EVIDENCE REPORT
No 149

Policy Anticipation, Response and Evaluation

Edible Insects and the Future of Food: A Foresight Scenario Exercise on Entomophagy and Global Food Security

Dominic Glover and Alexandra Sexton

September 2015

The IDS programme on Strengthening Evidence-based Policy works across seven key themes. Each theme works with partner institutions to co-construct policy-relevant knowledge and engage in policy-influencing processes. This material has been developed under the Policy Anticipation, Response and Evaluation theme.

The material has been funded by UK aid from the UK Government, however the views expressed do not necessarily reflect the UK Government's official policies.

AG Level 2 Output ID: 261

EDIBLE INSECTS AND THE FUTURE OF FOOD: A FORESIGHT SCENARIO EXERCISE ON ENTOMOPHAGY AND GLOBAL FOOD SECURITY

Dominic Glover[a] and Alexandra Sexton[b]
[a] Institute of Development Studies
[b] King's College London

September 2015

First published by the Institute of Development Studies in September 2015

Contents

Acknowledgements 3
About the authors 4
Abbreviations 5
Executive summary 6

1 Introduction 8
1.1 Background 8

2 Insects as food and feed: an overview 12
2.1 Human entomophagy: a global perspective 12
2.2 Nutritional profiles of edible insects 13
2.3 Potential environmental advantages 13

3 Methodology 16
3.1 Literature review, questionnaire and online discussion 16
3.2 The Foresight scenario exercise 16
3.3 Identifying drivers of change (STEEP) 17
3.4 Scenario framework 20

4 Scenarios 21
4.1 Scenario 1: A gated world 21
4.1.1 Context 21
4.1.2 Food production and consumption 21
4.1.3 Edible insects 22
4.1.4 Implications for global food security and food system sustainability 23
4.2 Scenario 2: New Asia 23
4.2.1 Context 23
4.2.2 Food production and consumption 24
4.2.3 Edible insects 24
4.2.4 Implications for global food security and food system sustainability 25
4.3 Scenario 3: Mundus middle-class 26
4.3.1 Context 26
4.3.2 Food production and consumption 26
4.3.3 Edible insects 27
4.3.4 Implications for global food security and food system sustainability 28
4.4 Scenario 4: Bread and circuses 28
4.4.1 Context 28
4.4.2 Food production and consumption 29
4.4.3 Edible insects 29
4.4.4 Implications for global food security and food system sustainability 29

5 Discussion and conclusions 31
5.1 Edible insects as food and feed 32
5.2 Will consumers bite? 33
5.3 Edible insects and global food security 35
5.4 Reflection on the value of Foresight scenarios 35
5.5 Conclusions 36

Annex 1 **Examples of insect-based food products on or near the retail market in Europe and North America** **37**

Annex 2 **Some producers of insects for livestock and fish feeds** **39**

Annex 3 **Overview of Foresight methodologies** **40**

Annex 4 **Questionnaire used to stimulate the online discussion** **43**

Annex 5 **Summary of the online discussion** **48**

Annex 6 **List of participants in the scenario workshop** **55**

References **56**

Boxes

Box 1.1 Meat alternatives: some novel protein foods 9
Box 1.2 Edible insect products on the market 10
Box 1.3 Chirp! Some Twitter accounts focusing on entomophagy 10
Box 2.1 Small-scale rearing of edible insects 15
Box 4.1 A day in the life: Oskar 22
Box 4.2 A day in the life: Aasiya 22
Box 4.3 A day in the life: Layla 25
Box 4.4 A day in the life: Pavel 27
Box 4.5 A day in the life: Byung-joon 29

Figures

Figure 2.1 Insects consumed by humans, by order 12
Figure 3.1 Scenario framework 20
Figure A1 STEEP drivers of change 40
Figure A2 Scenario example 41
Figure A3 Windtunnelling template 42

Tables

Table 3.1 STEEP drivers of change identified by workshop participants 18

Acknowledgements

We appreciate the support, advice and contributions of Alun Rhydderch of the School of International Futures; IDS Fellows Jim Sumberg, Gerry Bloom and Nick Nisbett; Kelly Shephard, Adrian Bannister and Steve Tovell from IDS Knowledge Services; IDS administrators George Powell-Stevens and Ollie Burch; Marcel Dicke; Andrew Müller; participants in a roundtable discussion on edible insects and the future of food – Arnold van Huis, Douglas McMaster, James Wilsdon and Nick Rousseau; IDS catering manager Gabriel Gutierrez and his team, including student volunteers Susan Nyirenda, Felicity Taylor, Walter Chenyika, Chidabha Chitsamphandhvej and Aditi Bhonagiri; the participants in our scenario workshop (whose names are listed in Annex 6); and the participants in our online discussion, whose names we do not have permission to list here.

About the authors

Dominic Glover is a Research Fellow in the Rural Futures cluster at the Institute of Development Studies (IDS) and member of the ESRC STEPS Centre, both based at the University of Sussex, Brighton, UK. His work focuses on issues to do with technological change, primarily in small-scale agriculture in the global South.

Alexandra Sexton is a PhD student and member of the Environment, Politics and Development Research Group in the Geography Department at King's College London, UK. Her PhD research is exploring the (bio)political and moral implications of alternative proteins, including lab-cultured meat, edible insects and plant-based proteins.

Abbreviations

BBQ	barbeque
BRICS	Brazil, Russia, India, China and South Africa
CSR	corporate social responsibility
EU	European Union
FAO	Food and Agriculture Organization
GHG	greenhouse gas
GMT	Greenwich Mean Time
HMMA	high-moisture meat analogue
IDS	Institute of Development Studies
INGO	international non-governmental organisation
MOOC	massive open online courses
NGO	non-governmental organisation
SCP	single cell protein
SOIF	School of International Futures
SPRU	Science Policy Research Unit
STEEP	Social, Technical, Environmental, Economic and Political
US	United States

Executive summary

This document reports on the findings of a small project in which we used the tools of Foresight to think about the potential of edible insects to contribute to global food security in a future global food system. Foresight offers a tool box of approaches and methods for thinking about the future in a methodical, deliberative way. Foresight methods can be used to anticipate (rather than predict) plausible future developments, which can help society to prepare itself to meet future challenges, and also to think about ways to steer towards desired futures and avoid negative outcomes.

Researchers have identified more than 1,900 species of insect that feature in human diets around the world. Edible insect species in general are found to be good sources of healthy protein together with some fat and dietary fibre, along with useful quantities of important micronutrients. It has been proposed that edible insects could make a significant contribution to global food security in the future. Specifically, some experts think that insects could be a more sustainable source of protein compared to conventional livestock because they convert feed to edible food more efficiently than chickens, pigs and cattle, while producing fewer greenhouse gas emissions and requiring less land and water. Edible insects are also being developed as an alternative feed for conventional livestock and farmed fish, in place of grain crops and fishmeal.

To consider the potential contributions of edible insects in the future global food system, we undertook three activities: a literature review; an online guided discussion with stakeholders, incorporating a questionnaire; and a Foresight scenario exercise. We involved stakeholders in the online discussion and scenario workshop who possessed relevant knowledge and expertise in fields such as entomophagy (insect-eating), nutrition, food security, public health and regulation.

The participants in the scenario workshop identified a selection of major trends and drivers of change that they expected to play significant roles in shaping the future. Two important themes were selected as axes to provide a structure for the scenario exercise. The chosen axes were *resource scarcity (intensified vs eased)* and *economic power (concentrated vs distributed)*. These two axes created four quadrants to be populated with future scenarios. The four scenarios developed by the workshop participants were as follows: *A Gated World* (characterised by concentrated economic power with intensified resource constraints); *New Asia* (characterised by distributed economic power and intensified resource constraints); *Mundus Middle-Class* (characterised by distributed economic power and eased resource constraints); and *Bread and Circuses* (characterised by concentrated economic power and eased resource constraints).

The scenarios depicted four different future worlds with remarkable vividness. Edible insects featured in all four scenarios, suggesting that some kind of edible insect sector producing food and feed is quite likely to emerge, and that funding for research into production technologies and safety issues would be a legitimate investment. In all four cases the sector was envisaged as bifurcated into a fine foods concept at one pole and a mass-produced protein substitute at the other. It is the relative size and importance of these two segments that varies between the different scenarios. The relevance of insect-based feeds in each scenario depended largely on whether conventional meat products remained an affordable and socially accepted option for consumers. Where this practice remained acceptable, insect-based feeds could contribute to making conventional livestock production more sustainable.

A future of widespread entomophagy is plausible but many challenges would need to be addressed before the industry could emerge on a substantial, even global scale. Research is needed into production and processing technologies and food safety issues. The economic viability of a future edible insect sector is substantially uncertain at present. It will depend on the size of the eventual market for edible insects as well as the scale economies of insect production and processing.

Human entomophagy could increase the availability and affordability of healthy protein in the developing world. Countries in tropical regions where insect-eating is already established may be in the best position to expand this market, and companies in these regions may have a competitive advantage in serving it. As developing countries become wealthier, insect-based foods may offer a more sustainable way to meet future protein requirements than conventional meat. However, the assumption that it will be easier to persuade consumers to eat insects than convince them to eat less meat should be tested, and it is possible that other meat alternatives such as vegetable or algal proteins may be as sustainable and marketable as insect-based foods, or even more so.

1 Introduction

1.1 Background

Insects have long been part of the human diet, though in most Western countries insects are generally regarded as pests rather than something good to eat. Today, some experts and entrepreneurs are proposing that edible insects should be developed as a sustainable source of quality protein for an expanding global population – a source that would have a much smaller environmental footprint than conventional meat (Looy, Dunkel and Wood 2014; van Huis 2013). This report considers this proposition using the tools of Foresight, which is an approach to thinking about how to prepare ourselves to meet future challenges and opportunities, and how to steer towards the kind of future we want.

How might humanity feed itself in the coming decades? United Nations statisticians have estimated that the global population may exceed 9.5bn by the middle of this century and continue to rise thereafter (Gerland *et al*. 2014). Increasing wealth is expected to drive higher average levels of consumption, including richer diets that incorporate more meat. Ongoing processes of urbanisation and land degradation are expected to reduce the amount of available land suitable for agriculture. Even without these looming threats, the existing ecological footprint of the global food system (production and consumption) is already considered unsustainable by many experts. The rearing of livestock to produce meat and dairy products is particularly troublesome because of the demands it places on land and other vital resources (Conway 2012; Godfray *et al*. 2010).

World prices for grain are expected to rise in the coming decades, which will increase the price of meat. This trend is stimulating the development of alternative protein sources. Edible insects are one of a range of novel 'meat alternatives' that are intended to deliver adequate quantities of healthy protein while using much less land and water than conventional meat production systems, and cutting greenhouse gas (GHG) emissions at the same time (see Box 1.1). A variety of insect-based foods are already on the market in Europe and North America, including freeze-dried whole insects and ground insect flours as well as a selection of ready-to-cook and ready-to-eat burgers, pastes, snack foods, pasta, baked goods, protein bars and confectionery items (see Box 1.2).

Eating insects is an idea that is currently attracting a lot of attention in mainstream and social media (see Box 1.3). Entrepreneurs and technical experts aspiring to create an industry producing edible insects for human consumption in Europe and North America, where insect-eating is not a widespread tradition, are lobbying lawmakers to create clear and permissive regulatory frameworks that would allow insects to be economically produced and sold as food and feed. What might be the implications of widespread entomophagy (insect-eating) for populations in poverty or in poorer parts of the world that are currently food-insecure? Could human or livestock entomophagy have an appreciable, positive impact on food and nutrition security in the expanding urban centres of the world, or in the global South? And if insect-eating were to take off in a big way, what would the edible insect sector look like? For example, where would insect-rearing and processing facilities be located? How big would they need to be and might they create jobs and enterprises for people? Would they displace existing livestock systems? Could edible insects make protein production more environmentally sustainable and improve the supply of affordable, healthy protein? These are the kinds of questions that face the entrepreneurs and scientists that are exploring the commercial potential of this sector.

Box 1.1 Meat alternatives: some novel protein foods

Novel protein foods can offer a high-quality alternative to animal protein with attractive features that distinguish it from conventional meat, including a smaller ecological footprint, a more humane production process and the ability to precisely calibrate nutritional content. A key challenge for novel foods in this market is to deliver an attractive product that has appealing sensory qualities that make it a viable substitute for meat.

Proteins from micro-organisms

Scientists have contemplated and investigated the use of micro-organisms to produce protein for over a century, both as a means to stave off an impending food crisis and as a commercially competitive alternative to conventional protein sources. The term 'single cell protein' (SCP) was adopted to embrace microalgae, bacteria, yeast and fungi. SCPs contain a high proportion of protein by weight, can be reared on readily available feedstocks such as agricultural and food wastes, cellulose, hydrocarbons and sewage, and require little land or water (Kihlberg 1972).

In the 1970s, huge investments were staked in SCP research by novel partnerships between petrochemicals companies and food businesses, in collaboration with public research institutes and prominent universities (Kihlberg 1972). In the context of the 1970s oil crisis and contemporary concerns about the 'population bomb' (Ehrlich 1968), some people thought that SCPs would be a vital food source to prevent mass starvation. In reality, over several decades, SCP research eventually yielded just a few commercial products such as:

- *Quorn*™, a mycoprotein (of fungal origin), developed in the 1970s by a partnership of the British chemicals company ICI and the UK-based food company Rank Hovis MacDougall, first commercialised in the UK in 1985.[1]
- *Algavia*™ lipid (fat) powders and protein flours derived from microalgae, developed and commercialised by Solazyme, Inc., a California-based biotechnology company established in 2003.[2]

Lab-cultured meat

Researchers at Maastricht University in the Netherlands have developed an experimental method for culturing animal stem cells, harvested painlessly from muscle tissue, *in vitro* (Post 2012). In August 2013, a sample of the lab-cultured meat product, in the form of a burger, was cooked and tasted during a public event in London, UK.[3]

Plant-based meat analogues

Plant-based meat substitutes based on soya (tofu) or texturised vegetable protein have been around for decades, but they have never captured more than a very small share of consumer demand, compared to meat. Recent developments in processing technology (especially extrusion) have led to the development of a new family of meat substitutes known as high-moisture meat analogues (HMMAs). These comprise carefully calibrated mixtures of vegetable flours (containing protein), starch, binding agents and fats together with flavourings, colourings and water, which are mechanically processed to produce edible protein substances that closely resemble meat in terms of texture, moisture and 'mouth feel'. Examples of commercial HMMA products include *Beyond Meat*,[4] *Match Meats*[5] and *Plenti*[6] (Zorpette 2013).

[1] www.quorn.co.uk (accessed 3 June 2015).
[2] www.algavia.com (accessed 3 June 2015).
[3] http://culturedbeef.net (accessed 3 June 2015).
[4] www.beyondmeat.com/ (accessed 3 June 2015).
[5] www.matchmeats.com/ (accessed 3 June 2015).
[6] http://plenti.eu/ (accessed 3 June 2015).

Box 1.2 Edible insect products on the market

Eating insects might seem strange in the West, yet there are already commercial edible insect products on the market that have been developed and marketed by numerous small start-up companies and food businesses (See Annex 1). Edible insect products hit supermarket shelves in Denmark, Belgium and the Netherlands during 2014. The Dutch chain Jumbo launched a range of edible insect foods at selected branches in November 2014 and began to offer the products in all its branches from January 2015 (BBC News 2014; EVMI 2015). In Denmark, the upscale supermarket chain Irma offered edible insect products in March 2015 but withdrew them after just two days because of concerns surrounding the uncertain legality of retailing edible insect products (*The Local DK* 2015). The regulatory status of edible insects in Belgium was clarified in January 2014 when the country's food safety authority approved ten insect species for human consumption (*Flanders Today* 2014a). Within months, two of the largest supermarket chains in the country, Delhaize and Carrefour, began stocking the products (*Flanders Today* 2014b; Sudinfo.be 2014).

Box 1.3 Chirp! Some Twitter accounts focusing on entomophagy

This is an incomplete list of Twitter accounts run by organisations and individuals who tweet about entomophagy:

@SahakhunBugFarm @green_kow @EntoMarket @ClourPower @snicketshq @criknutrition @VantommePaul @GoldenMetugi @UNinsectario @TheEdibleInsect @weeatinsects @LaViewEye @EdibleInsectNet @Bugzz_NL @EatBugsDetroit @ediblebug @entonote @DiminiCricket @BugsForDinner @ozark_fiddler @CricketFoods @EntoBentoFoods @gabeaspires @ediblebugfarm @EntoTheWild @JappTM @insectinfood @insectenmaal @kaki_enam @bugeaterlabs @FloEntoMove @Insectitos @FFPIDI @HotBuzzFood @chirpcuisine @AspireAmerica @AspireFG @bugburger @gyro_bars @uKaProteine @ThaiUniqueEU @HiCricket @CedricAuriol @MIGHTinsects @jahouse @go_ento @BugVivant @CrowbarProtein @jacuna_mx @TheRealCrickers @Entowarehouse @GREEiNSECT @TheBugShack @BigCricketFarms @GourmetCricket @ViurInsects @entovita @bugsenzo @cricklets @EntomophagyGuy @CndEntomophagy @InsectsFoodFeed @ISFFInsects @INSECTPOINT @BugsontheMenu @CritterBitters @PupaPlanet @InsproFoods @insecteo @Protein2050 @EatYummyBugs @entomoproject @eatgrilo @BenSBugs @EntoTech @Aldento_Sisters @MealFoodEurope @darjadobermann @4entoFEED @EuropeEntomo @KatharinaUnger1 @Insectiboro @eatgrubofficial @BittyFoods @SwissBugBurgers @exo_protein @BugGrub_com @AnaCDay @tiny_farms @EntomophagyWork @entomophagy1 @Micronutris @INSAGRI @OfBug @bugshop1 @Entomovores @Insecten_Eten @InFoods @eat_ento @bugmuscle @ediblebugs @insectfood @Juggling_Doctor @WorldEnto @BushGrub @grub_kitchen @RAINBOWMEALWORM @Turbobail @DonBugitoSF @SouthSouth1 @AndreaHitchon @insectescom @jkinyuru @read_and_eat_ @DrBugAppetit @Doo_s @wlu @AboutInsects @entophile

This report examines these issues from a development perspective. To do so, we used the methods and tools of Foresight. Foresight emerged originally in industry and has since been embraced by governments and other entities that are trying to prepare themselves to meet future challenges and opportunities. Foresight methods have been used in policy and planning by organisations engaged in international development policy and practice, including the UK government, agencies of the United Nations, the Rockefeller Foundation, international non-governmental organisations (INGOs) and governments in Africa (Bingley 2014; Ramalingam and Jones 2007).

Foresight is an approach to thinking about the future in an ordered, methodical way. More rigorous than speculation, it is, however, not concerned with prediction (which is essentially impossible) and certainly excludes crude extrapolation of historical trends into the future. Rather, Foresight is about thoughtful, deliberative *anticipation* of plausible developments that

might unfold. The Foresight toolkit includes a selection of quantitative and qualitative methods that may be used to help consider the possible ramifications of current activities and decisions; to identify future threats and opportunities and prepare to meet, avoid or exploit them; and to think about desirable futures and ways to steer towards them (Bingley 2014; Ramalingam and Jones 2007).

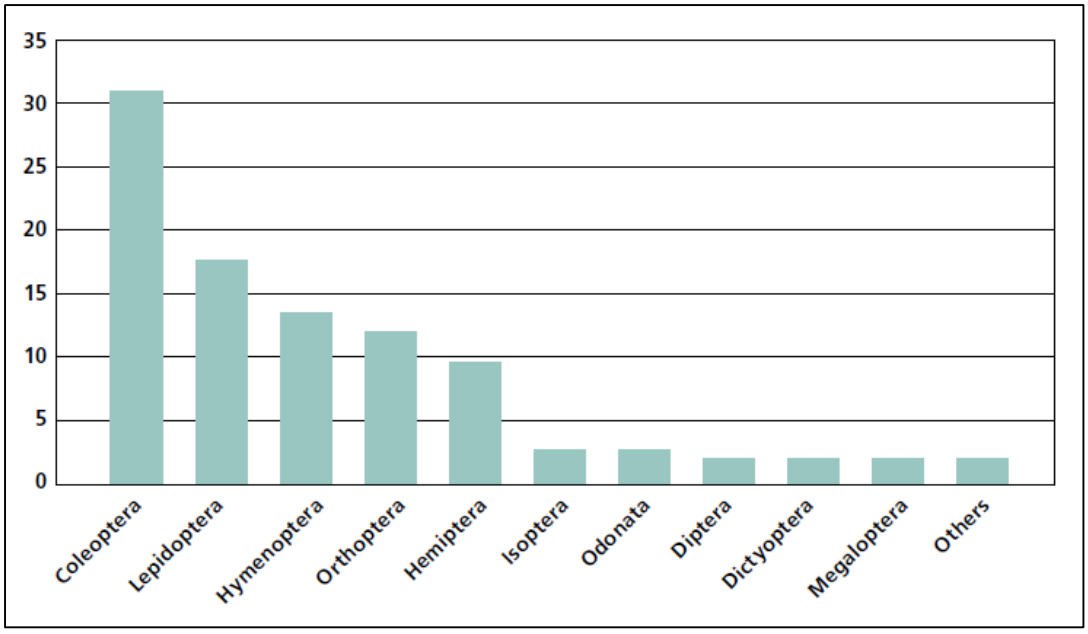
In the next section we present some technical information about edible insects and insect consumption. We then describe the set of Foresight methods used in this project, before presenting a set of future scenarios elaborated by participants in a Foresight workshop. We discuss the content of the scenarios and consider what insights they offer regarding the potential benefits and drawbacks of edible insects as a contribution to global food security in the coming decades. We then offer some reflections on the use of Foresight methods in this area and consider how they might be integrated with other methods and approaches. The final section summarises and concludes.

2 Insects as food and feed: an overview

2.1 Human entomophagy: a global perspective

Researchers at Wageningen University in the Netherlands have estimated that more than 1,900 insect species feature in human diets around the world, although it is difficult to be precise about the numbers. The most commonly consumed insects worldwide belong to the orders Coleoptera (beetles), Lepidoptera (butterflies and moths, mostly consumed as caterpillars), Hymenoptera (bees, wasps and ants), Orthoptera (grasshoppers, locusts and crickets) and Hemiptera (cicadas, leafhoppers, planthoppers, scale insects and true bugs) (See Figure 2.1). The favoured species differ regionally. Insects are consumed by people in dozens of countries, particularly in Southeast Asia, Oceania, southern Africa, Central America and the northern part of South America (van Huis *et al*. 2013: 9–10).

Figure 2.1 Insects consumed by humans, by order



Source: van Huis *et al*. (2013: 10). Reproduced with permission.

In some regions, the contribution of insects to the human diet has been appreciable. For example, in Zaire in the early 1960s it was estimated that about 10 per cent of the animal proteins produced in the country annually came from insects, and in certain areas of the country insects provided between one-quarter and two-thirds of the animal protein consumed by people.[7] A separate study estimated in the 1980s that the Tukanoans of Colombia obtained around 5–7 per cent of their animal protein from insects, peaking at up to 26 per cent (for women) in the May–June period. Peru and Zimbabwe are two other countries where entomophagy is thought to have contributed substantially to human food security (DeFoliart 1989).

Some scholars believe that the number of species and volume of insects consumed by people in the 'developing world' is likely to have been overlooked or systematically underestimated. They contend that insect species are not always merely a food of last resort – consumed to stave off hunger in times of food shortage – but seasonally available foods,

[7] Zaire is now the Democratic Republic of the Congo.

often prized as delicacies, that are integrated routinely into the diet. In some countries edible insects are widely traded commodities, for example *mopane* worms[8] in southern Africa and *chapulines*[9] in Mexico (DeFoliart 1989; van Huis *et al*. 2013).

2.2 Nutritional profiles of edible insects

The nutritional composition of edible insect species varies, but in general insects are found to be good sources of protein, some fat and some fibre. The proportion of protein per 100g of various insect species compares favourably with that from mammals, reptiles and fish. In terms of protein quality, edible insects can supply a range of essential amino acids, sometimes providing a vital supplement for the amino acid deficiencies of local staple foods. Some insect species contain considerable quantities of healthy unsaturated fats and essential fatty acids. Insects generally also contain high quantities of important micronutrients, such as iron and zinc, for example, while some also contain useful amounts of certain vitamins (DeFoliart 1989; van Huis 2013; van Huis *et al*. 2013).

The food value of edible insects depends to some degree on what the insects themselves have eaten, which leads to the supposition that the diets of insects raised for human or animal consumption could be modified to improve or optimise their nutritional value (van Huis 2013; van Huis *et al*. 2013).

Many insects are scavengers and this creates concerns about their possible role as vectors for the transfer of pathogens to livestock and humans. Insect pathogens are regarded as harmless or of very low potential risk to vertebrates; however, it is possible that bacteria, fungi, viruses or toxins (such as cadmium and lead) that are ingested by insects might accumulate in their bodies and be passed on to consumers. To reduce this risk, some insect species are 'degutted' (have their gut contents removed) before being processed as foods. This can be done mechanically (as it is with *mopane* worms) or by starving the insects for the last day or two of the rearing cycle. Processing methods such as washing, boiling and drying can eliminate some pathogens. As with any other food product, normal hygienic precautions need to be observed to prevent (re)contamination during processing and storage (van Huis *et al*. 2013: 118–21).

Some people experience allergic reactions to insect proteins. Allergic sensitivity can arise through prolonged exposure to insects and has been documented among entomologists, for example. It is thought that some individuals with existing allergic sensitivity to seafood may experience cross-sensitivity to insects (crickets and shrimps are quite close relatives, for instance) – however the cross-reactivity is not inevitable. On the other hand, it has been suggested that childhood exposure to chitin – the main substance making up the exoskeleton of insects – might actually improve immune system response to parasitic infections in the gut and reduce some allergic conditions (van Huis *et al*. 2013).

2.3 Potential environmental advantages

Producing edible insects is estimated to be considerably more efficient than conventional livestock-rearing. Insects are cold-blooded and a high proportion of the insect can be eaten and digested, and for these reasons the conversion ratio of feed to meat is higher for edible insects than for conventional livestock animals and poultry. It has been estimated that crickets, for example, are about twice as efficient as chickens in converting feed to meat, four times more efficient than pigs, and 12 times more efficient than cattle. It takes about 1.7kg of feed to produce 1kg of live crickets, compared to 2.5kg for chicken, 5kg for pork and 10kg for beef (these figures depend on the production methods used) (van Huis *et al*. 2013). A recent study has cast doubt on the feed conversion advantage of crickets compared to chickens

[8] *Mopane* worms are caterpillars of *Gonimbrasia belina* Westwood, a moth.
[9] *Chapulines* are grasshoppers of the *Sphenarium* genus.

(Lundy and Parrella 2015), but these conclusions have also been challenged (Imrie-Situnayake, n.d.) and further research is needed.

Insects also produce much lower GHG emissions per kilogramme than pigs or cattle. In addition, insects would produce much smaller flows of effluents than livestock mammals, which are a serious cause of pollution from intensive feedlots. Life-cycle analysis has indicated that mealworm production requires less energy than beef, a similar amount to pork, and slightly more than chicken or milk. In terms of land area required, compared to the protein yield of mealworms, about two and a half times more land is required to produce an equivalent amount of milk protein, two to three and a half times as much for pork or chicken, and ten times more for beef. Experts believe that insect production would also compare very favourably with conventional livestock in terms of water consumption (van Huis *et al*. 2013).

It has been proposed that edible insects could be reared on organic wastes such as manure, slurry and compost and then fed to livestock animals. This would help to process organic wastes and transform them into valuable alternative feedstocks for conventional livestock, instead of grain that might feed people directly, or grass, which requires large areas of pasture. However, feeding insects destined for human consumption on organic waste presents potential problems due to the infection risks noted above (van Huis *et al*. 2013).

Edible insects are also being exploited as ingredients for feeds for conventional livestock and fish, as well as pets (see Annex 2). Promoters of this idea argue that insects could be a more sustainable and economical feed source in place of fishmeal, soybeans, maize and other grains. Insects are components of the natural diets of fish and poultry. Insect species suitable for use as feed include the desert locust (*Schistocerca gregaria*), maggots of the common housefly (*Musca domestica*), domesticated silkworms (*Bombyx mori*), black soldier flies (*Hermetia illucens*), yellow mealworms, grasshoppers and termites. In South Asia, a diverse range of insects has been used in poultry feeds, including grasshoppers, crickets, cockroaches, termites, lice, stink bugs, cicadas, aphids, scale insects, beetles, caterpillars, flies, fleas, bees, wasps and ants (van Huis *et al*. 2013: 91).

Traditionally, edible insects have been harvested from the wild or from managed landscapes (semi-cultivated), although a few species (honey bees, silkworms and cochineal insects) have been domesticated for hundreds or thousands of years. A long-established commercial insect-rearing industry exists for the production of pet foods and fish bait as well as niche uses such as medical and medicinal applications, and insects that are kept as pets. Crickets are farmed commercially for food use in parts of Southeast Asia, notably Thailand, Vietnam and Laos (van Huis *et al*. 2013).

Scientific and industry experts anticipate that, to be profitable, a large-scale commercial industry rearing insects for food and feed would need to produce very large volumes, which implies a need for automation. Other challenges include securing consistent quality and quantities of suitable feedstocks, climate control systems, and achieving economies of scale to make the industry competitive with conventional livestock production (van Huis *et al*. 2013). Some projects and inventors are also exploring the possibility of rearing edible insects in small-scale production systems, including domestic units (see Box 2.1).

Box 2.1 Small-scale rearing of edible insects

The Flying Food Project is a multi-partner public–private collaboration that aims to develop simple and robust systems for producing edible crickets on a small scale. The project aims to introduce technologies that can be readily adopted by small-scale entrepreneurs and domestic insect producers in Kenya and Uganda. The aspiration is that the insects can contribute directly to household food security, provide an affordable protein source for poor consumers, and generate incomes for farmers and rural women (de Graaf 2015).

Farm 432 is a prototype for a domestic, table-top rearing unit that can produce edible black soldier fly larvae in small quantities. The unit is a sort of habitat comprising a series of interconnected chambers that provide a sequence of different spaces for different stages of the flies' life cycle. Farm 432 is designed to produce about 500g of edible insect larvae in two weeks, sufficient for a couple of meals.[10]

In summary, edible insects have been proposed as a healthy and sustainable protein source for human beings, with a considerably smaller ecological footprint than conventional livestock. It has also been proposed that insects could form the basis for food rations prepared for use in special situations, such as space exploration. For insect-eating to become mainstream, much will hinge on whether consumers can be persuaded to try insect-based foods and incorporate them into their regular diets. The edible insect industry and its regulators would need to demonstrate that insect-based foods can be palatable, nutritious, ethical, sustainable and safe. Insect foods and feeds would also need to be affordable and available in sufficient quantities to have an impact on global food systems (DeFoliart 1989; van Huis 2013; van Huis *et al*. 2013).

[10] The unit was designed by Austrian designers Katharina Unger and Julia Kaisinger of LIVIN Studio. For further information, see www.livinstudio.com/farm432/ and www.kunger.at/161540/1591397/overview/farm-432-insect-breeding (accessed 5 June 2015).

3 Methodology

To consider the potential contributions of edible insects in the future global food system, we undertook three activities: a literature review; an online guided discussion with stakeholders, incorporating a questionnaire; and a Foresight scenario exercise. Background information on these Foresight methods is provided in Annex 3. Our use of Foresight approaches and tools was guided by Alun Rhydderch, an experienced consultant and co-founder of the School of International Futures.[11]

3.1 Literature review, questionnaire and online discussion

The literature review commenced with a broad, open-ended search for relevant sources of information including academic papers, grey literature, websites, blogs and other online sources. We reviewed documents and web-based materials from the life and social sciences, the media, non-governmental organisations (NGOs), international organisations, government agencies, commercial businesses and individual advocates. Through this exercise we built up a current picture of the topic and the field, gained an understanding of key issues and debates, and identified prominent individuals, organisations, interest groups and other stakeholders in the sector. We used this information to inform our activities in subsequent phases of the project, including writing this report.

In December 2014 we convened a two-day online discussion. The event was advertised using social media and individuals were invited to register in advance. Registered participants were invited to complete a questionnaire before the event. Information about the questionnaire is provided in Annex 4 and the online discussion is summarised in Annex 5. These interactions further crystallised some key discussion points and highlighted areas of knowledge, ignorance and uncertainty. The insights gained from the questionnaire and discussion informed the design and selection of participants for the subsequent scenario workshop.

3.2 The Foresight scenario exercise

We invited selected experts and stakeholders to participate in a face-to-face Foresight scenario exercise over two days in March 2015. We invited a mixed group of participants including academic researchers, project managers, entrepreneurs and commentators on entomophagy issues. To supplement the expertise of participants who were already familiar with the topic of entomophagy, we brought in some people with complementary expertise in areas such as food security and nutrition, food safety regulation and science policy. Participants contributed in their personal capacities. The participants are listed in Annex 6.

The scenario exercise comprised two steps: a drivers-of-change analysis (STEEP exercise) followed by scenario-building using the ‘two axes’ method. The STEEP exercise is designed as a way to identify the broad, potent forces and trends that seem likely to shape the future, even if their development and eventual impacts may be profoundly uncertain. Scenarios might be understood as a set of thought experiments focused on identifying plausible pathways from now into the future, as well as the types and scales of sudden shocks that might take us by surprise.

[11] www.soif.org.uk (accessed 9 June 2015).

3.3 Identifying drivers of change (STEEP)

The first step in the process was to think about broad drivers of change that participants expected would shape society and economy in the coming decades. These could be expected to shape the societal, economic and technical context into which, or alongside which, an edible insect sector might or might not emerge. The drivers were generated by participants in a brainstorming fashion, then clustered by the participants and facilitators into loose groups under five broad categories: Social, Technical, Environmental, Economic and Political (STEEP). After the workshop, the drivers generated during the STEEP exercise were further organised, consolidated and summarised by the authors in order to present them clearly and concisely in this report (see Table 3.1).

Table 3.1 STEEP drivers of change identified by workshop participants

Social	Technological	Environmental	Economic	Political
Demographic changes: population size and distribution; ageing and youth; urbanisation; changes in household size; migration.	New information and communication technologies; cloud storage and 'always on' connectivity; novel uses of 'big data'; closed apps vs wwweb; the 'internet of things'.	Climate change: extreme weather events, unpredictable seasonal weather, droughts and floods, high and low temperatures, sea-level rise.	Rising inequality within nations; declining inequality between nations (e.g. 'Rising Powers', G20).	Political instability, conflicts and violence; impacts on human security/food security.
Changing food consumption habits; social food movements, e.g. locavore, artisanal, fast vs slow food, organic and fair trade; eating out; convenience foods; grocery shopping online; rise in Western vegetarianism and veganism; food fads and diet fads.	Advances in renewable energy and energy storage.	Pressure on land for agriculture and building: urbanisation (including megacities), land degradation; deforestation.	Changing quantity and diversity of international trade; dismantling of tariffs and technical barriers to trade.	Globalisation; shifts in power between states, corporations and social movements; harmonisation of regulations; centralisation vs distribution of political and economic power.
Pressure on health systems; longevity; diseases of ageing; increasing costs of medical and social care.	Open source technologies vs intellectual property rights and efforts to exert control and stewardship over technologies – ICTs, biotech, nanotech, etc.; 'DIY biotech'.	Risks of zoonotic diseases (e.g. bird flu, BSE[12]); antibiotic resistant pathogens; food scares.	Energy: changes in relative prices of energy generation technologies; pressure to exploit more inaccessible fossil fuel reserves.	National and global targets on sustainability, greenhouse gas emissions, MDGs/SDGs,[13] etc.
Trends in health and beauty, diet and fitness; obesity and overweight; good and poor nutrition; metabolic disease.	New biotechnologies and nanotechnologies; novel materials and processes; biomaterials and nanomaterials; 3D printing.	Decline in bee populations/pollinators.	Food and agriculture: search for new food sources, alternative sources of protein; community-supported agriculture; highly mechanised, automated, capital-intensive, data-hungry precision farming.	(In)equality; power of wealthy elites (philanthropy, corporate social responsibility (CSR), venture capital).
Nationalist, culturally chauvinist and xenophobic movements vs international solidarity movements and campaigns.	Protein alternatives: lab-cultured meat, mycoproteins, algal proteins, insect proteins.	Declining water tables, salination of soils, soil erosion; competition for water; diversion of rivers for irrigation and hydropower.	Circular economy: recycling and re-use, closed loops; sharing economy (enabled by apps, big data).	Access to information, education, knowledge, expertise; networking of political campaigns and social movements.

(Cont'd.)

[12] Bovine spongiform encephalopathy (BSE).
[13] MDGs = Millennium Development Goals; SDGs = Sustainable Development Goals

Table 3.1 (Cont'd.)

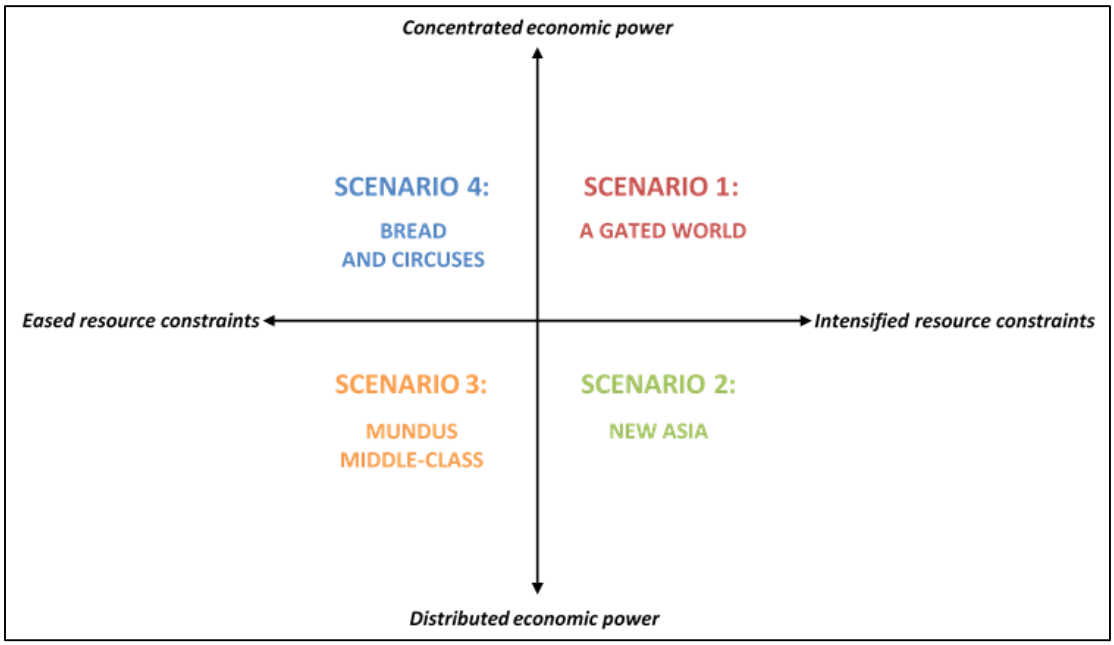
Social	Technological	Environmental	Economic	Political
Charitable giving, volunteering, social engagement, civic activism; environmental awareness and behaviour; concerns about animal welfare.	Massive open online courses (MOOCs) and online academies.	Trends in natural and agricultural biodiversity; monocultural production systems vs biodiverse and agro-ecological farming.	Bitcoin and other alternative/virtual (non-state) currencies; crowdfunding.	Fluctuating and unevenly distributed (mis)trust in public bodies, NGOs and corporations.
	Dependence of agriculture on petrochemicals.	Pollution (e.g. chemicals, plastics, heavy metals).	Changes in patterns of work, employment, enterprise, crowdfunding, etc.; DIY/maker movement; fixing and 'lifehacking'.	Social media as forum for news, communication, networking, information exchange, mobilisation, etc.
	Automation using drones, robots (e.g. driverless vehicles, robot companions).			

3.4 Scenario framework

Guided by the full set of STEEP drivers generated by the participants, the workshop facilitators identified two important themes that could serve as axes to provide a structure for the scenario exercise. The chosen axes were *resource scarcity (intensified vs eased)* and *economic power (concentrated vs distributed)*. These two axes created four quadrants to be populated with future scenarios. The workshop participants were divided into four groups to develop the four scenarios, which are described in detail below. These were later given names as follows (see Figure 3.1):

1. 'A Gated World'
2. 'New Asia'
3. 'Mundus Middle-class'
4. 'Bread and Circuses'.

Figure 3.1 Scenario framework



Participants in the scenario exercise were asked to look ahead approximately 15 years to the year 2030. In practice the deliberations ranged quite fluidly from the next decade to as far as 2050 and sometimes beyond. In other words the suggested timescale for these scenarios should probably be understood quite loosely, between approximately 15 and 35 years.

In the following sections we present the four scenarios. Each scenario is prefaced with some key characteristics and each begins with broad contextual developments before zooming in, in successive stages, to focus on the implications for food production and consumption in general, and edible insects in particular. Each scenario is accompanied by one or more vignettes illustrating 'a day in the life' of a person living in the hypothetical world envisaged by the scenario. Each scenario concludes with some reflections on the broad implications for global food security and food system sustainability.

4 Scenarios

4.1 Scenario 1: A gated world

Characterised by **Concentrated economic power × intensified resource constraints**
Key features: Vertically integrated, socioeconomically stratified food systems. Large-scale production of insects – usually in highly processed forms – by small number of global corporations for mass consumption.

4.1.1 Context

After 2015, economic power continues to be concentrated in fewer hands and in certain regions and cities. Meanwhile, geopolitical and environmental factors combine to intensify resource constraints.

Between 2015 and 2020, continued geopolitical instability in central and western Asia and North Africa, as well as a second major disaster involving a deep-drilling oil platform in the Mexican Gulf, seriously disrupt global supplies of oil. A stuttering global economic recovery is snuffed out almost immediately. In Europe and North America, policies of economic austerity continue to redistribute wealth from poorer to richer segments of society, but this policy stifles domestic consumption and attracts increasingly angry resistance from below. Modest economic growth continues in BRICS[14] countries, fuelled increasingly by domestic rather than international demand, but economic inequality intensifies here as well. Richer people retreat further into gated enclaves. Governments around the world resort to increasingly desperate measures to stimulate demand, but with oil prices at record highs the cost of living rises steeply. Anxiety about Western powers' dependence on fossil fuels is amplified by growing alarm about climate change when a series of intense storms and unseasonal weather patterns cause loss of life, great damage to physical infrastructure, and reduced crop harvests worldwide. At the same time, corporations and investors sitting on large cash reserves continue to search for investment opportunities.

4.1.2 Food production and consumption

Governments become intensely preoccupied with supplying their restless and uneasy populations with cheaper and more dependable food and energy supplies. Encouraged by policy changes and generous public subsidies, technology companies as well as institutional investors start to pour money into alternative technologies, including renewable energy and novel foods. Big corporations, national governments and large-scale investors are naturally inclined towards large-scale, centrally controlled, vertically integrated, technology- and capital-intensive innovations. Food companies deploy chemistry, genetic engineering and nanotechnology to develop alternative protein sources, including vegetables and various novel foods. With power concentrated in few hands, food and energy systems are driven quite rapidly in more efficient directions, but by technocratic rather than democratic or participatory decision-making. But niches also exist for small producers and catering businesses to serve affluent people who are looking for opportunities to consume high-status foods and enjoy unusual experiences. In this unequal world, the food system becomes increasingly stratified. Conventional meat and fish become high-status foods consumed primarily by the rich, who are ready to pay for a high-quality, organic, 'natural' product. For the mass of the population, conventional meat becomes a rare treat.

[14] The BRICS are a group of rising economic powers: Brazil, Russia, India, China and South Africa.

4.1.3 Edible insects

With the help of major investments in research and production systems, insect-rearing becomes more automated, productive, economical and competitive. Insect-rearing benefits from subsidies and incentives that encourage the recycling of waste streams. Meanwhile, unable to take advantage of the same opportunities or to compete with the efficiency of protein production using insects, the intensive rearing of conventional livestock becomes increasingly unviable as a business, as its environmental footprint becomes more socially unacceptable and officially proscribed.

In this scenario, edible insects are reared in very large quantities, delivering significant economies of scale, to produce an affordable protein source for mass consumption. Insect meal as well as small grubs are incorporated into many widely available processed food products, such as breads, pies, croquettes, burgers, nuggets, protein shakes, etc. These are consumed at home and served in school and office canteens and fast food restaurants. There is intense competition in the sector, based chiefly on price rather than quality.

A tiny market niche exists in which whole insects are consumed as an exotic treat by small numbers of affluent consumers dining at restaurants, cafés and festivals. But this is a once-in-a-while, occasional experience for a small slice of the population.

To make ends meet, a few people from less affluent sections of society resort to producing their own food in urban gardens, on balconies and rooftops. Domestic insect rearing proves to be an attractive option to some of these people because a useful protein supplement can be grown at home without requiring a lot of space.

Box 4.1 A day in the life: Oskar

Oskar is looking forward to an evening out with some friends. Apart from an hour in the gym at lunchtime, he has been working at home all day. As he waits for a driverless vehicle to take him to an exclusive leisure and entertainment complex nearby, he reflects that it has been three days since he last set foot outside his gated residential enclave. He meets his friends in a five-star restaurant where they order a selection of small dishes to share. The items are beautifully presented and they include a dressed salad containing crickets and a small flan decorated with buffalo worms. Oskar doesn't mind eating insects once in a while, but he would have preferred to go to the Argentinian place next door for a steak.

Box 4.2 A day in the life: Aasiya

Aasiya shares a one-room apartment on the 23rd floor of a tower in a mass housing complex. For lunch today, she heats up a microwave meal in the kitchenette of the nursing home where she works: meatballs with potato puree and beans. As she drops the meal's bioplastic sleeve into the yellow compost bin, Aasiya notices that the meal contains 'protein from various sources'. Obviously, this must include insect meal, but Aasiya wonders where else the protein might come from. The same type of label appears on the ready meals she and her colleagues warm up for the residents. They offer a choice of 'vegetarian', 'meat' and 'fish' dishes, but as far as Aasiya knows they all contain some kind of heavily processed protein derived from insect meal. The dishes don't taste too bad in Aasiya's opinion, but some of the older residents miss the meaty texture they remember from childhood.

4.1.4 Implications for global food security and food system sustainability

Insects are reared in so-called 'developing' countries and processed into foods in much the same way as in the 'developed' world – largely as generic proteins for mass consumption. Wealthy elites in these countries have lifestyles rather like those of wealthy people in cities all over the world, including the range of foods on offer. Fine cuisine versions of traditional local and regional foods exist to serve affluent populations, alongside a cosmopolitan mixture of foods from around the world.

Globally, the development of alternative protein sources has allowed the aggregate supply of dietary protein to remain abundant, while the ecological footprint of protein production has decreased. However, due to the highly processed nature of many protein-based foods, the consumption of preservatives, sugars, salt and saturated fats remains very high. The technical efficiency of food production systems has greatly increased, at the cost of a substantial reduction in crop, livestock and natural biodiversity. Experts and government planners are very concerned that, as a consequence, food system resilience overall has greatly reduced, making food systems very vulnerable to shocks such as infectious diseases, adverse weather and economic instability.

Conventional livestock rearing has become much more sustainable than pre-2015, primarily because of a sharp reduction in scale. Huge, intensive stock-rearing facilities have disappeared, replaced by a small number of farms that supply elite, niche markets with high-quality, sustainably reared heritage breeds. Fierce cost competition within the edible insect sector threatens the sustainable nature of this protein alternative. However, the global market for rarer species of whole insects remains very small and does not pose imminent threats of over-harvesting.

4.2 Scenario 2: New Asia

Characterised by **Distributed economic power ⨯ intensified resource constraints**
Key features: High-consumption global economy with cosmopolitan tastes and regional production systems, in which conventional meat becomes uncompetitive.

4.2.1 Context

After 2015, economic power begins to be more widely distributed both within and between nations. Partly as a consequence of this wider distribution in economic power, demand increases and resource scarcity intensifies.

As the economies of Europe, North America and Japan continue to struggle to recover from the 2008 economic crisis, the long-term redistribution of economic power from the G8[15] outwards to the G20[16] and the BRICS continues. Within the rising powers, an emergent middle class claims an increasing share of the rewards of economic growth, and soon these countries no longer depend so heavily on demand in the 'old powers' for raw materials and manufactured goods. Meanwhile, within the established powers, popular revolts against economic austerity oblige governments to adopt more redistributive economic policies; this becomes easier as the rising powers grow and global demand for goods and services increases. As a result, inequality within the 'rich countries' also declines and demand increases as more people find they have a disposable income. After a prolonged slump, the global economy begins to grow again, but we are now living in a much more multi-polar world. In particular, it is a more Asian world: the distribution of economic power has led to much greater influence for the world's great population centres in Asia, and as a result a high

[15] The Group of Eight (G8) leading industrial economies of the world, successor of the G6 and G7, meeting regularly from the 1970s onwards.
[16] The Group of Twenty includes 19 major economies of the world plus the European Union.

proportion of the world's consumer goods and cultural products now cater to Asian tastes as well as or instead of traditionally dominant Western preferences. This includes food. However, because transportation costs are high, densely populated consumption hotspots – megacities – are becoming increasingly important regional hubs, which exert very strong influence on production systems in their immediate surroundings.

4.2.2 Food production and consumption

The redistribution of economic power creates enormous demand for consumer goods, food and energy. Larger numbers of economically empowered consumers are demanding more food of higher quality and diversity. Food systems are quite regional, dominated by urban population centres, and consequently some regional differences remain in both production systems and consumption patterns. At the same time, widespread education and cultural globalisation broaden people's tastes and willingness to try new foods. Traditional Asian foods and cuisines – noodles, rice, tofu, meat, soups, Asian vegetables, and so on – are popular, have a high status, and become prominent in the diets of people around the world. This includes some insects, for example in Thai-style dishes and snacks.

Land and real estate prices are high. Many people live in tiny apartments in large urban areas. Paying high rents or large mortgages, people living in these areas have few incentives or opportunities to save or invest in land or real estate. Instead, they console themselves with discretionary spending on leisure activities, 'experiences' and disposable consumer goods. This includes food. Most people eat out for most meals every day, either alone or with friends and work colleagues. Consequently there is a huge growth of food catering businesses of all shapes and sizes – cafés, restaurants, canteens, food kiosks, street vendors and fast food outlets. A variety of international ingredients and flavours become popular within diversified diets.

Conventional meat and livestock rearing become both more expensive and less socially accepted. Between 2015 and 2020, a couple of zoonotic disease outbreaks occur (like Mad Cow Disease, swine flu or bird flu), which conventional drugs cannot cure and several thousand people lose their lives. These episodes increase consumer aversion to intensive livestock-rearing and lead to more stringent regulation of the industry, which drives up costs and makes conventional meat more expensive. Simultaneously, a better-educated population is becoming more conscious of ethical consumption and there is a high demand for, as well as the income to afford, foods that claim to be healthier and more ecologically or socially sustainable. There is a rise in vegetarianism and veganism as well as a search for protein alternatives, including insects. However, this movement is in tension with the sheer volume of demand, and in fact pressure on natural systems rises inexorably.

4.2.3 Edible insects

In this world, edible insects are part of a diverse range of foods on offer from a wide diversity of sources, including conventional meat and fish, which represent a small share of typical diets. Though insects are available in supermarkets and delicatessens, or online for delivery to the domestic kitchen, they are mostly consumed outside the home – in the form of packaged snacks, on-the-go meals from street vendors, fine dining in restaurants, and everyday dishes in workplace canteens and cafés. Insects are available in both lightly and heavily processed forms, and the insect ingredients are sometimes advertised prominently as a distinct selling point and sometimes labelled obscurely as generic 'protein'.

In this market, there is room for producers and processors of diverse shapes and sizes. Some small-scale entrepreneurs specialise in particular insect species for particular markets, such as restaurants and gourmet catering businesses, while large-scale operations produce insect meals in large quantities for sale to food processors who incorporate insect protein invisibly into microwave-ready meals, cakes, pies and other processed foods. Significant

investments in R&D have succeeded in developing and refining insect-rearing systems to the point where they are efficient and cost-competitive, with significant economies of scale. Pension companies and large investment institutions routinely include insect producers in their portfolios.

Insects are also produced in small-scale (domestic and community-operated) production systems. Table-top insect-rearing equipment similar to Farm432 is available to domestic consumers for use in cramped apartments. Apartment blocks have been built that incorporate insect-rearing systems. These farms are operated by the building managers, who distribute the harvested insects to the residents as part of the building services agreement. Residences in these buildings are in demand and rents are high.

Insect feeds are also prominent in this scenario because they help the conventional livestock industry to meet its ethical and regulatory commitments, which helps to make conventional livestock and fish production systems more economically and ecologically sustainable and less demanding of costly agricultural land. This trend is encouraged by the dual revenue streams on offer to insect feed producers, who are paid by municipal authorities and businesses to process waste, as well as earning money from the sale of insect feeds.

Box 4.3 A day in the life: Layla

Layla eats breakfast every day in the delicatessen on the ground floor of her apartment complex. At lunchtime she generally goes to one of the food stalls near her office building. She prefers Asian foods and eats an insect-based noodle or rice dish at least once a week. Layla thinks, if you're going to eat insects, you may as well enjoy the real thing and not just chew on a burger that might or might not have some insect protein in it (she doesn't trust labels). But today she has a salad for lunch because she's meeting a friend for dinner tonight: they're going to the Thai place that specialises in giant water bugs.

4.2.4 Implications for global food security and food system sustainability

Tropical regions have a built-in competitive advantage in insect-rearing because of their climatic conditions. Increasing wealth in economic hotspots of the global South means that local investors and entrepreneurs have established successful insect-rearing and insect-processing companies. They have some technical know-how and cultural advantages that enable them to serve the discerning palates of insect consumers in their regions. Western producers tend to concentrate on bulk insect proteins that are widely consumed in invisible forms, while the small volumes of gourmet insect ingredients required to meet demand in Europe and North America are typically imported. Urban insect rearing has helped reduce food miles and created value from waste streams.

Access to protein around the world has improved since 2015, due in considerable part to the edible insect sector. Consumers are able to choose between a wide range of protein alternatives, including fresh and nutritionally rich whole insects and more heavily processed and packaged insect-based foods with long supply chains and extended shelf life. The conventional livestock industry has greatly declined around the world, especially the large-scale intensive operations that were rendered unviable by stricter regulations. Insect-based animal feeds have helped with cost efficiencies but, for most people, conventional meat consumption is an occasional treat. Some environmentalists have raised concerns about the carbon footprint of insect supply chains, and also the traceability of certain species. Insect exports from Asian companies are one source of concern, while insect production in colder Western nations is criticised for its dependence on energy-hungry climate-controlled production facilities.

4.3 Scenario 3: Mundus middle-class

Characterised by **Distributed economic power × eased resource constraints**
Key features: Major technological advances (particularly in energy and consumption) and transformation in consumption behaviours towards less exclusive and wasteful ownership models.

4.3.1 Context

After 2015, economic power becomes less concentrated within and between nations. Meanwhile, resource constraints are eased in this world by two powerful, complementary movements: technological advances, particularly in energy generation and consumption; and simultaneously a transformation of consumption behaviour.

The geopolitical and economic ramifications of the 2008 economic crisis unfold more slowly and with more profound and lasting effects than is appreciated by most observers in 2015. Though many people anticipate that 'the West' will continue to experience a long-term decline in economic power relative to the 'rising powers', it is less widely recognised that some profound, secular changes are underway in technology and society. As the political power of an educated, affluent and internationally mobile middle class increases, the effectiveness of central governments is undermined in various aspects. This increases the power not only of transnational companies but also that of diffuse and fluid social movements and civil society formations of diverse kinds. The latter are decreasingly national in character, more like shifting coalitions of interests, values and causes that cut across historical categories of nation, race and ethnicity. It is a 'post-national' world.

On the technology front, rapid improvements in renewable energy technologies quickly increase the efficiency and lower the costs of both generation and storage. As early as 2020, fossil fuels are universally perceived as a sunset industry, yet the transition to a new energy system is proving fairly smooth and easy. Political leaders are confident that global energy supplies are secure into the foreseeable future, coming overwhelmingly from distributed, renewable sources. By 2030 the price of energy is low and stable, while greenhouse gas emissions have fallen sharply and most scientists think that the worst effects of climate change will be avoided.

In this situation, billions of people worldwide have a disposable income; nevertheless, consumption does not increase as sharply as might have been expected. Taxes shift from income to resource consumption. The level of average consumption per capita begins to converge around the level currently enjoyed by middle-class people in middle-income developing countries/emerging economies. Apart from a change in attitudes and behaviour, another reason for this trend is that technology enables a more efficient distribution of scarce natural resources – for example, just-in-time, onsite manufacturing reduces waste and distribution costs; and an economy based on services and sharing means that consumer durables such as washing machines, vehicles and power tools, not to mention land and buildings, are used much more efficiently. With their material needs catered for, people choose to have fewer children, to work less and spend more time doing things they find satisfying; for some, this includes growing and preparing food.

4.3.2 Food production and consumption

The abundance of renewable energy has made fossil fuel extraction relatively costly, reducing the volume of economically exploitable reserves. Consequently, while farm mechanisation has continued to increase through the use of electrically powered machines, drones and robots of various kinds, mineral fertilisers and crop protection chemicals have become prohibitively expensive for most purposes. Alternatives have been developed,

including biopesticides and biofertilisers as well as more targeted chemicals incorporating nanotechnology. There has also been a shift towards more agro-ecological farming methods and practices. Insects are used routinely in animal and fish feeds. Together, these changes have made conventional agriculture more ecologically benign.

In this scenario a shift towards alternative sources of protein, including edible insects, is a small part of the reason why the economy has become less resource-intensive. People in general are better educated and informed about food issues and diverse food cultures. Many people choose to spend more time and money on food and culinary experiences, including raising, harvesting, and preparing their own food, and for some people this includes raising and consuming insects. The price of conventional meat rises due to widely supported environmental and animal welfare regulations, but an affluent population can still afford to buy it quite often. Overall, the wide availability of conventional foodstuffs means that there is no compelling technical reason or economic incentive to develop alternative protein sources, so insect consumption remains a niche alongside a wide range of other foods.

Though material prosperity looks positive in 2030, there are environmental storm clouds on the horizon when it comes to food. Unlike durable consumer goods such as cars and household appliances, foodstuffs cannot be consumed by more than one person. Affluent people are consuming large quantities of diverse foods, including conventional livestock and other foods (such as palm oil) that have a significant environmental impact. Consequently the pressure to produce more, high-quality food remains intense and the environmental footprint of agriculture remains quite high. Experts warn that food prices, which have been low and stable, may become increasingly volatile on a rising trend.

4.3.3 Edible insects

In this scenario, an insect production/consumption value chain emerges, but it is just one small segment of the market alongside various others, not a dominant feature. Some people choose to eat insects as a sustainable and ethical choice, and the market grows slowly based on this consumer demand. Edible insects in various forms are available from various outlets, both as whole insects consumed as exotic treats on special occasions and as an everyday meat/protein alternative, which is often incorporated invisibly into various mass-consumed processed foods. Edible insects are commonly used in animal feeds, which helps to make conventional meat and dairy production a bit more sustainable in the medium term. Some people raise their own insects at home or in community groups. Still, insects represent only one part of diverse diets and many people continue to consume conventional meat. However, as pressure on the environment intensifies, developing and expanding the insect-based foods industry looks like a plausible strategy to make the food system more sustainable beyond 2030.

Box 4.4 A day in the life: Pavel

Pavel checks on his crickets once a day, though they are quite easy to care for in his semi-automated, climate-controlled domestic rearing-and-processing unit. The unit, which Pavel purchased online, sits next to the refrigerator in his kitchen. It delivers a fresh batch of ready-to-cook crickets about once a week, which Pavel cooks and eats at home. His friends – who generally eat insects only occasionally – point out that he could easily grab a cheap packet of dried crickets from the corner shop, but Pavel enjoys rearing his own, and this way he knows where his food is coming from. The chirping of the crickets has become a background noise to everyday activities, a familiar and friendly sound that says ‘home’. Tonight Pavel is making a salad combining crickets with leaves and beans from the urban community garden.

4.3.4 Implications for global food security and food system sustainability

The average standard of living globally has significantly improved and technological advances have increased access to food. Food and nutrition security indices have improved at individual and household level. The general shift in consumption behaviour has benefited small- and medium-sized, locally owned and operated food businesses. Food production systems in general are more sustainable and supply chains are generally shorter. Most people continue to eat conventional foods (this includes insects where they have been a traditional component of the diet) but insects are not providing a significant share of dietary protein for most people. A range of other protein alternatives is available to cater for those who choose to avoid conventional livestock products. The consumption per capita of conventional meat has fallen sharply.

4.4 Scenario 4: Bread and circuses

Characterised by **Concentrated economic power × eased resource constraints**

Key features: Geopolitical power concentrated in two interdependent economic blocs (the 'West' and an Asian sphere in the east dominated by China). Population concentration in megacities, with food production organised around these regional hubs.

4.4.1 Context

In this scenario the means of production are owned by the very few and geopolitical power is concentrated in the metropolitan centres of two dominant but mutually interdependent economic blocs (the 'West' and an east Asian sphere dominated by China), as well as a 'second rank' of regional powers (including the European Union (EU), India, Indonesia, South Africa, Nigeria and Brazil), which contend and cooperate with one another for influence. It is an economy of 'bread and circuses', whereby abundant resources mean that elites are able to secure the compliance of the masses with adequate food, shelter and leisure opportunities. But this high-consumption society continues to impose a heavy burden on natural resources and systems.

In the years after 2015, as the world recovers from the economic crisis, China becomes increasingly assertive in South and Southeast Asia. Unwilling to confront China directly, Japan and the US, as well as Russia, resign themselves uneasily to Chinese hegemony over her southern neighbours. The Asia-Pacific region becomes the cockpit of global geopolitics. India and Indonesia contest Chinese power in their immediate neighbourhoods, but as they contend with internal problems they feel unable to challenge her assertively. European power declines relatively while regional powers such as Brazil and South Africa become wealthier and more influential. International trade increases, including in food products.

Within these powerful nations as well as in other countries, power becomes highly concentrated in the hands of a wealthy elite of well-connected business and political families. Automation in manufacturing, services and other economic sectors leads to a decline in employment, but the system is generating an economic surplus. As economic inequality increases, governments bolster their legitimacy by making welfare payments and providing affordable public services to their people. Philanthropic foundations and corporate social responsibility programmes are established for the same purpose.

The centralisation of economic and political power allows large corporations and government research agencies to give a strong and decisive direction towards efforts to respond to climate change and make the economy more environmentally sustainable. However, this shift is not achieved by democratic or participatory means. For instance, although citizens enjoy the benefits of a generous welfare state, a strict one-child policy is enforced.

4.4.2 Food production and consumption

Food production relies less heavily on conventional agriculture, because this reduces the uncertainty and risk that stem from growing crops in the open. A great proportion of food is produced indoors, in greenhouses and factories. With many people living in cramped apartments in large cities, neighbourhood canteens provide food for large numbers of people. These centralised kitchens can be more efficient in their use of food ingredients and recycling of waste. The concept of 'nutrition services' has entered the vocabulary as a business category. Few people have much knowledge about or interest in where their food comes from or what is in it. In cities especially, the skills of processing and preparing meals have become almost entirely professionalised; very few people know how to prepare dishes from scratch and very little food preparation is done in the home. Domestic kitchens are small and simple and people spend little time in them. However, the wealthy elites are willing to spend considerable sums on fresh, natural, functional, nutritionally balanced, fine-quality, 'authentic' and organic foods produced in traditional ways.

Much of the food people eat is in the form of heavily processed food products produced and packaged by large food companies, rather than fresh meat, fruit and vegetables. A range of novel processing methods and synthetic additives is used by the food industry to create foods that are palatable and thought to be nutritionally balanced. The diversity of basic food commodities has decreased, yet the food industry employs a vast range of ingredients, many of them aids to processing, conditioning agents and the like. The industry has invested a lot of effort to develop variations in appearance, texture and flavour. Biofortified and 'functional' foods are normal.

4.4.3 Edible insects

Elites eat insects occasionally as an exotic treat – on occasions of conspicuous consumption, for entertainment and self-expression. Insect protein is produced in bulk for the masses and consumed regularly in invisible form, in cakes, breads, pastries, burgers, pies, croquettes, cookies, etc. Often insect protein is mixed with other alternatives (such as vegetable-based proteins), though labelling is usually vague as to what types are used. Most people (including the wealthy) eat these more processed products, as fresh foods are less available and generally perceived as more risky due to less controlled and hygienic methods of production (i.e. outdoors).

Box 4.5 A day in the life: Byung-joon

Byung-joon works three hours a day. He eats all his meals in a canteen that is run and heavily subsidised by his employer, an electronic chip company that is owned by a big conglomerate, Green Kite. He is also able to spend his electronic meal vouchers there, which he receives monthly from the city benefit office as a supplement to his income. Most of the items in the canteen are packaged and branded with a green kite. Many of the items on sale include insect meal, though Byung-joon cannot always tell which ones or what kind of insects are used. Once, at a cousin's wedding, Byung-joon tasted a piece of pork but he prefers Meat-U-Wish, a Green Kite protein product that is available in convenient blocks, slices, nuggets and pastes in several different flavours. Byung-joon's parents have encouraged him to give up paid employment and return to their ancestral village far outside the megacity he currently lives in; but land is scarce nowadays, city life is easier, and Byung-joon would not know how to grow food on his own farm.

4.4.4 Implications for global food security and food system sustainability

Food production, including insect rearing and processing, is a big industry in the countries of the former 'developing world', but the processes are largely automated and often take place inside climate-controlled buildings close to urban centres. Only low-waged, unskilled jobs are

available in the industry. In poor rural villages, especially those further away from population centres, not much has changed: people continue to eke out livelihoods from small patches of land, where they grow conventional crops with little support or interference from governmental authorities or scientific institutions. The lack of satisfying employment in cities is leading some people to migrate back to rural areas. In urban areas, centralised canteens have made the delivery of calories to large numbers of people more efficient. However, some marginalised critics of the food system raise concerns about the precariousness of a system where so many urban dwellers lack the facilities and skills to provide for their own food. Though there is enough food, and the nutrition services industry claims that its products offer balanced nutrition, medical professionals have raised doubts about the healthiness and nutritional composition of foods that are heavily processed, compositionally simple and partly synthetic. Waste and food miles have been reduced quite sharply, so the ecological footprint of the food system as a whole is rather smaller per capita compared to 2015, though it is catering for a larger population and therefore the overall impact on the environment is greater.

5 Discussion and conclusions

Taking the four scenarios as a whole, a few very powerful themes stand out. The first was the expectation of ongoing demographic change, including population growth, changes in patterns of settlement and population distribution (especially urbanisation and the growth of megacities), and (in most of the scenarios) a general increase in human migration and mobility. Another was climate change and its intimate connections to agriculture and the food system (both as causes of climate change and as a set of systems likely to be profoundly affected by a more volatile climate). Changes in human lifestyles and consumption patterns were also prominent, including concerns about issues such as obesity and public health.

Another prominent theme was economic change and a set of expectations around industrial transformations, which are likely to exert a very powerful influence on the future. In part this theme was cemented into the scenario exercise, due to the choice of economic power distribution and resource scarcity (eased or intensified) as the two defining axes. Thus, pathways leading to increased equality or inequality were programmed to emerge, but within that rubric there remained space for participants to distinguish between (in)equality within and between nations, for example.

With regard to resource scarcity, energy and land stood out inevitably as two key issues; yet in spite of the prevailing mood of contemporary gloom surrounding the energy issue, for example, the workshop participants did not find it particularly difficult to imagine a future in which technological and behavioural changes have resulted in energy security ceasing to be a major concern for governments and citizens. Some readers may find this trajectory optimistic, yet in recent years the technologies of renewable energy generation and storage have increased sharply in efficiency and declined steeply in price, so perhaps the storyline is not so implausible after all. The discipline of a Foresight exercise requires us to take such possibilities seriously rather than discounting them without a second thought.

What of the fate of edible insects in the global food system? During the last session of our scenario workshop, we moved to a Foresight exercise called ‘windtunnelling’ (see Annex 3). Windtunnelling is a companion method to scenario-building. Once the scenarios have been developed, one can use windtunnelling to assess the likely effectiveness of alternative policy options, business plans or strategies within the different scenarios. The idea is that the different strategies can be tested in scenarios in the way an aerofoil design is tested in a wind tunnel. Does the aerofoil fly? Would the proposed policy achieve its goals in the given scenario? Alternatively, can we devise policies and strategies that would likely guide the world towards more desirable outcomes and avoid negative pathways?

Due to time pressure (a case of poor planning that we will learn from), we were unable to pursue the windtunnelling as a group to a satisfying conclusion during the workshop. However, we have kept the task of windtunnelling in mind during the writing of this report. The fundamental and rather interesting insight from the scenario exercise is that edible insects seem to occupy a plausible niche in all four of the imagined futures. This suggests that foods and feeds containing edible insects may quite readily emerge within a considerable range of foreseeable conditions and situations. Indeed, as documented in the second section of the report, such products are already emerging; in particular, insect-based feeds have moved beyond a proof-of-concept stage and may capture a share of the feeds market if they can achieve economies of scale to become competitive against alternative feeds, such as fishmeal and grain. A key question is whether these feeds can meet the quality, supply and price demands of the livestock feeds market.

Based on these scenarios, a food policy analyst or an investor might reasonably conclude that some kind of edible insect industry is quite likely to emerge and is worth investing in. In windtunnelling terms, we might judge that a current policy or strategy that is designed to encourage the development of insect-based foods and feeds would appear to be quite 'robust', in that an investment in such a strategy looks quite likely to pay off in some way across a range of foreseeable futures. But would the returns on investment be attractive in financial and social terms? These questions are difficult to judge, based on the scenarios alone.

5.1 Edible insects as food and feed

While all the scenarios foresee some kind of plausible niche for insect-based foods, it is notable that this market is envisaged as bifurcated into a fine foods concept at one pole and a mass-produced protein substitute at the other. It is the relative size and importance of these two segments that varies between the different scenarios. Relevant factors here seem to be economic (in)equality and the fate of conventional livestock under the different scenarios. In several of the storylines, conventional meat production using intensive livestock-rearing has declined sharply because it has become unpopular or unaffordable, remaining perhaps as an occasional treat for an affluent middle class or an ostentatious display of wealth by a small elite. Probing a bit deeper, we can distinguish between scenarios where a substantial slice of the population has rejected conventional meat for ethical reasons or due to health concerns, and scenarios where conventional meat has remained a desirable commodity although factors such as climate change and resource scarcity have dramatically increased the costs of production, making the product a scarce luxury item.

In the former situation, edible insects could be conceived as a product that would attract socially and environmentally conscious consumers seeking a healthy and responsible alternative to conventional meat. Consumers of this type might be quite open to eating novel foods, including whole insects. In the latter case, insects were largely conceived as a more efficient (and therefore affordable) means of producing and consuming protein. The imagined consumers in this scenario might be thought of chiefly as price-conscious meat-eaters seeking acceptable, affordable substitutes for the familiar appearance and sensations of conventional meat products. This suggests that insect-based food ingredients such as meals and flours might be incorporated invisibly into a wide range of processed foods. In either case, a niche market for gourmet whole insects might also exist; the size of this market might depend on the distribution of economic power as well as consumer attitudes towards eating both insects and conventional meat.

Insect-based feeds slotted into the scenarios rather neatly when there was a demand for feeds to rear conventional livestock. In Scenario 1, A Gated World, conventional meat was still in demand among the elite; however, they were seeking a naturally reared product. In Scenario 4, Bread and Circuses, conventional meat products had been extensively displaced from the market by a wide range of processed protein alternatives. In the other two scenarios it was easy to envisage an insect-based feeds industry that could help make conventional livestock rearing more sustainable.

The scenarios envisaged a range of different production scales from domestic insect-rearing systems to insect farms producing very large volumes. Insect production might be a professionalised industry, a community-organised affair or a private hobby. A range of factors contributed to these different models, including the economics of insect rearing, the resolution of technical challenges (such as automation), economic inequality, and public attitudes and values towards meat, livestock and insects.

One hurdle, which concerns many of the people engaged in promoting edible insects but which did not surface very strongly in the scenarios, is regulation. In Europe, for example,

regulations concerning livestock slaughter and animal feed ingredients have been designed to suit conventional livestock and will present an obstacle to the emergence of an insect feeds or foods sector unless they are altered. In particular, as a consequence of the 'Mad Cow Disease' crisis, feeds containing animals may not be fed back to livestock. However, it has been argued that the risks arising from insect-based feeds are not the same as those arising from feeds containing material from sheep or cows (van Huis *et al*. 2013). Champions of the edible insect sector are keen to get these rules changed, although others (including a participant in our scenario workshop) warn that any changes to regulations would need to be handled sensitively in order to avoid provoking any suspicion on the part of consumers that industry and regulators are taking unnecessary risks with food safety or quality. The analogy invoked by our workshop participant was the breakdown in public trust in regulations that contributed to widespread rejection of transgenic crops and foods in Europe.

As discussed in the second section of this report, the theoretical hazards arising from the mass production and consumption of edible insects are believed to be small, yet they are greater than nil, and further research is needed in order to clarify the true nature and extent of such risks and how to manage them effectively. Our four scenarios suggest that investments in this kind of research, and possible regulatory changes which might be based on such research, favouring edible insects, would be legitimate. However, the scenarios and online discussion confirm that, by themselves, these measures would not ensure that an edible insect industry could emerge and become successful.

5.2 Will consumers bite?

Producing and consuming insects are already established practices in many countries, both for subsistence and on a commercial scale (e.g. in Thailand, Hanboonsong,Jamjanya and Durst 2013). But the real likelihood of a substantial shift to insect-eating in the 'West' remains difficult to assess. These scenarios are not predictions but explorations. A factor that was mentioned frequently during the online discussion as well as the scenario workshop was that of consumer preferences, often seen as an obstacle to insect-eating. However, we know that food preferences and habits can change and have changed dramatically. For example, a cuisine of East Asian origin comprising rice, seaweed and raw fish would once have been considered disgusting by many people in Europe and North America, yet today sushi- and sashimi-inspired dishes are widely available in supermarkets, sandwich shops and convenience stores. Even pasta was once regarded in northern Europe as a strange foreign food, yet millions of Britons would now consider a packet of dried pasta a kitchen cupboard essential. So perhaps in 35 years' time it will indeed be quite commonplace for European or North American consumers to eat insects for lunch or dinner. But on what scale? SCPs were originally envisaged as a food that would prevent mass starvation (see Box 1.1). Today, Quorn (for example) is a successful commercial product, yet it occupies a rather small and specialised niche in the food market.

To probe further into this question, it may be fruitful to delve into a small, interesting tension that exists in part of the narrative that has been created to motivate interest in insect-eating as a potential contribution to global food system sustainability. The tension arises in the following way. It is emphasised on one hand that people are eating a lot of meat and we can only expect them to want more as they become wealthier. This is often spoken of as an inescapable trend that humanity has to live with, since people love to eat meat whenever they can afford it and we cannot expect them to change. Therefore we have to do something about it, and eating more insects may be that thing. On the other hand, continues the narrative, it is realistic and feasible to think that we could convince people to change their behaviour by eating insects instead of conventional livestock, and it is worth trying this in order to make meat consumption more sustainable.

In the first part of the narrative it is accepted that demand for conventional meat is a fact of life, while in the second part we are invited to accept that current patterns of meat consumption are something contingent that might be changed, in part by invoking the same argument that might otherwise be used to persuade people to eat less meat: that eating insects is a more ethical and sustainable form of consumption.

This is not a confounding tension, because giving up meat from conventional livestock and replacing it with an acceptable substitute are two, qualitatively different propositions. But the tension reveals something important about how the argument in favour of entomophagy is underpinned. It rests on the idea that insect meat can be a ready substitute for conventional meat, and that an increase in insect-eating could help to reduce the consumption of conventional meat.

It is notable that this argument is not about protein nutrition as such. Protein malnutrition is rarely a distinct problem in its own right. Nutritionists take it as a rule of thumb that when calorie intake is sufficient, in general protein will not be lacking (Schroeder 2008). So the meat-demanding consumers of our imagined future should not be understood as people seeking to satisfy their basic requirement for protein, but rather as consumers with an expansive appetite for the succulence, flavours, textures, aromas and social status of meat.

We might then think of the development of an entomophagy sector as a supply-side intervention, encouraged by technocrats who accept the future demand for meat but aspire to make that appetite more ecologically sustainable. It follows that stimulating demand to correspond to the supply is a key challenge. Entomophagy enthusiasts talk about achieving this in two basic ways. One is to produce insect-based food products that are such appealing substitutes for conventional meat-based foods that consumers are happy to accept them (consciously or not) on a like-for-like basis. By this means, conventional meat products might be edged out of the market so long as the insect-based substitutes can compete on price. This scenario clearly emphasises the production of generic insect proteins, in the form of flour or meal, using whichever species can be reared in greatest quantities for a keen price.

An alternative approach is to persuade consumers to adopt an entirely new product on its own merits. This might include the consumption of whole insects, although it does not necessarily preclude incorporating processed insect ingredients into pies, burgers and cakes (and doing so transparently, as a selling point). The key factor would be that the product would be appealing in its own right as an alternative food option that would be marketed as such. In this perspective it is easy to foresee the emergence of a niche market for edible insects, in which some people would choose to eat insects because they developed a positive taste for them. However, seen in this light, the displacement of conventional meat seems less necessary to the narrative, unless the insect-based food products are so appealing that large numbers of people choose them over conventional meat products. This forces us to recognise that an expansion of consumer enthusiasm for insect-eating might not be enough on its own to push conventional meat products out of the market. Much may depend on whether producers are able to continue producing conventional meat at an affordable price, and this may have a determining influence on whether consumers will prefer to eat it or opt for an alternative. And in such a scenario, whether insects would win market share ahead of other meat alternatives based on algae, fungi, vegetable protein or lab-cultured meat remains a wide open question.

This insight draws attention to the importance of some of the ‘shocks’ that were contemplated during the scenario exercise – shocks such as an outbreak of zoonotic disease or an epidemic illness that could not be controlled by antibiotics due to overuse of these drugs in intensive livestock-rearing. Shocks like these might lead to more stringent regulations or widespread consumer rejection of conventional meat products. These could be enough to make today’s methods of intensive livestock-rearing uneconomical and

uncompetitive, and make the prospects for proteins from insects or other sources a lot brighter.

This is likely to depend on three sets of interrelated factors. First, insect-rearing technologies and systems would need to be developed that are effective and reliable and deliver a product that meets the quality demands of the food industry and consumers. Second, these systems would need to be economically competitive, a necessity that seems likely to require the achievement of significant scale economies, which in turn may depend on automation. Third, sufficient consumer demand would need to exist. These factors are closely linked, for obvious reasons.

5.3 Edible insects and global food security

This project was created to consider above all the potential of edible insects to contribute to, even underpin, global food security in the future. What then could be the implications for human populations that are currently vulnerable to under- and malnutrition or who lack secure food supplies? This scenario exercise has not delivered a clear or definitive answer to this question. However, we can highlight some general observations.

First is the insight that some nations in the global South already have traditions of insect-eating that seem to make it more likely that their populations might adopt or expand their consumption of this more sustainable food. However, some people in the sector fear that the Westernisation of local tastes in these countries, as well as the perception that eating insects is a resort of the poor, rural and food insecure, is leading the increasingly urbanised populations of the global South to turn away from insect-eating. These same voices argue that the sight of Westerners eating insects might cause Southerners to re-evaluate their perception of this traditional food.

Second, tropical nations may have an inbuilt competitive advantage when it comes to insect-rearing. Because insects are cold-blooded, they require heat to reproduce and grow. This would likely make insect-rearing in temperate climes an energy-hungry operation, especially if the species traditionally consumed in tropical regions were chosen as the target species. (It has been suggested that the edibility of various species that are native to cooler regions might be assessed.) These two factors lead some people to the view that entrepreneurs and companies in tropical regions might enjoy a competitive advantage in these markets.

On a macro scale, the production and consumption of edible insects might well increase the supply and improve the affordability of high-quality protein, while avoiding the severe stress to the environment that would accompany any expansion of current systems of intensive livestock-rearing. And on a micro scale, it seems plausible that some people might become enthusiasts for producing as well as consuming their own insects, perhaps on a domestic or community scale, and that this might occur in rural areas as well as the expanding megacities of the global South. But these are tentative conclusions surrounded by a great deal of uncertainty. Much will depend on whether simple and easily managed systems, equipment and know-how are available and widely taken up.

5.4 Reflection on the value of Foresight scenarios

Our intention in this project was to explore and make some sense out of a range of current uncertainties; in this respect that the richness and vividness of the four scenarios has produced some very valuable insights. The workshop participants succeeded in generating four distinct scenarios that are broadly plausible and fairly coherent. Each of the scenarios integrates a mixture of social and institutional, behavioural, macroeconomic, technological and ecological dimensions to create visions of possible futures that are satisfyingly complex and thought-provoking. Collectively, the four scenarios touch upon all the major trends and

drivers of change that had been identified by the participants during the STEEP exercise. The scenarios also incorporate several kinds of shocks and surprises – unpredictable negative and positive events, such as outbreaks of zoonotic disease, oil price shocks, and technological breakthroughs – that add a sense of drama and narrative drive to the scenarios without destroying their credibility or negating their value as tools for stimulating reflections on the future of edible insects.

This project has also come across a characteristic limitation of Foresight, where solid data are often lacking. As an aspiring new industry, entomophagy does not generate the quantity and quality of technical and financial information that is churned up routinely by mature industries. New start-up companies are currently trying to work out conceptually and experimentally how their businesses might work, including their technical operations (the design and management of insect-rearing facilities) and financial planning (operational costs, market size, potential profits, and so on). We found that such companies are preoccupied by the day-to-day effort to get their businesses off the ground and lack the time to engage with a Foresight exercise such as this one.

Possibly we might have been more successful in this aspect of the research if we had used a Foresight method such as Seven Questions, which uses short interviews (that may be carried out orally or in writing) to elicit information from experts directly involved in the field. However, some of the information we would have liked to obtain might be considered commercially sensitive, so it is possible we would still have failed to bring it to the surface.

5.5 Conclusions

Protein deficiency is quite rare unless individuals are also short of calories, and can normally be addressed by increasing food intake rather than supplementing the amount of protein in the existing diet. It follows that the arguments in favour of human insect-eating are primarily concerned with the sustainability of meat production, and in this respect the ecological footprint of insect meat has been shown by initial studies to be significantly smaller than meat from mammals (depending on factors such as choice of feed types, and the geographical location and scale of production). However, people generally do not eat ‘protein’, they eat food and they want it to be tasty and satisfying. (The exception to this general rule is the niche demand for protein supplements among fitness and body-building communities.) If insect-based foods can be made appealing and affordable then there is no compelling reason to doubt that an edible insect industry will emerge. It may be segmented into a gourmet market and a generic protein ingredient market, for which the commercial-development challenges will be distinct.

A future of widespread entomophagy is plausible but many challenges would need to be addressed before the industry could emerge on a substantial, even global scale. Research is needed into production and processing technologies and food safety issues. The economic viability of a future edible insect sector is substantially uncertain at present. It will depend on the size of the eventual market for edible insects as well as the scale economies of insect production and processing.

Human entomophagy could increase the availability and affordability of healthy protein in the developing world. Countries in tropical regions where insect-eating is already established may be in the best position to expand this market, and companies in these regions may have a competitive advantage in serving it. As developing countries become wealthier, insect-based foods may offer a more sustainable way to meet future protein requirements than conventional meat. However, the assumption that it will be easier to persuade consumers to eat insects than convince them to eat less meat should be tested, and it is possible that other meat alternatives such as vegetable or algal proteins may be as sustainable and marketable as insect-based foods, or more so.

Annex 1 Examples of insect-based food products on or near the retail market in Europe and North America

Company/ Organisation	Location	Principal products
Green Kow	Belgium	Insect pastes and spreads
Goffard Sisters	Belgium	Pasta made with insect flour
Bug Food Gastronomy	Belgium	Insect-based events catering
Damhert	BeNeLux	Burgers, nuggets and schnitzel containing ground buffalo worms
Next Millennium Farms	Canada	Insect-based flours (crickets and mealworms)
Cookie Martinez	Canada	Insect-based event food (cookies, canapés)
Crik Nutrition	Canada	Cricket protein powder
Inspro Foods	Canada	Developing insect-based food products
Insectéo	France	Dried cricket and mealworm snacks
Jimini's	France	Dried cricket and mealworm snacks
Micronutris	France	Biscuits/cookies, chocolates and macaroons containing or decorated with whole or ground insects; whole dried crickets and mealworm snacks
Sexy Food	France	Whole insects (giant waterbugs, super worms, sago worms, giant black ants, scorpions, crickets, grasshoppers, rhino beetles, queen weaver ants, mealworms)
gryö	France	Cricket-based bars (in development)
Snack Insects	Germany	Dried grasshoppers, mealworms, buffalo worms; chocolates and lollies containing various insects
Crowbar Protein	Iceland	Cricket-based protein bars
DeliBugs	Netherlands	Dried mealworms and locusts
Insectable	Netherlands	Buffalo worms, locusts and mealworms
DeliBugs/Insect Europe	Netherlands	Whole insects (grasshoppers, mealworms); confectionery; sweet and savoury snacks
Grub	UK	Dried grasshoppers, crickets, mealworms and buffalo worms; chocolate fudge containing crickets
CroBar Protein	UK	Cricket-based protein bars (seeking crowdfunding)
Ento	UK	Insect-based snacks and ready meals (in development)
Bush Grub	UK	Confectionery (lollipops, candy bars); savoury snacks (salt and vinegar crispy whole crickets, BBQ-flavoured mealworms)
Snickets	UK	Insect-based snacks (not yet available)

Archipelago	UK	Restaurant serving insects and other ‘exotic’ foods
Grub Kitchen	UK	Insect-based BBQ restaurant
BugGrub	UK	Whole insects (small crickets, hoppers mix, mixed pupae, jungle trail mix, shield bugs, grasshoppers, sago worm larvae, specialty packs); chocolate-covered big crickets; Thai zebra tarantula; cricket flour
The Bug Shack	UK	Insect-based event food; whole insects (in development)
Hot Buzz	UK	Insect-based events catering
Chapul	US	Protein bars containing cricket flour
All Things Bugs	US	Cricket flour
Aspire	US	Crickets; cricket flour
Bitty Foods	US	Cricket-based cookies; cricket-based baking flour
Six Foods	US	Cricket-based crackers (‘Chirps’)
Exo Protein	US	Cricket-based protein bars
Hopper Foods	US	Cricket-based granola
Don Bugito	US	Insect-based sweet and savoury snacks (chocolate/chilli-lime/toffee/spicy crickets, mealworms and superworms; *Chinicuil*-based salt; cricket-based granola)
HotLix	US	Insect-based savoury snacks (lightly seasoned mealworm larvae and cricket ‘Snax’ boxes); confectionery (lollipops, brittle, candy)
Ento Market	US	Insect-based sweet and savoury snacks; flours; confectionery; whole insects
Clour Power	US	Fresh cricket-based products made to order (pizza, cakes, breads, cookies)
Crickers	US	Cricket-based crackers; cricket-based cookies (in development)
The Cricket Girl	US	Cricket-based snacks
Critter Bitters	US	Handcrafted cocktail bitters with roasted crickets (in development)
BugEater Labs	US	Cricket flour
Insectitos	US	Cricket cookies; worm brownies; protein bars; cricket flour; savoury snacks (seasoned crickets and mealworms)

Source: 4ento (2015) and authors’ own compilation.

Annex 2 Some producers of insects for livestock and fish feeds

Company/Organisation	Location	Principal products
SPS Feed	Germany	Insect-based animal feed
AgriProtein	South Africa	Larvae-based animal feed (MagMeal); protein oil for pet food and industrial swine production (MagOil)
MealFoodEurope	Spain	Produce insects for food and feed
Insagri	Spain	Produce insects for food and feed
Edible Bug Farm	UK	Developing insect farm for food and feed
EnviroFlight	US	Insect-based animal feed
EntoBento	US	Insect-based pet food and treats
Rainbow Mealworms	US	Insect-based pet food and fishing bait
Nutrition Technologies	Vietnam	Black soldier fly-based fishmeal and fish oils

Source: Authors' own compilation.

Annex 3 Overview of Foresight methodologies

The three principal Foresight methods used in this project were:

- Drivers of change analysis ('STEEP')
- Scenario-building using the 'two axes' method
- Options testing ('Windtunnelling')

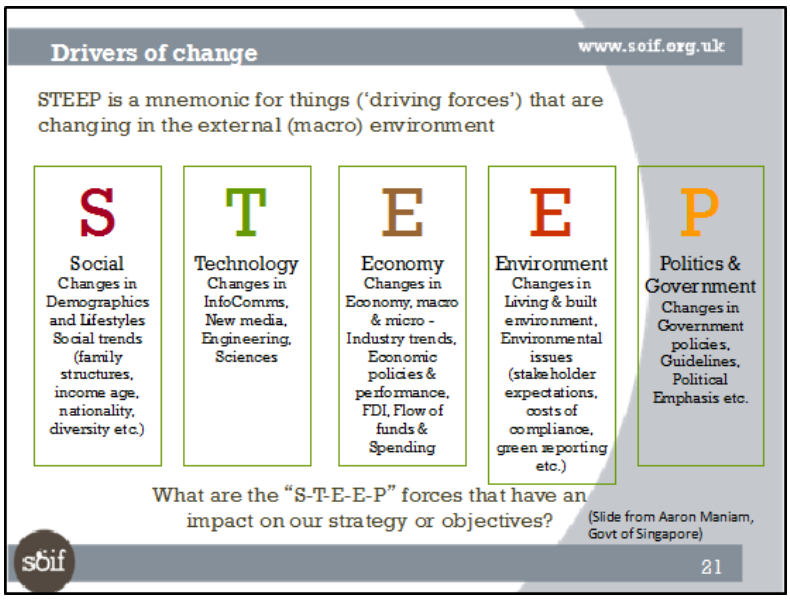
Below is a brief overview of these methods. Our use of these techniques was guided by Alun Rhydderch of the School of International Futures.

Drivers of change analysis ('STEEP')

In this exercise, a group of participants identifies major trends and drivers of change, usually in a workshop. Participants draw on their specialised knowledge and general awareness of a range of different kinds of information, which might include research and horizon-scanning data, economic and demographic models, political and legislative trends, and cross-country analysis. The participants also use their judgement and intuition to assess which drivers of change will play an important role in shaping future trends and outcomes relevant to the topic they are looking at.

The STEEP framework ensures that there is coverage of Social, Technological, Economic, Environmental and Political factors (see Figure A1). The exercise may begin with individual brainstorming and proceed to a group discussion. Participants are asked to identify which among the identified drivers of change are *most important* and *most uncertain* in their effects or implications, for the period under consideration. This may be done by some sort of informal voting as well as by consensus, with a key role played by the facilitator(s). The goal is for the group to identify about 10–15 key drivers of change that are generally agreed to be important, or about which participants feel there is considerable uncertainty, or both.

Figure A1 STEEP drivers of change

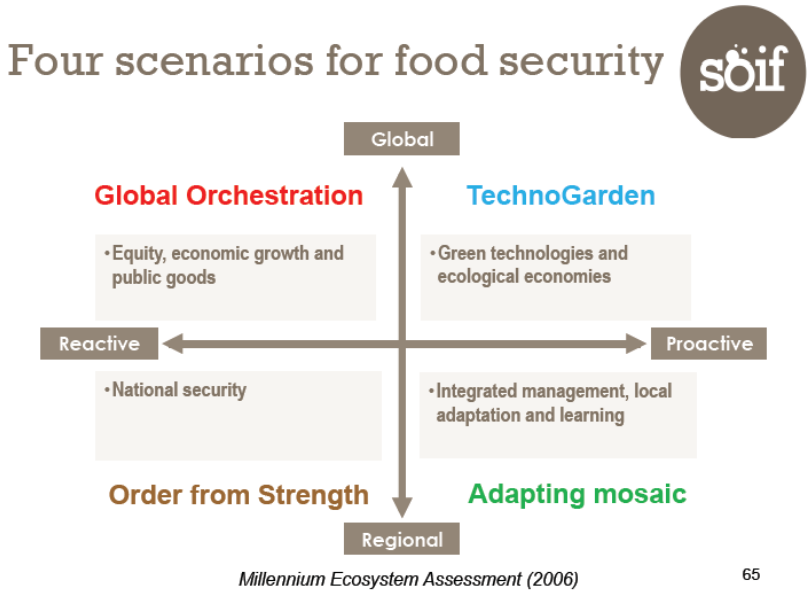


Source: Alun Rhydderch, School of International Futures (pers. comm.).

Scenario-building

The output of a STEEP exercise can be used to create a framework for a scenario-building exercise. One of the most common approaches to building scenarios is the 'two axes' method (also known as 'axes of uncertainty'). The group and/or the facilitators identify two axes that best encapsulate the prominent (i.e. important and uncertain) themes emerging from the STEEP exercise. The two axes create four 'scenario spaces' (see Figure A2).

Figure A2 Scenario example



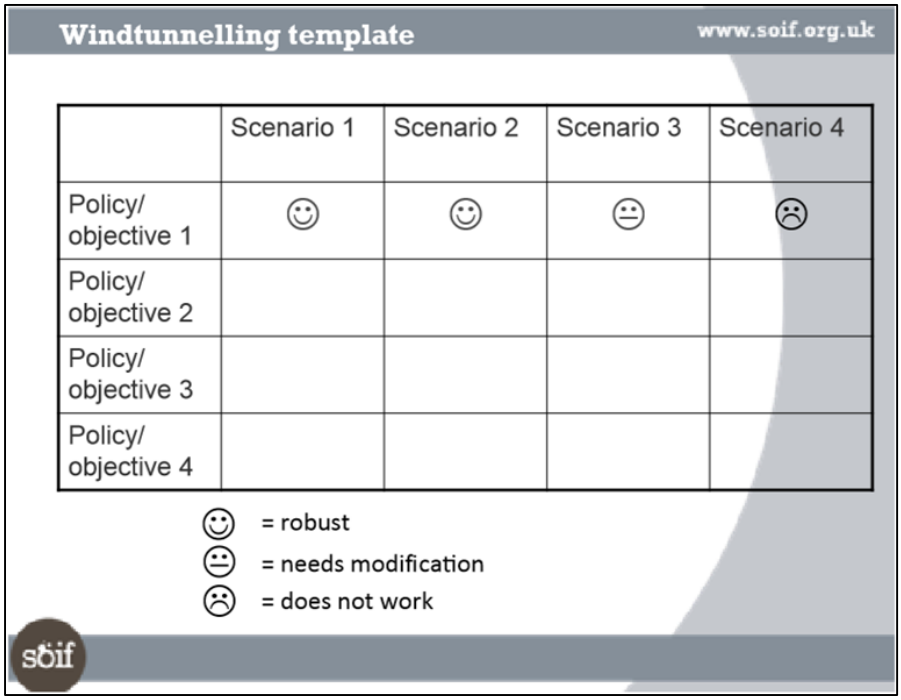
Source: Alun Rhydderch, School of International Futures (pers. comm.).

The workshop participants are then organised into four groups to work on one of the four scenarios. Drawing on the previous STEEP exercise and striving for a reasonably coherent and plausible future, the participants are invited to write up their scenario in the form of a narrative that conjures up what the world in each quadrant is like for the people living in it. The four scenarios provide alternative versions of the future, relevant to the policy or plan being developed. They are not predictions of the future, but plausible versions of what might happen in discrete and contrasting futures. Ideally the four scenarios will contrast with one another in striking, thought-provoking ways, and collectively they should touch upon most or all of the trends or drivers identified in the STEEP exercise.

Options testing (Windtunnelling)

Windtunnelling is a method to assess how a particular policy or strategy would perform or fare in different scenarios. The analogy is with the testing of the aerodynamic properties of a vehicle, such as an aeroplane, in a wind tunnel. The idea is to assess whether, or how well, the selected policy or strategy is likely to 'fly' in each scenario. Policies or strategies to be evaluated might be chosen from existing or draft plans, or alternatively candidate policies may be formulated by groups in a workshop exercise. Participants consider how effective each policy or strategy is likely to be in each of the scenarios. Policies that seem likely to perform well across several scenarios are considered 'robust', while others might be suitable only in one or two of the scenarios. Windtunnelling might also be used to consider policies or strategies that might help to steer future developments towards a more positive scenario rather than a negative one.

Figure A3 Windtunnelling template



Source: Alun Rhydderch, School of International Futures (pers. comm.)

Annex 4 Questionnaire used to stimulate the online discussion

Participants who signed up for the online discussion (see Annex 5) were invited to complete the following questionnaire in advance. The questionnaire was drafted using ordinary wordprocessing software and then converted into an online format using the online survey tool SurveyMonkey.[17]

The goals of this exercise were to stimulate the discussion participants' thinking, to get an idea of the views and attitudes of the participants in advance, and to provide material that could be used by the facilitators to guide the discussion. Out of 44 people who registered for the online discussion, only 16 responded to the questionnaire. In addition, of course, all the discussion participants were self-selecting. Consequently, the results are not representative or useful statistically and therefore we do not present them here. We present the questionnaire here to give insight into our methodology and to illustrate some important themes arising from the topic of entomophagy.

Note: The text below is a cleaned-up, near-final draft version of the questionnaire design; however, in the final implementation of the online version the questionnaire was edited and shortened, so it differed in certain respects from this plan.

A. Consumption patterns and the developing market for insect-based foods

1. Please complete the following statements by selecting the most likely option, in your opinion:

a) Insect meals and flours (ground-up/powdered insects) will be present among the ingredients of many mainstream food products in typical supermarkets…

b) Freeze-dried whole insects such as crickets, mealworms and locusts will be readily available in typical supermarkets…

Response options:

Within 5 years; 5–10 years; 10–20 years; 20–30 years; More than 30 years; Never

2. Consider the following statements and assess their likelihood:

'In the year 2050…

- Insects will be very common in commercial animal livestock feeds'
- Insects will be very common in commercial aquaculture feeds'
- Insects will be very common in commercial pet foods'
- Insects will be very common in commercial human foods'
- Insects will be very common in certain specialised human foods, such as ration packs for use in disasters and emergencies or by military forces, astronauts, athletes and medical patients – but not necessarily in foods typically eaten by ordinary consumers'

Response options:

Very unlikely; Possible but unlikely; Likely; Very likely

3. Consider the following statement: In 2050, the typical consumer in Europe and North America will choose to consume insects at least occasionally, as a normal part of their diet.

a) In your view, how *likely* is this to come about?

Response options:

Unlikely; Not very likely; Neither likely nor unlikely; Likely; Very likely

[17] www.surveymonkey.com/ (accessed 8 June 2015).

b) In your view, how *desirable* is this?

Response options:

Undesirable; Not very desirable; Neither desirable nor undesirable; Desirable; Very desirable

4. Please consider the following statement and choose the most likely option, in your opinion: In 2050 a typical European or North American consumer might obtain the following proportion of their dietary protein from insect sources:

Response options:

less than 5 per cent; 5–10 per cent; 10–30 per cent; 30–50 per cent; greater than 50 per cent; None

5. Visibility of insect consumption. In your view, how likely are the following scenarios?

'In the year 2050...

- Insects will be readily available as an invisible/"hidden" ingredient in processed foods such as pies, burgers, croquettes and bread products – and this will be prominently advertised and widely known'
- Insects will be readily available as an invisible/"hidden" ingredient in processed foods such as pies, burgers, croquettes and bread products – but this will not be prominently advertised or widely known'

Response options:

Very unlikely; Possible but unlikely; Likely; Very likely

6. Marketing of insect-based foods. In your view, how likely are the following scenarios?

'In the year 2050…

- Ground insects will be marketed as flour for home cooking and baking'
- Whole insects will be marketed as a specialty ingredient for preparation at home'
- Insects will be marketed as a health food'
- Insects will be marketed as specialist nutrition for athletes and fitness enthusiasts'
- Insects will be marketed as snacks or confectionery products'
- Insects will be marketed and consumed primarily in specialist restaurants, at food festivals and in banquets'
- Insects will be marketed just like other common foods are today'

Response options:

Very unlikely; Possible but unlikely; Likely; Very likely

B. Production

7. Which *three* species or types of insects are most likely to be developed as commercial products for human food and for animal/aquaculture feed? (Select up to three in each column):

Response options:

Radio buttons arranged in two columns, 'Human food' and 'Animal and/or aquaculture feed' – respondent may choose up to three per column. Options offered were as follows:

Mealworms; Black soldier fly; Housefly; Silkworms; Locusts; Crickets; Moths; Caterpillars; Butterflies; Bees; Ants; Cockroaches; Grasshoppers; Fleas; Wasps; Termites; Lice; Aphids; Cicadas; Beetles; Spiders; Other [please specify].[18]

8. Location of production facilities

a) In 50 years, worldwide, insect-rearing and insect-processing facilities for human food might include:

[18] Spiders are not insects but arachnids; however, some spiders are edible and consumed by humans.

- Very large, industrial-scale commercial facilities
- Small and medium commercial enterprises
- Small community-owned and operated production facilities
- Domestic/household insect-rearing for own consumption
- Rearing facilities in densely populated urban areas
- Rearing facilities in peri-urban areas/rural areas and small towns close to population centres
- Rearing facilities in rural areas
- Rearing facilities in affluent, economically advanced and technologically sophisticated countries and regions
- Rearing facilities in poor, economically underdeveloped and technologically disadvantaged countries and regions

b) In 50 years, worldwide, insect-rearing and insect-processing operations are likely to be carried out in:
- Combined operations located in the same facility
- Separate facilities but necessarily located close together
- Separate facilities that may be located far apart, with long-distance transport of insects from rearing facilities to processing plants

c) Insect-rearing and processing into human foods for commercial sale will require:
- Highly sophisticated knowledge, skills and equipment that will be very costly to acquire
- Modest knowledge, skills and equipment that could be accessible to small-scale businesses and entrepreneurs
- Very simple knowledge, skills and equipment that will be accessible to almost anyone, including domestic producers and small start-up firms.

Response options:
Very unlikely; Possible but unlikely; Likely; Very likely; Don't know

C. General attitudes towards edible insects as food and/or feed

9. To feed the world in the context of climate change, population growth and richer diets, widespread entomophagy is: *[radio button, forced choice]*

a) An option among others that we should explore
b) Highly desirable
c) Absolutely necessary
d) Inevitable
e) Not really relevant

10. Please consider the following arguments in favour of insect consumption by humans and rate them on a scale of 1–5 (with 1 being least important/compelling and 5 being most important/compelling). You may also disagree with the statement *[Likert scale + option to disagree with the statement]*

a) Insects are delicious
b) Insects are nutritious and healthy
c) Eating insects is fun and adds an interesting new option to the human diet
d) Producing meat from insects is more ecologically sustainable than producing meat from traditional livestock
e) Insect-based foods are versatile and can substitute for a wide variety of conventional meat- and fish-based dishes
f) Insect consumption would enable malnourished and undernourished people to improve and diversify their diets
g) Insect production and consumption will create opportunities for small-scale entrepreneurs, and could contribute to sustainable economic growth in developing countries

h) Insect production and consumption will create opportunities for large companies, and could contribute to sustainable economic growth in developed countries
i) Commercial insect production and consumption will create a lot of jobs
j) Insects can be reared and slaughtered in ethical and painless ways
k) Insect production systems are scalable and can be located close to centres of processing and consumption
l) Insects can be reared and prepared conveniently at home

11. To encourage consumers to eat insects, it is best to promote insect foods as: *[radio buttons, forced choice]*
a) a healthy and nutritious choice
b) an ethical choice
c) a delicious choice
d) a natural, traditional choice
e) a progressive, modern choice
f) an adventurous choice
g) a sustainable choice
h) a safe, scientifically approved choice

12. Should insect-derived ingredients in food be labelled? *[Radio button, forced choice]*
a) No (no need/undesirable)
b) Subtly (listed among ingredients)
c) Prominently (drawing attention)
d) It should be seen as a positive selling point or brand identity

13. To encourage consumers to eat insects, it is best to: *[Radio button, forced choice]*
a) Be fully transparent: through marketing, prominent labelling, visible insect parts in foods
b) Incorporate insects invisibly, label them as required but not prominently
c) Both, for different market segments

14. Are you personally in favour of: *[forced choice]*
a) Food products containing visible traces of insects
b) Insects being incorporated invisibly as flour/meal
c) Both options, for different products or markets

15. To persuade consumers to eat insects, it is best to: *[Ranking 1–5]*
a) Engage in open dialogue and give consumers the choice: organise debates and discussions, festivals; encourage independent media coverage; put insect food products onto the market and let them compete for consumers' money
b) Make insect-eating cool, hip and stylish: enrol opinion leaders, celebrities, celebrity chefs, and cultural elites and let mass media do the rest
c) Use rational and ethical arguments to convince them: educate consumers about hunger, poverty, and malnutrition, the ecological unsustainability of intensive livestock husbandry and meat-eating, and the potential of insect-eating to address these problems
d) Stimulate favourable emotional responses to insect-eating: emphasise taste, texture, aroma, pleasure, adventure, enjoyment, fun, etc.
e) Show Western consumers that many people already eat and enjoy insects: highlight entomophagy in other cultures

16. What is your attitude towards the foods you eat? Consider the following statements and indicate how closely they match your view: 'I regard food primarily as… *[on a scale of 1–5, with 1 being 'least like me' and 5 being 'most like my attitude']*
a) Packages of the nutrients I need to be healthy and active'
b) Fuel/calories to get through the day'
c) A sociable and convivial experience – a way to relax with friends and family'

d) A sensual and pleasurable experience'
e) A way to connect with the natural environment and the seasons'
f) A link in a chain that connects me with local and global food producers'
g) An expression of my political or ethical values'
h) A potential risk to my health or wellbeing'
i) A source of temptation'

17. Obstacles and challenges to the development of a production system and market for human insect consumption: On a scale of 1–5 [with 1 being least important and 5 being most important], how important are the following:

a) Achieving economies of scale
b) Refining insect-raising and processing technologies
c) Assuring food safety and hygiene
d) Creating a favourable regulatory framework
e) Consumer acceptance
f) Logistics and distribution
g) Finance and investment
h) Marketing, packaging and retail
i) Animal welfare concerns
j) Achieving and maintaining consistent quality
k) Producing sufficient quantity – to meet demand, to make a difference to sustainability
l) Competing with alternative food and feed products on price and quality
m) Making the edible insect business accessible to small-scale as well as large-scale enterprises
n) Generating scientific evidence on the safety and nutritional value of edible insects

Annex 5 Summary of the online discussion

This summary was drafted by Kelly Shephard (IDS).

Overview

The online discussion took place from 06:00 GMT on Tuesday 9 December 2014 to midday GMT on Wednesday 10 December 2014. This document provides an overview of the discussion and summarises the views expressed.

The event was advertised on the social networks Twitter and LinkedIn. The discussion was held on the Eldis Communities platform.[19] Forty-nine individuals from a range of backgrounds signed up, including academics, entrepreneurs, and other people with an interest in changes to the global food chain. Contributors were located in the US, the UK and other Western European countries, Scandinavia, Kenya, India, Hong Kong, Thailand and Mexico.

The online discussion in numbers:

- 44 registered participants visited the space during the event, 22 of whom visited more than ten times.
- 218 posts (including the thread openers) were contributed during the event.
- 29 individuals contributed to the discussion, eight of whom commented more than ten times.

Approach

The discussion was based on themes identified in advance, which were compiled into a discussion guide. An online survey was sent to participants before the discussion; 16 participants completed this survey and their responses were used anonymously to help shape the discussion guide.

The discussion was lightly moderated by members of the IDS project team (Kelly Shephard (editorial), Adrian Bannister and Steve Tovell (technical support)). Dominic Glover (lead IDS researcher) and Alexandra Sexton (research assistant) engaged with participants throughout the discussion, posing questions and inviting participants to consider particular issues and topics.

The discussion was launched in a single thread but later split into multiple threads: What are the opportunities for and challenges facing global entomophagy? What edible insect products are most likely to be developed and how will they be shaped by consumer demand? Will edible insect production and consumption systems look different in poor countries compared to rich? What strategies will shape future production systems for edible insects?

One participant (Julie Lesnik) started a separate discussion thread entitled ‘Insects: The real Paleo Diet’, which attracted some contributions on edible insects as an ancient source of protein for humans. Another participant (Brian Cook) started a thread on the theme of ‘National and International Organisation and Government Regulation’.

[19] http://community.eldis.org/ (accessed 7 June 2015).

Summary of the discussion

The discussion touched on diverse issues, relating to edible insect production and consumption in both affluent and poor countries. Participants considered technical and ethical issues, marketing strategies and consumer attitudes, issues of production scale and location, and regulatory matters, among other topics. The full discussion can still be viewed by Eldis Community members online at http://community.eldis.org/edible-insects.

The level of activity was high, with some participants writing extensive contributions and posting more than ten times. This section provides a snapshot of some of the themes and points made.

Production systems

Participants discussed where and how insects for human food might be produced, processed and marketed. Production systems of various different types, locations and scales were discussed.

Katharina Unger drew attention to her award-winning design for a domestic, table-top unit for rearing black soldier flies for domestic consumption [Farm 432]. However, whereas Jonas House did not discount domestic rearing, he warned that consumers 'can't be expected to shoulder the burden of climate change adaptation alone'. Rather, said Jonas, larger reforms need to occur at the global and industrial levels of food production.

On the subject of domestic insect-rearing, Jenny Josephs shared the following comment:

> *I'm not convinced that small-scale home breeding will take off on a large scale, but I do think some people will have them, in order to (1) see where their animal protein comes from, (2) save on costs by rearing their own insects, and (3) be responsible for the animal protein they eat.*

Jenny felt many people – particularly in Western nations – would not suddenly become comfortable with handling and/or killing insects. This was thought to be an issue not only because of people's negative attitudes towards insects but also a consequence of the fact that people have become increasingly distant from animal husbandry and slaughtering in the last century.

To normalise rearing of insects and all of the processes this entails, some participants suggested that engaging children and schools would be a key strategy. Jenny Josephs also noted that increased experience of home farming might 'drive improvements in farmed animal welfare'.

Participants touched on the question: at what scale could insect production be made profitable? The labour intensity of insect-rearing was identified as a particular issue. Another issue was the energy needs required for insect-rearing in temperate regions, to maintain the required temperature for efficient production.

Jonas House opined that in order to make an impact on current meat production, insect production will have to be on 'a very large scale'. Wendy Lu McGill considered that producing edible insects in sufficient volume for a commercial industry would be a particular challenge for developing countries. She proposed that 'a first step is to examine how these countries could first produce enough insects via raising them to even consider creating [insect-based food] products'.

One participant floated the idea that insect production facilities might be integrated into the architecture of residential tower blocks, so that the energy required for insect-rearing might

also be used to heat the residents' apartments. Picking up on this idea, another participant wondered whether the residents might be involved in rearing the insects and harvesting them for immediate consumption.

Kieron Kirkland shared information from The Open Bug Farm concerning the recommended space required for different insects and methods for increasing efficiency of production through using 'lost space'. Kieron also shared his personal experiences and experimentation with increasing production efficiency, commenting:

> *We're focusing a lot on sensor networks and automation to try and reduce individual involvement in the area and experimenting with synthetic lighting (this is actually very cheap using open source hardware that is globally available and accessible). Of course the heat is one of the key challenges in rearing some insects in colder areas, less an issue in warmer ones. So where ambient heat is high enough that will reduce costs, and make having several smaller farms more feasible. Equally with the light, in urban spaces in the global North of course there's less sunlight than at the equator so electric lighting is needed.*

When asked whether traditional farmers were likely to move into insect-farming, Wendy Lu McGill commented, 'I hope that raising insects will grow both [at] large and individual scales, and grow in both 'cold' and 'warm' places'. Florian Nock added 'I don't think that traditional livestock will change to insect, but some agricultural farmers maybe. They have the space and the food. In Thailand, some farmers grow maize specially for feeding and harvesting the insects instead of selling the maize'.

Some participants reported that raising insects for human consumption is currently more costly than raising insects for animal or fish feed. Wendy Lu McGill wondered whether there might be information, practices and lessons that might be transferred from the existing industry that raises insects for pet food. Brian Cook summed up:

> *The entomophagy movement in most temperate climates is in its infancy and the 'arthroculture' (I think I just made that up...) farming systems are still using small bins with egg-crate cartons for production, but I believe the more we can incorporate the concept of energy and nutrient 'life cycle' into this industry the stronger the future of arthroculture will be.*

Existing practices of harvesting edible insects from the wild were also mentioned by Wendy Lu McGill. She noted that wild harvesting practices vary from place to place. In some locations women and children were commonly involved, while for certain species men did the harvesting.

Feedstocks, waste management and closed loops

One of the earliest topics to be raised by a participant was the possibility of using 'waste' as feedstock for insects. This issue also related to discussions about the possibility of rearing edible insects in urban areas.

Eduardo Fernández commented that insects could play a role in the management of wastes, reducing the area required for composting and making it possible to generate food from waste. For example, a participant suggested that the large quantities of pre-consumer waste generated by urban food markets might be diverted to insect-rearing (for appropriate species), and that this would help make cities more sustainable and resilient. By turning waste into food this could potentially solve 'several vexing issues at once'. Eduardo positioned this idea in a broader concept he called 'Multiple Loop Farming' in which so-called 'waste' would be seen as the starting point of other production cycles.

However, participants also noted that the safety and quality of edible insect products would be affected by the quality and consistency of the feedstocks used, and that this might be an obstacle for efforts to produce high-quality human foods by using pre- or post-consumer organic wastes as a feedstock for edible insects.

Jarrod Goldin made the following comments on the use of organic wastes as feedstocks:

> *Organic production will raise costs, best way to mitigate cost is feed input. Using pre- or post-consumer waste is the way to go but the challenge is in controlling the feed input and the optics of using waste (especially post-consumer) for the people eventually eating the insect [i.e. consumer attitudes towards consuming insects that are fed on waste]. Also, the more organic the more oily (in a good way) but this can also make 'baking' or infusion a bit more difficult.*

Food safety

Some participants raised concerns about the safety of insect-based foods, arguing that this issue would have to be addressed before insect consumption could be widely accepted. Jenny Josephs felt that it would be 'a long time before the industry was regulated and safe'. She pointed to the work of the EU project PROteINSECT in this area.

A participant noted that there are issues around the bioaccumulation of toxic substances in insects through the foods they consume, such as heavy metals and dioxins. This comment thus highlighted another aspect of the need for consistent quality and safety of feedstocks used for edible insect production.

Policy and regulation

Relating to the issue of food safety, several participants discussed the policy and regulatory frameworks that would be needed to support an edible insect industry. Jonas Claeys noted that the EU considers a food to be 'novel' (requiring special regulatory approval) if it has not been consumed on a significant scale within the EU before 15 May 1997 (meaning that the long history of insect-eating elsewhere in the world is ignored). Jonas also noted that under EU law insects are currently regulated as livestock and therefore they may not be fed on wastes, manure or animal products (unless they are destined for pet or fish feed), and they have to be killed in certified slaughterhouses.

Looking at policy and regulation from another angle, Robert Nathan Allen (known as RNA) argued that edible insect producers should be supported with state subsidies, just as other livestock and crop producers are: 'Why shouldn't we be rewarding farmers who are willing to innovate ahead of the curve for a better future for everybody?' In addition, RNA argued that consumers should also be rewarded for choosing insect protein rather than alternative sources: 'If I eat 1lb less beef in a year, and add 1lb of insects, how many showers worth of water did I save?'

Regarding ethical frameworks, Jonas House highlighted the need to maintain hygiene standards in production, commenting that:

> *Overcoming the equation of insects with dirt is an important step, and some sort of rigorous and trustworthy system of assuring cleanliness will probably be important. The PROteINSECT team have discussed this issue – even though it is possible to rear insects on abattoir waste and faeces, this is likely to represent a bit of an image problem, if not a safety issue.*

Consumer attitudes

Various participants highlighted food culture and consumer acceptance as important issues to be tackled for an emerging edible insect industry. RNA mentioned what he calls 'the ick factor' and asked 'how do we get people to eat [edible insect products], and then how do we get them to actively choose it over other options?'

Wendy Lu McGill expressed concern that food habits are changing in developing countries under the influence of globalisation. She noted that even in countries where insect consumption is an established practice, increasingly affluent consumers are being influenced by Western consumption patterns and are turning away from insect-eating. Wendy felt that increasing insect consumption in 'developed' countries might legitimise entomophagy even in places where it is already part of the local food culture: 'given globalisation, and the way that Western food choices have spread around the world, increasing Western acceptance of entomophagy could positively affect cultures that never stopped eating insects'.

RNA commented that celebrity endorsements could be valuable in changing consumer attitudes: 'The more we get celebrities to talk about the idea, the easier it is to educate a public that has been shown a legitimising factor of influence, and it helps the top-down approach of cultural dissemination'. KBrasch, however, raised concerns about which celebrities become involved in the promotion of insects, asking whether it is helpful and positive for people like Andrew Zimmern, the host of 'Bizarre Foods' [a television programme broadcast on the Travel Channel] to be associated with the edible insects movement.

Other strategies for increasing consumer acceptance were discussed. Louis Sorkin, among others, suggested that insect flour could serve as an introductory market product. However, Jonas House argued that if home-rearing of insects increases then people would not be 'too concerned about the visibility of whole insects'.

Jonas also noted that there has already been successful uptake of entomophagy through specialist athletic products and high-end restaurants, trends which are largely due to existing demand amongst certain consumers for muscle-building protein powders, as well as the tendency for 'exotic and "authentic" food... to be consumed as a form of "cultural capital" by particular types of consumers (cf. Lisa Heldke's *Exotic Appetites* [book])'.

Jonas also noted that '"edgy" or "exotic" food consumption tends to have a gendered dimension, i.e. is associated with masculinity or the performance thereof', which he believed will particularly add to the success of athletic products, particularly amongst male consumers.

Florian Nock also suggested that some consumers may favour insects over vegetable proteins as a meat alternative, stating that it might be easier to change 'a plate composed of starch-vegetables-meat' by one of 'starch-vegetables-insect', rather than one of 'starch-vegetables-vegetable protein'.

The pros and cons of associating insects with the Paleo Diet as a normalisation strategy were also discussed. Julie Lesnik wrote that the Paleo Diet is fundamentally flawed in its use of human evolutionary science to justify the dietary model it promotes. She instead suggested that insects could be marketed as part of the '"real" Paleo Diet' that was based on a better understanding of human evolution; however, she highlighted that 'the problem is that the "real" paleo diet did not include a lot of animal protein, so that does not help promote insects as much as it should help people to reduce their reliance on meat'.

Celine Laisney opined that in developed and temperate countries, insect foods might be a short-lived fad; she also expressed concern that importing insects or insect powder would 'go against the locavore trend' and that attempting to produce insects in colder climates would

require large amounts of energy. These factors could therefore jeopardise the aim of developing insects as an environmentally sustainable alternative to current livestock production. A need for more comparative studies of the sustainability of insects versus vegetable proteins was also raised.

Research and development

The entomophagy community faces many areas of ignorance and uncertainty. Eduardo Fernández highlighted the need for research on various topics, including the range of species that could be used (including the potential to use native species); the nutritive value of different species; ensuring food safety when using insects that are fed on organic wastes with pharmaceutical compounds; and how to optimise industrial mass-rearing methods. He also asked 'what don't we know?'

Louis Sorkin called for more investigations into human allergenicity and highlighted a current project on this topic, in which he is participating with a Dutch research team.

Jonas House also suggested that market research will be important because 'trying to anticipate the cultural and commercial place of insect-based foods early on will be difficult, and… perhaps strategies to meet demand will need to be developed as such foods permeate the market'.

Wendy Lu McGill added that there was much to learn about existing entomophagy practices/uses such as wild harvesting of insects, and existing market structures for edible insects (often in the informal sector).

Discussions concerning animal welfare in insect production also led to calls for more research into ethical treatment of insects and their ability to feel pain – these points are summarised in a later section of this document.

Edible insect species mentioned during the discussion

Numerous different edible insect species were mentioned by name during the discussion. Martin Kanja noted that six insect species are commonly consumed in Kenya, including water beetles, grasshoppers and four species of termites. Wendy Lu McGill recommended silkworm pupae, produced as a by-product of silk production in India, South Korea and other countries. Locusts and especially mealworms and crickets were also mentioned several times during the discussion by different participants. Black soldier flies were mentioned as food for both fish and animal feeds.

Market segmentation

Several participants felt that a future market for edible insects would likely be stratified into different types of products for different market segments, differentiated by the types of consumers and the occasions when insects might be consumed. One participant envisaged the following segmentation of the market:

- products containing processed insects (e.g. energy bars, biscuits or flour), for people who want to try eating insects but are not yet ready to consume whole insects;
- whole insects that are readily available and affordable for people who want to see the insects and be creative with them – likely species would be house crickets, locusts, and mealworms;
- whole insects of more rare and expensive types for special occasions, where production would be sustainable only on a small scale, avoiding over-harvesting.

Jonas Claeys shared the types of insect products recently introduced onto the market in Belgium: ‘burgers, spread, potato croquettes with mealworms, crickets etc.’. He noted that these had been greeted with a lot of media attention when they were first launched, but it was difficult to assess consumer reaction since then.

Animal welfare issues

Celine Laisney raised the issue of animal welfare and whether concerns on this issue extended to insects. Jenny Josephs expressed the view that insects ‘generate far less concern for animal welfare than is apparent for traditional animal protein, as their welfare needs are easily met in terms of space, food, water and light’. Jonas Claeys agreed that ‘animal welfare is quite easily met for insects. But if they really do feel pain then they'll have to be killed in a proper way, before we use them in our meals’.

RNA noted that freezing, electric shock or gas were humane methods for culling insects, but noted that such methods might not be available to many micro-farms in rural or developing areas. Therefore, he said, boiling is the ‘go-to method’ for efficiency and food safety. RNA drew participants’ attention to a project summary from the UN Food and Agriculture Organization (FAO) that ‘addresses food safety and ethical/regulatory frameworks for these situations’.

Florian Nock shared an online article that expressed the view that vegans should feel obliged to eat insects, in spite of their aversion to eating animals, because insect consumption would conform to fundamental vegan values of animal welfare and sustainability. This article also pointed out that insects (and other animals) are routinely killed in the production of nominally vegan or vegetarian products, either through pest management practices or harvesting methods.

KBrasch wrote that the adoption of entomophagy for vegetarians and vegans is dependent on why they have chosen their dietary lifestyles: ‘if it's for sustainability reasons then I don't think they have a problem eating insects (some vegetarians/vegans at my programs have been very positive and willing to try it). However, if you believe that no animal should be killed for consumption then that may be a different story’.

KBrasch also shared a link to a media article that discusses the ability for insects to feel pain, and drew attention to this particular quote as an interesting side of this debate:

> *Other entomologists insist that the idea of insect suffering is totally implausible... Robert Elwood, a professor of the biological sciences at Queens University in Belfast, notes that pain would provide insects no evolutionary advantages. ‘From an evolutionary perspective’, he told the* Post*, ‘the only reason for pain that makes sense to me is that it enables long-term protection. The average lifespan of a field cricket is a few weeks – its protection, in essence, comes from its remarkable reproductive efficiency, not its ability to learn from mistakes’.*

Additional links and resources

The following links were shared during the discussion:

- Live Foods Direct: www.youtube.com/watch?v=5Lp7qr-9qhs and www.youtube.com/watch?v=rG0oqR9JOS8
- Edible Insects – Future Prospects for food and feed security www.fao.org/docrep/018/i3253e/i3253e.pdf
- Insect-rearing education and rearing programme www.ncsu.edu/mckimmon/cpe/opd/insectRearing/

Annex 6 List of participants in the scenario workshop

Note: Participants contributed in their personal capacities. The scenarios developed during the workshop were collective products created for the purposes of Foresight and discussion; they do not reflect the views of individuals and are not endorsed by them or their organisations.

Name	Affiliation
Adam Routledge	Edible Bug Farms (UK)
Alexandra Sexton	King's College London/Institute of Development Studies (IDS) (UK)
Alun Rhydderch	School of International Futures (UK)
Ana C. Day	4ento (CH)
Arnold van Huis	Wageningen University (NL)
Becky White	Environmental Change Institute, Oxford University (UK)
Chris Münke	Food and Agriculture Organisation of the United Nations (FAO)
Dominic Glover	Institute of Development Studies (IDS) (UK)
Elin Röös	Food and Climate Research Network, University of Oxford (UK)
Erik Millstone	Science Policy Research Unit (SPRU), University of Sussex (UK)
Florian Reinhardt	Grilo (UK)
Gerry Bloom	Institute of Development Studies (IDS) (UK)
Henk van Deventer	TNO (NL)
Jenny Josephs	The Bug Shack (UK)
Jonas House	University of Sheffield (UK)
Julia Kaisinger	LIVIN Studio (AT)
Lars-Hendrik Lau Heckmann	Danish Institute of Technology (DK)
Matt Anderson	Edible Bug Farms (UK)
Nick Nisbett	Institute of Development Studies (IDS) (UK)
Sophie Laurent	Ynsect Biotech (FR)

References

4ento (2015) *Insect Food Products Currently Available*, 4ento.com, www.4ento.com/2015/02/23/insect-food-products-currently-available/ (accessed 3 June 2015)

BBC News (2014) 'Edible Insect Products go on Sale in Dutch Supermarket Chain', 1 November, www.bbc.co.uk/news/world-europe-29865959 (accessed 4 June 2015)

Bingley, K. (2014) 'A Review of Strategic Foresight in International Development', *IDS Evidence Report* 94, Brighton: IDS

Conway, G. (2012) *One Billion Hungry: Can We Feed the World?*, Ithaca NY; London: Cornell University Press

DeFoliart, G.R. (1989) 'The Human Use of Insects as Food and as Animal Feed', *Bulletin of the Entomological Society of America* 35: 22–35

de Graaf, M. (2015) 'Dutch Experience and Local Knowledge Boost Insects Rearing in Africa', ICCO website, www.icco-international.com/int/news/news/eating-insects-increases-prosperity-in-kenya-and-uganda/ (accessed 5 June 2015)

Ehrlich, P. (1968) *The Population Bomb*, New York: Sierra Club/Ballantine Books

EVMI (2015) 'Jumbo Landelijk met Insectenproducten [Jumbo Goes National with Insect Products]', 5 January, www.evmi.nl/marketing-sales/jumbo-landelijk-met-insectenproducten/ (accessed 4 June 2015)

Flanders Today (2014a) 'Insects Approved for Human Consumption', 3 January, www.flanderstoday.eu/living/insects-approved-human-consumption (accessed 4 June 2015)

——(2014b) 'Delhaize Launches Line of Insect Products', 18 September, www.flanderstoday.eu/business/delhaize-launches-line-insect-products (accessed 4 June 2015)

Gerland, P.; Raftery, A.E.; Ševčíková, H.; Li, N.; Gu, D.; Spoorenberg, T.; Alkema, L.; Fosdick, B.K.; Chunn, J.; Lalic, N. *et al*. (2014) 'World Population Stabilisation Unlikely This Century', *Science* 346.6206: 234–37

Godfray, H.C.J.; Beddington, J.R.; Crute, I.R.; Haddad, L.; Lawrence, D.; Muir, J.F.; Pretty, J.; Robinson, S.; Thomas, S.M. and Toulmin, C. (2010) 'Food Security: The Challenge of Feeding 9 Billion People', *Science* 327.5967: 812–18

Hanboonsong, Y.; Jamjanya, T. and Durst, P.B. (2013) *Six-legged Livestock: Edible Insect Farming, Collecting and Marketing in Thailand*, Bangkok, Thailand: Food and Agriculture Organisation of the United Nations, Regional Office for Asia and the Pacific

Imrie-Situnayake, D. (no date) 'Crickets vs. Chickens? We're Missing the Point', *Exo Protein Blog*, http://blog.exoprotein.com/crickets-vs-chicken/ (accessed 21 June 2015)

Kihlberg, R. (1972) 'The Microbe as a Source of Food', *Annual Review of Microbiology* 26.1: 427–66

Looy, H.; Dunkel, F.V. and Wood, J.R. (2014) ‘How Then Shall We Eat? Insect-eating Attitudes and Sustainable Foodways’, *Agriculture and Human Values* 31.1: 131–41

Lundy, M.E. and Parrella, M.P. (2015) ‘Crickets are Not a Free Lunch: Protein Capture From Scalable Organic Side-Streams Via High-Density Populations of *Acheta domesticus*’, *PLoS ONE* 10.4: e0118785

Post, M.J. (2012) ‘Cultured Meat from Stem Cells: Challenges and Prospects’, *Meat Science* 92.3: 297–301

Ramalingam, B. and Jones, H. (2007) *Strategic Futures Planning: A Guide for Public Sector Organisations*, London: Ark Group

Schroeder, D.G. (2008) ‘Malnutrition’, in R.D. Semba, M.W. Bloem and P. Piot (eds), *Nutrition and Health in Developing Countries*, New York: Humana Press

Sudinfo.be (2014) ‘Les Insectes Débarquent dans les Magasins Carrefour Aussi [Insects are Launched in Carrefour Stores As Well]’, 28 September, www.sudinfo.be/1111713/article/2014-09-27/les-insectes-debarquent-dans-les-magasins-carrefour-aussi (accessed 4 June 2015)

The Local DK (2015) ‘Danish Supermarket Sells Insects – For Two Days’, 16 March, www.thelocal.dk/20150316/danish-supermarket-sells-frozen-insects-for-two-days (accessed 4 June 2015)

van Huis, A. (2013) ‘Potential of Insects as Food and Feed in Assuring Food Security’, *Annual Review of Entomology* 58.1: 563–83

van Huis, A.; van Itterbeeck, J.; Klunder, H.; Mertens, E.; Halloran, A.; Muir, G. and Vantomme, P. (2013) *Edible Insects: Future Prospects for Food and Feed Security*, FAO Forestry Paper 171, Rome: Food and Agriculture Organisation of the United Nations

Zorpette, G. (2013) ‘The Better Meat Substitute’, *IEEE Spectrum*, www.spectrum.ieee.org/energy/environment/the-better-meat-substitute (accessed 21 June 2015)

Brighton BN1 9RE

T +44 (0)1273 606261
F +44 (0)1273 621202
E ids@ids.ac.uk
www.ids.ac.uk