

THE FUTURE IN PRACTICE

THE STATE OF SUSTAINABILITY LEADERSHIP



A 'doubly-green' revolution

Professor Chris Gilligan

In a close working relationship, artist Michèle Noach and horticulturist Ian Martin grew plants in an artificially warm environment, creating the *Arctic Poppy Chronicles* in 2012.



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Professor Chris Gilligan is Head of the School of Biological Sciences, Professor of Mathematical Biology and Head of the Epidemiology and Modelling Group at the University of Cambridge. He is also Chair of CPSL's Management Board. Interview by Wayne Visser.

According to the latest figures by the UN Food & Agricultural Organisation, 13 per cent of the world's population is undernourished, including 33 per cent of the population of the least developed countries. Furthermore, the world faces a potential food crisis in coming decades as the population grows inexorably and as climate-related changes intensify pressures on food production. Given that the most productive land is already being used around the globe, simply increasing crop production is not the answer.

One way to safeguard food security is to increase the yield of crops from the same amount of land, while also minimising the amount lost to pests and pathogens – the so-called 'untaken harvest'. Outbreaks of disease can sometimes reach epidemic proportions, wiping out entire crops, often with substantial social and economic consequences. Today, epidemics such as cassava mosaic disease, citrus canker, and a particularly alarming new wheat pathogen, Ug99, threaten important agricultural and food crops in regions across the globe.

This is the area on which Professor Chris Gilligan's research focuses. He believes that global food security is one of the major challenges we face in the 21st century.

"Each year, despite remarkable improvements in crop-protection strategies such as breeding disease resistance, a quarter of the global crop production is still lost in the untaken harvest, and plant pandemics are a constant threat," he explains. "One way, amongst others, to reduce these losses is to develop mathematical models that can help regulators, policymakers and growers to track disease and develop surveillance and eradication strategies."

This is precisely what Professor Gilligan and his team of mathematicians and statisticians have developed during his

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tenure of a Biotechnology and Biological Sciences Research Council (BBSRC) Professorial Fellowship. Their mathematical toolkit not only provides a new way of predicting the risks and hazards associated with crop production, but also, crucially, generates intelligence on the cost-effective management and control of that threat.

The economic and social benefits of food security through disease control are clear. However, Gilligan also sees effective epidemiological control as part of a 'doubly-green' revolution to increase yields but to do so sustainably. This involves integrating research

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expertise in the natural, clinical and social sciences with insights from the humanities, to develop tractable solutions that are sustainable, socially equitable and ecologically successful.

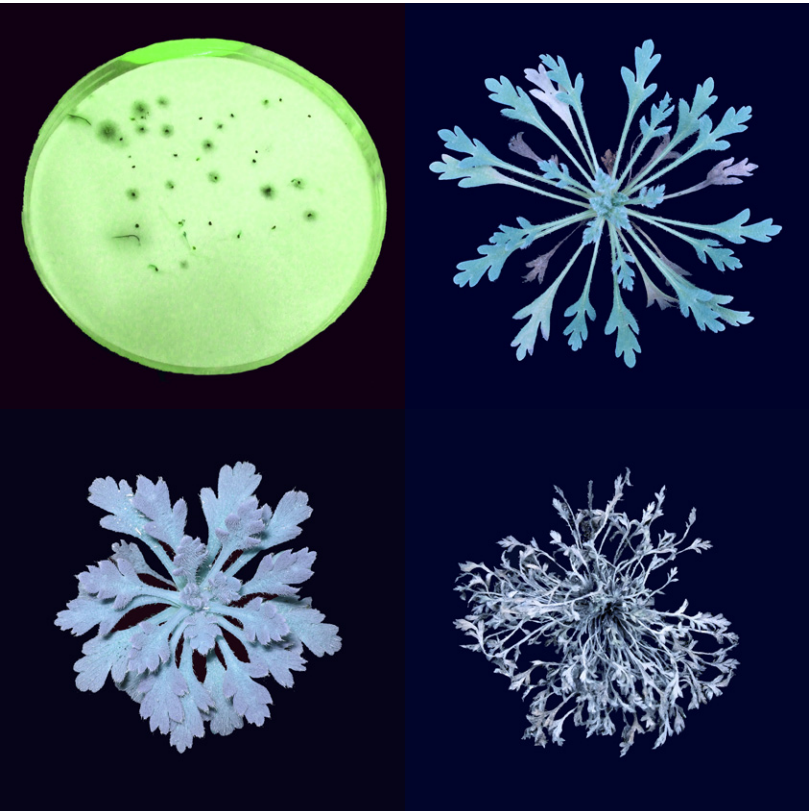
For Gilligan and his team, in practice, this does not mean banning chemical or genetic controls of plant disease, but rather ensuring that their effectiveness and impacts are well understood and carefully managed. This is why his research helps to identify epidemiological strategies that minimise the risks of failure of chemical and genetic control. In many cases, this allows for more selective, intelligently targeted and locally applied controls, resulting in an overall lower negative impact on humans and the environment.

The goal of resilience

One of the central aims of Gilligan's research is to increase the resilience of our agricultural – and associated biological, scientific and human – systems. This critical element of sustainability is only possible when we are better able to model and respond to uncertainty.

In the case of the invasion and persistence of a disease, working out where to look for it and how frequently, and then predicting what will happen and how best to control it, can be fraught with challenges. Not only can the scale of an epidemic be hidden – for instance some infected plants might be symptom-free and yet transmit infection – but, as Gilligan explains, there is also an element of uncertainty in how infection is transmitted.

"Dealing with complicated systems that have a biological, economic and social component is inevitably challenging. In addition to this 'noise' is the potential for the disease to take what you might imagine to be an unlikely turn. The art of modelling is to identify as simple a model as possible that captures



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the inherent features of the system, and then to use it to explore the likelihood of disease spread, allowing for uncertainties.”

As the Cambridge scientists have discovered, the secret has been to allow many possible scenarios to play out through the model. Bayesian methods of statistical inference are used to allow for uncertainty in understanding how an emerging epidemic spreads, and the model is then updated as new data become available. This allows the group to predict the most likely future spread of disease based upon current knowledge.

Working in collaboration with the UK Department for Environment, Food and Rural Affairs and the United States Department of Agriculture, Gilligan’s group has successfully integrated a fundamental biological understanding of how certain diseases spread with epidemiological models that incorporate data from geographic information systems about landscape and weather. The result is a toolkit that enables end-users to identify the risks and hazards of disease detection, spread and control. Supported by the Gates Foundation, Gilligan’s group is now applying these methods to analyse strategies for the control of plant disease in African agriculture.

Improving decision-making

Any form of disease control involves costs and crucial decision-making. Where mathematical modelling can help is in enabling regulators to use resources strategically in the most effective way.

One recently published report from the team looked at Asiatic citrus canker, a bacterial disease of the economically important citrus crop of the USA, Brazil and Australia. Eradication

attempts have already proved to be extremely costly – a decade-long attempt in Florida which began in 1995 cost in excess of \$1 billion and led to the removal of millions of citrus trees.

The new results flagged up an important point, which informs a political dilemma concerning the removal of diseased trees to eradicate the disease when the pathogen infects both residential and commercial trees. The two constituencies, home owners and growers, are linked by dispersal of the pathogen, and what happens in one constituency affects the other. Hence, an eradication effort must be co-ordinated in both areas.

“It is precisely this type of intelligence about disease dynamics that is so important for regulatory bodies to be aware of,” explains Gilligan. “With this knowledge, it would be possible to choose a control strategy that satisfies the objectives of both commercial and residential citrus tree owners.”

Often the recommendations of the models are counter-intuitive. “Contrary to expectations, for some diseases, the best strategy is to operate an intermediate level of detection rather than a high level of vigilance,” he says. “In fact, even a slight change in the balance between the resources allocated to detection and to control may lead to drastic inefficiencies in control strategies.”

For some diseases, the best control method for an outbreak in two regions is to control the smaller outbreak first and then to concentrate on the larger one. “The common assumption would be to try to equalise the level of infection in both regions by first tackling the larger outbreak, but for some diseases this is the worst you can do – much better to concentrate resources on eradicating

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them in the region with the lower infection,” explains Gilligan. “The models allow us to identify where best to deploy control, and where there would be wasted effort.”

Anticipating the future

The models have not only been used for studying plant pests and pathogens, but also to study the spread of pesticide resistance, and the transfer of genes from genetically modified crops to wild populations. And because the underlying mathematics and epidemiological modelling are similar regardless of the disease, the toolkit can also be targeted towards the surveillance of human diseases and pandemics.

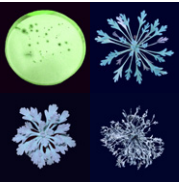
A key aim of the research programme has been to develop a resource within which end-users can easily try out and simulate a range of control scenarios – adjusting parameters such as how often surveys are conducted, how successful detection is, what level of eradication is aimed for, and which control strategy to use.

Gilligan anticipates one particularly important use for the toolkit in the near future: a new strain of the wheat pathogen called stem rust, Ug99, emerged in Uganda in 1999 and has

been spreading north, across the Red Sea and into the Middle East. “We don’t yet know when it will arrive in major wheat-growing areas such as Europe and the Indian subcontinent, but we are at least five years away from having a wheat variety that can resist the pathogen. When the pathogen arrives, and it is very likely that it will, it could inflict severe shortages in wheat production, costing billions of pounds. We need to be ready – and this means having the capability to detect, track and control the disease effectively.”

Gilligan’s research approach embodies much of what has come to be understood as sound principles of sustainability – understanding problems systemically and applying context-specific solutions; anticipating future threats and preparing solutions to cope with them; thinking about the long-term consequences of our short-term actions; using cross-disciplinary skills and knowledge to solve interconnected, multi-level problems; embracing new technology while remaining conscious of its risks; and applying scientific progress to serve people and the planet rather than catering only to narrow economic interests.

The State of Sustainability Leadership is CPSL’s annual thought leadership report, delivering insight and challenge from our world-wide network of business leaders, policymakers and academic experts. This year’s edition, to be published in full in December 2012, is focused on the theme of business and the long-term – what leaders can do to understand and shape the future. CPSL is an institution within the University of Cambridge’s School of Technology. www.cpsl.cam.ac.uk



Michèle Noach developed *The Arctic Poppy Chronicles* throughout her artist residency as part of the ‘Slow Art’ programme at the Eden Project. Meticulously documenting the poppies’ adaptive capabilities in a rapidly warming environment, she worked alongside Eden horticulturist Ian Martin as they grew and observed the poppies over a 3-year period. The poppies’ survival inspired a thrilling working relationship between artist and scientist, creative and rigorous in equal measure, which was published as *Poppyflakes*. CPSL is proud to be collaborating with Cape Farewell, which works with artists and scientists on a cultural response to climate change. www.capefarewell.com