmark, *Stop Wasting Food* (Stop Splid Af Mad), is a non-governmental organisation aiming to shape public opinion in a drive to prevent food waste, urging and empowering consumers to take action[17].

Other initiatives attempt to work across the whole supply chain, recognising the need to intervene at all stages to effectively tackle the issue. In the UK, Courtauld Commitment 2 galvanized the food manufacturing and retail industry in efforts to reduce food waste, resulting in 240,000 tonnes of household food waste being avoided between 2009 and 2012[18]. The series of Courtauld commitments are voluntary agreements funded by the UK government and industry that set out to improve resource efficiency, reduce carbon and water emissions, and reduce waste within the UK grocery sector. The latest – Courtauld 2025 – involves a wide range of players from industry to academia in tackling the issues[19].

The FUSIONS project piloted and evaluated seven social innovations aimed at reducing food waste, including school-based projects and the use of social events. The evaluation concluded that "Whilst social innovation in itself cannot completely solve the issues of food waste and food poverty, the seven FUSIONS feasibility studies, along with evidence from numerous other socially innovative projects, suggests that it can be extremely effective and should be considered as one of a suite of policy tools deployed to tackle the issues"[20].

Building on FUSIONS, REFRESH is an EU research project that also involves China, which aims to contribute towards SDG 12.3[21]. It will develop strategic agreements to reduce food waste with governments, business and local stakeholders in four pilot countries (Spain, Germany, Hungary and the Netherlands), formulate EU policy recommendations and support national implementation of food waste policy frameworks, and design and develop technological innovations to improve valorisation of food waste[22].

Food redistribution also has a role to play in preventing food waste, with recent figures suggesting that at least 270,000 tonnes of surplus food from the UK food and drink industry could be redistributed to feed people each year[23]. In the UK, WRAP leads a Food Redistribution

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▲ **Figure 2. An anearobic digestion (AD) facility, which can recycle food waste to generate biogas which can be used to produce renewable energy. (© loraks | Fotolia)**

Industry Working Group, as part of Courtauld 2025, which has developed four simple principles to help increase food redistribution without impacting on food safety or brand integrity[24]. One of the UK's major players, FareShare, redistributed more than 10,000 tonnes in 2016 and there appears to be a real focus on increasing this substantially over the next few years, exemplified by a recent goal announced by WRAP and Courtauld Commitment signatories to double surplus food redistribution in the UK by 2020 against a 2015 baseline[25].

Surplus food that cannot be redistributed to humans can, where it is safe to do so, be fed to animals. Millions of tonnes of surplus food is used in this way across Europe, reducing the need for animal feed from other sources. Recent research shows that there is scope to divert more surplus to this source[23], bringing with it environmental benefits.

To help drive progress towards achieving UN SDG 12.3, Champions 12.3 was set up. It is a coalition of leaders from around the world dedicated to inspiring ambition, mobilizing action, and accelerating progress toward achieving SDG Target 12.3[26]. The Champions' recent report concludes that much more needs to be done and calls for governments and companies to:

1. set ambitious targets to motivate action;
2. quantify and report on food loss and waste, and monitor progress over time through 2030; and
3. accelerate and scale up adoption of policies, incentives, investment and practices that reduce food loss and waste.

FOOD WASTE RECYCLING AND VALORISATION

Where food waste cannot be prevented, then current best practice is for it to be collected separately and recycled either through anaerobic digestion (AD) (which generates biogas that can be used to produce renewable energy) or composting. This practice has grown rapidly in the UK[27] and in many other European countries and there is huge scope to do much more of this. The UK food manufacturing industry for example sends 0.5 Mt to recycling and virtually no food waste to landfill[28]. The outputs from the recycling of separately collected food waste through AD and composting, can be used safely as a fertiliser to help grow more food. Recent research has shown the agricultural benefits from both of these forms of recycling supply[29]. There is huge scope to grow this practice right around the world, reducing resource use, greenhouse gas emissions and, where used properly, improving soils.

Not only is there scope to grow the practise of recycling food waste, there is also considerable scope to make better use of underutilised resources in food waste and create new products and value using biological and chemical biorefining techniques. So called advanced 'valorisation' of waste could have real potential to deliver innovative products with lower environmental impact. For example, according to recent research on waste from the food industry, they could be used as feedstocks to produce materials for bioplastics, cleaning agents, cell culture media and even anti-oxidants[30]. There is certainly scope to do much more of this, bringing economic, social and environmental benefits.

WHAT NEXT?

In recognition of the seriousness of the issue, ever more ambitious targets are being set on reducing food waste. In September 2015, countries adopted a set of goals to end poverty, protect the planet, and ensure prosperity as part of a new UN sustainable development agenda[21]. Each goal has specific targets to be achieved over the next 15 years including goal 12.3 which, as noted above, calls on all nations to halve food waste and reduce food loss by 2030. Although it is not binding, it sets a very clear level of ambition and countries will be expected to report progress. The European Union and its member states support the initiative and it is has been adopted in the current draft of the EU Circular Economy package[31].

Individual countries have also set their own goal independent of the UN SDG, with Scotland pledging to cut food waste by a third by 2025[32] and the USA setting a goal of 50 per cent reduction by 2030[33]. Industry bodies have also set targets, for example the Consumer Goods Forum's Food Waste Resolution aims to halve the amount of food wasted within the operations of its retailer and manufacturer members by 2025, through prevention and increased recycling[34].

Ultimately it will be important to know more about what works and to replicate it globally. Voluntary agreements are likely to be part of that picture, and consumers need to play an important role in changing habits and practises. Work in many countries has shown that food waste can be reduced, but even in those that have done a lot of work on this issue like France, Netherlands, Sweden and the UK, no country has got close to UN SDG 12.3 yet. There is time (although only 13 years to hit the SDG goal 12.3) and a need for commitment, measurement and action across supply chains and in the home[21]. There are encouraging signs that we know a lot about how we can deliver the reductions required, but given the progress on reducing food waste in homes has stagnated in the UK in recent years[9], we need to find even more innovative ways of engaging people and helping them change. There is also scope to make much better use of the surplus food and food waste that does arise. These are the challenges and opportunities we face and it will be important to act, and act now. Food is a hugely valuable resource and we need to make much better use of it to help feed the nine billion people that are likely to be living on the planet in 2050.

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Making a meal of food waste

Michelle Reeve reviews the charities and apps that are working towards redistributing surplus food to the community.

Food is wasted at all stages of production and consumption. At the farmers' doorsteps, perfectly edible food is rejected because it does not meet aesthetic requirements by the distributors, retailers or restaurants. From misshapen or non-ripe fruit and vegetables, to eggs deemed to be the 'wrong' shape or texture, these seemingly sub-par foods often simply won't be accepted. Though they may be taken to farmers markets, sales are by no means guaranteed, and leftover produce is often just thrown away. In the UK, this surplus food produced across the grocery supply chain equates to 2.6 million tonnes of food waste per year[1].

It's not just the production side of the industry that's to blame, either. Once the food reaches our homes, we in the UK throw away over seven million tonnes of food annually – over half of which is edible[2]. Despite their magnitude, these numbers actually represent a reduction in food waste from previous years, though

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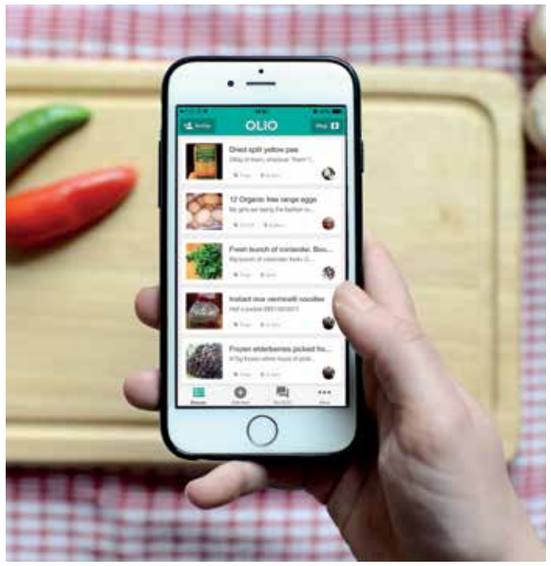

▲ **Figure 1. The OLIO mobile app.**

▲ **Figure 2. Too Good To Go.**

not much was known about the scale of food waste before 2008, when food was still discarded as part of general waste. However, we clearly still have a way to go if we are to significantly lower the amount of food wasted globally, both from the supply chain and from households themselves.

Now that the problem of food waste is better known to the public, businesses are taking steps to reduce the issue. For example, some supermarkets are now introducing 'wonky veg' to their ranges at a lower price than their standard fruit and vegetables, in a bid to encourage consumers to use this produce and prevent it being wasted.

But consumers are also taking matters into their own hands. With the rise of 'easy to use' technology and the prevalence of smartphones, a number of concepts and apps have been developed in order for surplus food to be bought cheaply, given away, or cooked into meals for those in need, redistributing food waste from individual households to big restaurant chains. Until such a time when edible food is no longer being thrown away on such a vast scale, the common mission of these groups is to make sure this excess food is at least put to good use. Here, we feature some of these innovative projects based in the UK and Ireland.

OLIO

In developed countries, over half of all food waste comes from households, with the average UK family throwing away £700 worth of edible food each year ($2,275 for a US family). OLIO[3] is a free app that solves this problem by connecting neighbours with each other, and with local shops and cafés, so that surplus food can be shared. Users (consumers, volunteers or local businesses) upload a photo of their items to the app, and neighbours can request anything that takes their fancy. Items typically found on OLIO include food nearing the end of its shelf life from shops, cafés and markets, cakes from home bakers, and groceries from household fridges when people go away, move home, have a party or go on a diet.

OLIO launched across the UK in January 2015 and in its first year signed up over 125,000 users who have together saved over 170,000 items of food – equivalent to over 35 tonnes and almost 80,000 meals. By harnessing the power of mobile technology to reconnect neighbourhoods, OLIO is enabling thousands of local food sharing networks to flourish, ensuring that our most precious resource – food - gets shared, not thrown away.

TOO GOOD TO GO

Launched in the UK in June 2016, Too Good To Go (TGTG)[4] is a free mobile app which aims to prevent restaurant food waste. Users can purchase restaurant food which would otherwise be thrown away at massively reduced prices and up to a maximum of £3.80. TGTG's mission is to place the lost value back into food as something that should be eaten and not wasted, and through each order they aim to highlight the scale of edible food waste.

Since launching, TGTG have gone on to rescue over 13,000 meals, and now have operations in eight UK cities: London, Leeds, Brighton, Birmingham, Manchester,

▲ **Figure 3. Aoibheann O'Brien and Iseult Ward – the founders of FoodCloud.**

Liverpool, Newcastle and Cardiff. Their app has already been downloaded over 90,000 times, and demand is pressing for the team to add to their partner portfolio of 200 restaurants. Following a successful crowdfunding campaign in autumn 2016, where they raised almost £10,000 from members of the general public, TGTG plan to expand truly nationwide in 2017 on their mission to save even more food from heading to the bin.

FOODCLOUD

FoodCloud[5] is an Irish-based social enterprise which was set up with the aim of addressing the problems of food waste and food poverty by bringing communities together through shared food. FoodCloud has two innovative solutions. Firstly, FoodCloud connects retailers with surplus food directly to local charities in the UK and Ireland through a unique software platform. Using the platform, staff in a store can upload details of their surplus food, and local charities linked to the store through the FoodCloud system receive a text message to notify them of its availability. Secondly, FoodCloud Hubs rescues, stores and redistributes large volumes and a diverse range of surplus food from farms, manufacturers, and distributors to the charities across Ireland in manageable quantities. There are currently three FoodCloud Hubs nationally in Cork, Galway, and Dublin.

FoodCloud and FoodCloud Hubs have facilitated the redistribution of the equivalent of 8.5 million meals of food from food businesses to charities. Their innovative and technology-led approach to surplus food redistribution contributes to a different future, where food waste prevention is recognised as an opportunity that can save resources, create jobs, alleviate hunger, conserve water, and reduce greenhouse gas emissions.

RUBIES IN THE RUBBLE

Rubies in the Rubble[6] is a premium food brand making delicious tasting products from fruit and vegetables that would otherwise be discarded in our food supply chain. They are on a mission to create a market for

▲ **Figure 4. One of the products by Rubies in the Rubble, made with surplus vegetables.**

perfectly good but currently discarded produce, working directly with UK growers to source fresh fruit and vegetables straight from the farm. They use out-graded produce which doesn't meet the aesthetic requirements of supermarkets and which has no secondary market. Examples include berries that are too ripe to meet retailers' shelf life requirements, irregularly shaped Bramley apples which are more costly to peel than regular shaped apples, or tomatoes that are either too ripe or simply in over supply. To date, Rubies in the Rubble have rescued over 700,000 fruits and vegetables; the energy required to grow these could drive a car round the world 22 times!

Rubies in the Rubble believes that we need to better manage what we have. Through their products they aim to be both a practical solution to reducing food waste in our supply chain, and to raise awareness about food waste.

FOODCYCLE

FoodCycle[7] is a national charity working in towns and cities across the UK. They take good food otherwise destined for the bin and put it to good use by cooking community meals for vulnerable people. FoodCycle combines waste food from supermarkets with volunteers and spare kitchen spaces to create hot, tasty, healthy three course meals for people dealing with food poverty and loneliness. This national network of volunteer powered projects runs in Bath, Bristol, Birmingham, Cambridge, Clacton-on-Sea, Durham, Exeter, Leeds, Liverpool, Manchester, Norwich, Peterborough, Portsmouth, Sheffield and across London. Volunteers create positive social and environmental change in their communities, and use surplus food that would otherwise have been wasted.

FoodCycle serves over 750 community meals per week by using over one tonne of reclaimed food. Over 80 per cent of guests say they have made friends and feel more a part of the community since coming to a FoodCycle meal, and over 90 per cent of volunteers have developed a better understanding of other cultures and backgrounds.

CONCLUSION

These projects highlight the breadth of innovation currently occurring to tackle surplus food. Many more such schemes and apps exist, and their numbers are growing. As the public become more aware of the very real problem of food waste, not only are these initiatives increasing in popularity, but pressure can also be put on the supply chain and large food businesses to actively take steps to prevent food being wasted.

It would be wonderful if we lived in a world where edible food was no longer thrown away, but in the meantime, creative and community-building projects like these are succeeding in making sure that food 'waste' is not wasted, but eaten, as it should be.

ES

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▲ **Figure 5. Shop worker giving surplus food to a FoodCycle volunteer.**

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Could environmental 'upstanders' change the way we see food forever?

Kate Power suggests that although conforming to mainstream, high-impact ways of living is 'normal', it is obstructing progress on climate change and food security; could celebrating environmental 'upstanders' challenge norms and break the spell of conformity?

One third of food produced globally is wasted[1], over one third of adults (1.9 billion) are overweight or obese[2], and global per capita consumption of protein is 36 per cent higher than recommended[3]. The world already produces enough food to feed 10 billion people: "Hunger is caused by poverty and inequality, not scarcity"[4].

The way we produce and consume food results in avoidable malnutrition as well as being one of the root causes of climate change - and climate change itself is a major challenge for food security[5].

To break this cycle, there is a need to promote diets that are healthy and environmentally sustainable as part of the overall transformation to low impact lifestyles – not only to feed nine billion people, but also to free up more land for use as a carbon sink, for example through reforestation, in order to have a chance of keeping future temperatures to less than a 1.5 °C rise – which is crucial to food security.

WHY FOCUS ON BEHAVIOUR CHANGE?

Climate change is often portrayed as a technical or political issue that can be solved through renewable technologies and global agreements. While these are essential, it will not be possible to avoid dangerous climate change – and the corresponding threats to global food security – without significant change to our ways of living and organising our society; for example, it is now widely acknowledged that it will not be possible to achieve the goal of the Paris Agreement to limit global temperature rise to less than 2 °C without minimising global consumption of meat and dairy[6].

Political processes are important, but currently too slow to prevent dangerous climate change tipping points from being passed: glaciers are already melting and will continue to melt unless global average temperatures return to their previous, more stable base, regardless of political agreements to "limit warming" to less than 2 °C. There is a need for a rapid shift to a carbon neutral/ carbon negative way of life – which means that our behaviour needs to change.

WHICH CHANGES ARE NEEDED?

Recommendations for 'sustainable behaviours' have tended to focus on individuals taking responsibility for making small, incremental changes that only have a marginal impact on their emissions. For true sustainability to become a reality, a societal shift is needed to ways of living that prevent an increase in global warming.

The word 'sustainable' is often used erroneously to mean 'less unsustainable' or incrementally better than business as usual: this type of marginal improvement is referred to as 'weak sustainability'[7]. Change that is sustainable in the true sense of the word – i.e. change that is commensurate with planetary boundaries – is referred to as 'strong sustainability'[7,8].

There have been efforts to define targets for strong sustainable living, as well as experiments in trying to achieve 'one planet living' or 'one tonne households'[9]. But there is no consensus on maximum and minimum levels of sustainable consumption that would be sustainable while meeting human needs; targets for sustainable living (in developed countries) would enable a more congruous response from authorities, businesses and civil society[10].

Despite the lack of precise targets, it is clear that three quarters of a household's consumption emissions are attributable to food, housing and mobility, and that

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some of the highest impact activities are flying, car driving, home heating and unsustainable diets[11]. The highest impact food related behaviours are consumption of meat and dairy products, and food waste. A recent study projects that by 2050, food-related greenhouse gas emissions could account for as much as half of the possible emissions budget if global warming is to be limited to less than 2 °C[12]; food-related behavioural change is essential for preventing this increase in emissions.

SUSTAINABLE BEHAVIOUR: FOOD CONSUMPTION

Half of the world´s grain crop is fed to farm animals, even though close to 1 billion people do not have sufficient access to food; this is extremely inefficient, as it takes about 3 kg of grain to produce 1 kg of meat[13].

Emissions from livestock farming could be reduced, but the technical abatement available today could only cut the total environmental impact by about 20 per cent[14]. Adopting plant based diets could reduce emissions by up to 70 per cent, which is roughly commensurate with to the reductions in emissions that are required to avoid catastrophic climate change[12]; so, if most people do not switch to plant based diets, additional emissions saving will be needed from even deeper reductions in other areas of consumption, in addition to the deep reductions that are already required.

Research shows that adopting a low impact diet is unpopular with most people, and that reducing dairy consumption is even less popular than eating less meat[15]; there are strong habits, values and social norms around consuming animal products, which has also made it an unpopular target for policymaking.

Changing food habits can be challenging, partly because food tends to be an emotive issue, bound up with our cultural and personal perceptions of what a 'normal' diet is. However, practices and norms do shift – sometimes rapidly, as with attitudes to drink driving, smoking or congestion charges; a recent survey suggests that in the UK, veganism has increased 360 per cent in the last decade and is growing in other countries too[16].

BOX 1. CONSUMPTOGENIC SOCIETY

"When new products and living standards are normalised, not only expectations are formed, but simultaneously, the new standards are built into the social and material structures of society and sometimes even take on the character of constraints. A car-based society with widespread suburban settlements and undeveloped public transport turns the car into a necessity or at least a commodity that requires much dedication to forgo: compulsion becomes the other side of the coin of freedom"[18].

WHY IS CHANGE SO HARD?

We live in a *consumptogenic* society[17]: the institutions, infrastructure, social norms and discourse of society promote and normalise high impact consumption.

Infrastructure encourages us to conform to mainstream patterns of consumption, by facilitating ways of doing things (such as driving to work); this partly determines which behaviours are easy or difficult (for example, see **Box 1**). In this way, consumption of goods and services that may once have been luxurious or aspirational starts to become ordinary, necessary and possibly habitual[19].

In addition to the infrastructural drivers (prices, regulations, availability, technology, advertising etc.), human behaviour is also motivated by a mix of social-psychological drivers (social norms, values, attitudes, identity, habits etc.). Even those citizens who self-identify as 'green' are often not able to undertake all the sustainable behaviours they are aware of or aspire to. Sometimes this is due to lack of time or price disincentives: however, the greatest barriers are social[20].

Our consumption is greatly influenced by the lifestyles of those around us: friends, family, colleagues, and by the lifestyles (both real and fictional) portrayed on television and in the media[21]. Most people find it stressful to have a lifestyle that is significantly different from their peers, and feel that buying less stuff is one of the hardest aspects, due to the pressures of consumerism in wider society[20]. There are usually no taboos for

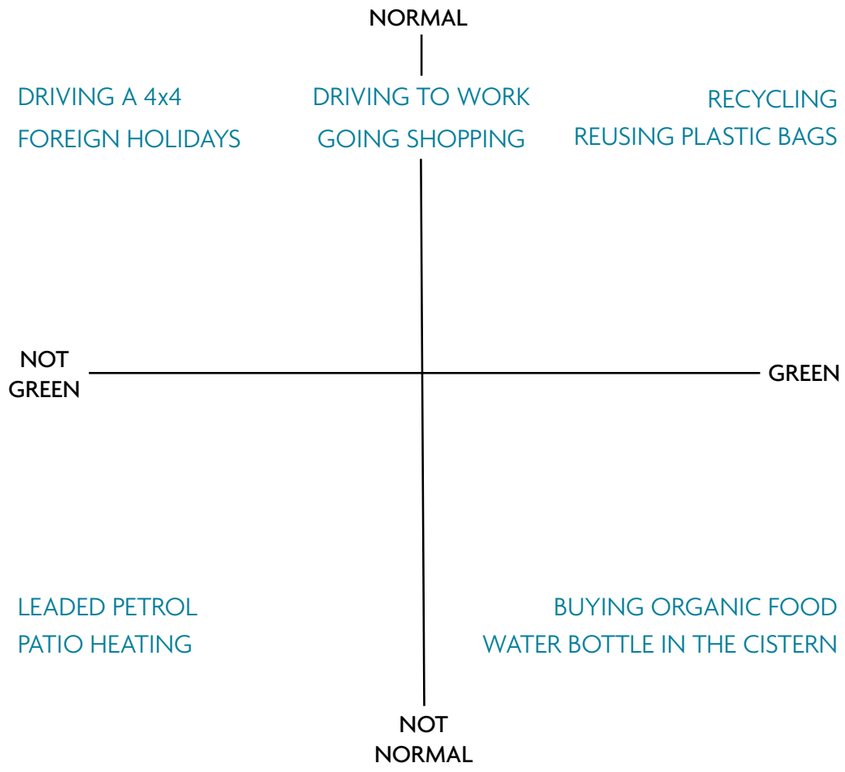
unsustainable behaviours, such as car ownership or meat consumption; in fact, often the reverse is true, and those attempting to live sustainably feel obliged to justify their choices. This has been described as a "*Glass floor*"[22] of taboos and social expectations that makes it difficult for many motivated people to reduce their environmental impact, as it is uncomfortable when our lifestyle is 'outside' mainstream norms and practices.

THE PAIN OF NON-CONFORMITY

When practices are perceived as normal – for example driving a car, or eating meat - they are taken for granted as part of normal life and therefore not challenged, even though people may be aware that they are not sustainable[23]. In addition, other activities that are recognised to be sustainable are not adopted by the mainstream because they are perceived as not normal – for example putting a bottle of water in the toilet cistern to reduce water consumption: one research participant commented "I'm going to tell my friend about that, she'll love that, she's so green", reflecting a general sense that this type of behaviour is for 'green people' rather than 'normal people'[23]. Thus, many people ignore sustainability initiatives that fall outside of current behavioural norms because they perceive them as irrelevant, niche behaviours for sustainable citizens.

Figure 1 shows the extent to which an activity is perceived as normal compared with perceptions of how 'green' it is. It is interesting to note that recycling has been normalised, whereas driving to work is still seen as normal and not yet seen as 'not green'.

Although conformity is a choice, the consequence of not conforming is social sanctions, either at the individual level in the form of guilt – when personal norms[24] are violated – or at the level of the social group[25] through reprimand, social judgement or ostracism[19]. It can involve damage to career and reputation, loss of relationships with friends and family and other tangible negative impacts[26].



▲ **Figure 1. Diagram illustrating perception of certain activities, placing them on scales of normality and sustainability. Adapted from Rettie et al[23].**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Neuroscientists have found that such social rejection activates the same part of the brain as physical pain: we are extremely sensitive to the threat of social ostracism and our brains send clear signals to take action to avoid it[27], possibly because in prehistoric times exclusion from the tribe would have meant extreme risk[28].

Conformity and social norms play a key role in determining ways of thinking and behaving: at present, this powerful instinct is working against sustainability, but if harnessed, could be one of the quickest ways to mainstream low impact practices as normal and desirable and ensure that high-impact consumption behaviour (for example flying, driving, eating meat and dairy products, wasting food) become taboo.

SOLUTIONS: MAINSTREAMING 'GREEN'

Mainstreaming sustainable practices – for example, eating meat only on special occasions – so that they become normal and therefore desirable for most people, can be achieved through governance as well as action by all parts of society. Media and marketing can promote sustainable ways of living as 'normal' rather than 'green', for example, by showing celebrities and authorities performing sustainable practices or using sustainable products, as well as promoting information about the popularity of the behaviours[23]. In addition, it is essential to reposition unsustainable practices that are currently viewed as normal so that they are viewed as 'not normal', socially unacceptable behaviours.

Leadership can contribute to more official changes in normal standards of behaviour. For example, in 2009, the prime minister of Bangladesh ordered male government employees (including ministers) to stop wearing suit jackets and ties to work, to enable air conditioning systems to be used less[29]. Japan has a similar scheme - the Cool Biz campaign - which discourages suits and ties and encourages keeping the thermostat at 28 °C[21]. These examples show how some aspects of consumption behaviour can quickly become more sustainable by relying on conformity to 'new normal' standards of

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▲ **Figure 2. The mayor of Turin has declared it a 'vegetarian city'. © matteozin | Fotolia**

behaviour, especially if powerful and prestigious groups are included, and leadership is utilised to embed new norms.

Businesses can also shift social norms towards more sustainable practices: an example is the oat-milk company *Oatly*, which uses the marketing pitch that their oat milk is 69 per cent lower in terms of greenhouse gas emissions than cow milk. In the summer of 2016, Oatly sponsored a festival in Gothenburg, Sweden, which was entirely milk-free, and at the same time challenged the entire city of Gothenburg to go dairy free for 72 hours to reduce greenhouse gas emissions. The event claims to have saved 3,991 CO_2 emissions during the three days, as well as giving many people their first taste of plant-based milk.

LEADING CHANGE THROUGH GOVERNANCE

National policy making has a profound impact on the framing conditions for consumption, including infrastructure, business practices, economic incentives and societal attitudes and norms. The role of cities and local authorities is increasing as municipalities find themselves on the front lines of climate change mitigation and adaptation – for example, the mayor of Turin has declared it a "Vegetarian city", and plant based businesses are increasing as a result.

Policy makers often fear that interventions targeting consumption will not be tolerated by the public, and it is true that social norms – in this case referring to an assumption about the extent to which others will support a policy and social pressure to conform – are an important determinant of policy acceptability.

However, people will support policies that may initially seem 'too controversial' if they see that others also support the policy – they believe that they will share the individual costs of the behavioural change and benefit from the positive societal consequences[30]. This knowledge can empower policy makers to promote stronger interventions with greater positive environmental impacts, by communicating social norms for sustainability and where they exist, for specific behavioural targets.

BOX 2. POLICY TOOLS AND INTERVENTIONS

- Targets, strategies and action plans, e.g. China´s target of reducing meat consumption by 50 per cent.
- Regulation, e.g. banning advertising of high impact products, such as meat and dairy.
- Economic, e.g. differentiated VAT to incentivise low-impact diets.
- Behavioural, e.g. use of default options to promote plant based dishes in public institutions, such as universities, hospitals, schools, armed forces, prisons, council offices, parliament and ministries, and at public events.
- Informational, e.g. health professionals and educators informed of the health benefits of reduced animal consumption and possibilities for healthy, plant based diets.
- Business models and business self-regulation (also in response to civil pressure), e.g. retailers agreement to limit '3 for 2' offers on perishable food in order to avoid food waste.

IF YOU CAN´T 'BE THE CHANGE', SUPPORT THE CHANGE

The term 'upstander' refers to anyone that stands up against injustices[31], and this term is often used with regard to anti-bullying or violence prevention programmes. In relation to sustainability, the term 'upstander' could refer to people who are reducing their environmental footprint, those involved with community sustainability initiatives, businesses and institutions achieving a net positive impact, activist organisations and protesters, and people who are sustainability pioneers within mainstream institutions, which could include researchers, policymakers and many others.

Celebrating upstanders and making their actions visible can help to break the spell of conformity: some of the

classic experiments of psychology show that observing even one other person ´doing the right thing´makes us much more likely to act upon what we know is right, even if we are acting in opposition to the mainstream[32,33].

Providing support to upstanders could be achieved in a variety of ways: perhaps even just using the term 'upstanders' might help to positively frame sustainable practices. Many existing programmes train people to recognise social influences such as conformity, and practise resisting them in everyday situations[34] mostly in relation to social situations, such as discrimination; utilising such techniques to normalise sustainable behaviour could be transformational.

It is high time to acknowledge that mainstream Western lifestyles are unethical and destructive: creating a taboo against high impact behaviours such as eating animal products, air travel and car driving is imperative if we are to prevent catastrophic climate change and create a just society that can redistribute land and food fairly among nine billion people.

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CASE STUDY

Alternative proteins: meet the future of meat

Victoria Circus discusses recent psychological research on alternative proteins, and how a fondness for conventional meat may influence your opinions of them.

Meat production has a negative impact on the natural environment in a number of ways from intensive resource use, deforestation and habitat loss to the emission of harmful greenhouse gases. Shockingly, meat production is responsible for more emissions than the whole of the transport sector combined[1]. This downplayed environmental secret is beginning to become common knowledge.

So why do we continue to eat meat? There are many biological, economic, psychological, social and cultural factors at work: the desire to be full, a craving for a savoury flavour, pure enjoyment, nutritional reasons such as its high protein content, its ease of availability, and a familiar food within friend and family circles which can ultimately define our identity, are just some of the reasons why we continue to consume meat despite its environmental impact. Relating to identity, 'meat attachment' is a recently identified construct that has been found to negatively correlate with an openness to vegetarianism. It is measured through answers to a series of questions aiming to identify how much eating meat is part of a person's identity. For example, an avid meat eater would have a high meat attachment score and a low openness to vegetarianism score, with a vegetarian scoring the opposite. This construct has been used in studies looking at the underlying attitudes of participants who were reducing their meat consumption, and will be discussed in further detail at a later point.

In order to mitigate the harmful impact conventional meat has on the environment, a widespread reduction in consumption is needed. However, already the notion of 'reduction' in itself is pitted against the antagonistic human tendency for loss aversion[2], and generally not wanting to go without. 'Alternative' meat-like products instead may be able to provide the biological, physical, psychological, social and cultural comforts that conventional meat offers its consumers. A rethink of our meaty preferences is especially needed when considering the future backdrop of population growth and increases in global meat consumption.

MEET THE NEW MEAT

Three alternative 'meaty' products that have been identified as emerging novel protein sources by the UK Food Standards Agency[3], are laboratory grown meat, edible insects and meat substitutes.

Laboratory-grown (or in vitro) meat is grown as a cell culture in a growth medium instead of inside an animal. It is estimated to be commercially available within the next five years[4]. Laboratory-grown meat attracted a lot of attention in 2013 when the first burger to be grown in a laboratory was ready to be taste tested by food critics. Much of the focus was on its hefty price tag; not exactly a bargain at £125,000. The critics claimed that it had a meaty texture and consistency, but

lacked juiciness. Compared to conventionally farmed livestock, laboratory-grown meat is considerably less damaging to the environment, producing 96 per cent fewer greenhouse gas emissions, using 45 per cent less energy and requiring 99 per cent less land to produce[5,6], making it an attractive sustainable alternative.

Insects are typically consumed in non-Western cultures, where up to 96 different insect species are known to be eaten by humans[7]: ants, beetles, caterpillars, crickets, grasshoppers, locusts and termites to name just a few. These insects also emit fewer greenhouse gases than conventional livestock[8] and have lower land use requirements due to their size. In addition, up to 80 per cent of their bodyweight is edible and digestible, compared to just 55 per cent of a chicken and 40 per cent of a cow, thus providing a highly efficient source of protein.

Meat substitutes attempt to mimic the characteristics of conventional meat through their texture, flavour and appearance. They are usually made from plant and fungi-based sources such as soya, wheat, gluten and mycoprotein. The production of a plant-based diet has also been found to require significantly less land and water than its meat-based counterpart[9,10].

An increase in health awareness, consideration of animal welfare and sustainability are helping to drive the consumption of meat substitutes, and the expanding market for them is set to be worth £3.8 billion by 2020[11].

CURRENT ISSUES WITH ALTERNATIVE PROTEINS

Rationally speaking, all three are more sustainable and protein-rich alternatives to conventional meat, therefore we should all be actively seeking to eat them at the next available opportunity, right? Well, a basic psychology lesson[12] will teach you that unsurprisingly, humans don't always make rational choices. Evidently so, alternative proteins remain just that; 'alternative', because they are competing against cheap, available and socially acceptable conventional meat.

So what exactly is getting in the way of us making more sustainable protein choices? A limited number of consumer studies[13,14] and online polls offer an insight into the perceived psychological barriers that stand in the way of the consumption of alternatives. With laboratory-grown meat, it is deemed unnatural, and suffers from other key issues, such as health and safety, high cost, and potential negative social and economic repercussions. Similarly, disgust and the so-called 'yuck factor' are key problems clouding the perception of insects as appealing and appropriate sources of protein. Meat substitutes are often seen as being lower in sensory attractiveness compared to conventional meat, and often face the consequences of food neophobia[15].

Research on psychological drivers and understanding the reasons why consumers choose alternative proteins over conventional meat is even more limited, however some has been carried out. For example, the environmental benefits of laboratory-grown meat and the positive ethical and moral implications of meat substitutes are a major selling point. Are these benefits enough to outweigh powerful emotional and psychological responses, such as disgust and health and safety concerns? We only need to look at how controversial topics such as genetically modified food have been received by the majority of the public, to know that communication around novel types of food and issues of public safely need to be dealt with very carefully in order to prevent their reception being disastrous.

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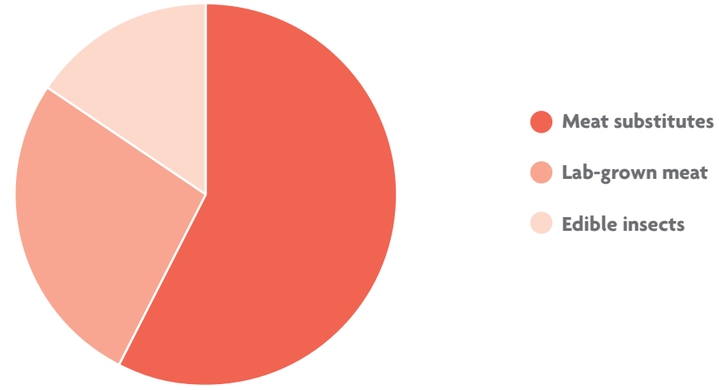

▲ **Figure 1. Results of a public survey indicating the popularity of different alternative proteins being considered for consumption as part of an everyday meal [16].**

It seemed to researchers at the Global Sustainability Institute that in order for these products to stand a chance at being accepted by consumers and be seen as viable alternatives to conventional meat, then a further understanding was needed of the psychological perceptions towards them.

WHAT WOULD YOU EAT?

A study was carried out using informal focus groups where members of the public were invited to openly discuss all of the different reasons why they personally would or wouldn't want to eat the three alternatives, for the development of an online survey. Many barriers and drivers to consumption were identified and these were condensed into categories and used as suggested options in the subsequent survey. Unlike similar studies, the researchers chose to recruit meat eaters, vegetarians, vegans, pescatarians and all manner of special diet-followers so as not to overlook any potentially interesting insights. In the survey, participants were asked whether they would eat laboratory-grown meat, insects or meat substitutes as part of an everyday meal. The alternatives varied in popularity, with the findings displayed in **Figure 1.**

Being the least popular, the main reason why people said they wouldn't want to eat the edible insects were psychological or emotional issues such as disgust, which aligned with previous research. Other key reasons included them being perceived as having an unappealing appearance, taste or texture and people preferring other sources of protein. The main reasons why people favoured meat substitutes were for moral or ethical reasons including animal welfare considerations, followed by health or nutrition benefits and them being perceived as environmentally friendly.

A measure of meat attachment was also incorporated into the survey in order to see how this construct interacted with people's perceptions of alternative proteins. It was found that people who were more attached to eating meat were more likely to want to consume laboratory-grown meat and edible insects with the top reason being their perceived environmental friendliness. People less attached to meat, who were mostly vegetarians and vegans, were more likely to want to consume meat substitutes for moral and ethical reasons.

IMPLICATIONS FOR TAILORED MESSAGING

This study offered an insight into the psychological deliberations of different individuals towards more sustainable alternative proteins. Significant differences have been identified between the perceptions of participants who are more or less attached to eating conventional meat. The implications of this research links back to the underlying motivation of wanting alternative proteins to be more widely consumed in order to begin mitigating the environmental impact of conventional meat.

CASE STUDY

The findings could be used for tailored messaging by companies promoting these alternatives. Understanding the psychological drivers to consumption of these products means they can be applied in marketing and advertising. Evidently, the environmental and sustainability benefits of both laboratory-grown meat and insects needs to be highlighted in campaigns aiming to promote them as viable alternatives, particularly to people who currently enjoy eating conventional meat. This could be done by using eco-labelling, for example. In several years' time when laboratory-grown meat is commercially available, if consumers in a supermarket have the choice between a conventional beef burger and a laboratory-grown beef burger packaged with a green sticker sporting an environmental message such as 'Future Friendly', then this might be the nudge they need to choose the more sustainable option. Similarly, emphasising the moral and ethical arguments for consumption of meat substitutes to people less likely to be attached to meat, may increase their consumption. For example, an advert in a vegetarian magazine might have a humorous animal welfare related slogan such as "No animals were harmed in the making of this lunch" to advertise a new range of plant-based meat substitutes. At the same time, focusing away from the psychological barriers to consumption of some alternatives, is also needed, such as the unappealing appearance and disgust response associated with edible insects. This may be done through product development, such as harnessing the beneficial nutritional content of edible insects, but processing and presenting them in more appealing ways. For example, obtaining protein from a powdered insect flour used in a chocolate chip cookie might be received more favourably than crunching down on a whole, quite obviously recognisable, cricket.

Applying the findings of academic research and diverting the focus away from the psychological barriers to consumption of specific alternative proteins, and placing an emphasis instead on the main drivers, would help generate tailored messaging when promoting these alternatives for consumption. When pitted against cheap, available, socially acceptable, yet environmentally costly conventional meat, this could be the first step towards a more sustainable future of food.

ES

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