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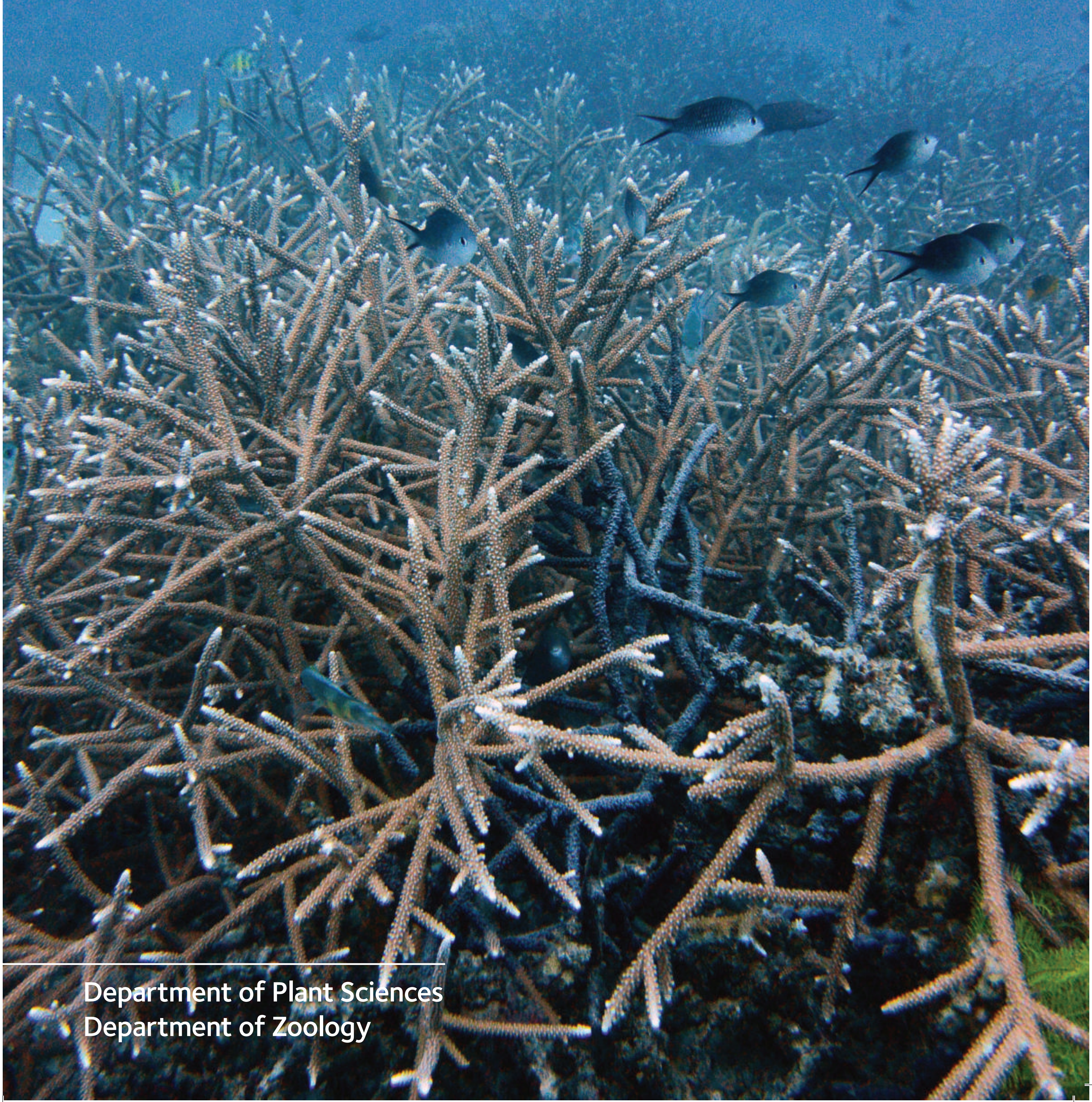


Department of Plant Sciences
Department of Zoology

Liam Dolan
Head of Plant Sciences Department

This year has been marked by momentous events; there have been some great research accomplishments but the sudden closure of the Tinbergen Building which houses the Department of Zoology was a terrifying event that has shaken us to the core. Working closely with our colleagues in Zoology we ensured that the teaching of the undergraduate degree in Biological Sciences was disrupted as little as possible. Not one lecture was cancelled in the aftermath of the closure. Credit for this goes to Peter Darrah (Director of Undergraduate Teaching), Siobhán Organ (Undergraduate teaching co-ordinator) and Roni McGowan (Department of Plant Sciences Administrator), as well as the entire administrative and support teams from both Departments. I am immensely grateful to them for going that extra mile in this emergency.

While the closure of Tinbergen building could have posed an existential threat to our subject, it actually presents us with huge opportunities to enhance the future of biosciences at Oxford. Conversations have started to discover ways in which this potential disaster can be transformed into a once in-a-century opportunity to develop 21st century infrastructure that is up to addressing the major global challenges of our age.

I shall stand down as the Head of Department in the summer of 2017. It has been a privilege to serve in this role for the past five years. I have particularly enjoyed discovering the wonders of the ground-breaking research carried out in the Department by presenting it to external agencies and donors. Sharing discoveries, such as the identification of the horn of Africa as a major biodiversity hotspot (Cicely Marshall and William Hawthorne), the description of new species of *Ipomea* and potential new crops (John Wood and Robert Scotland), and the modulation of plant stress by modifying plastid function (Paul Jarvis), has been an immense pleasure. Even more exciting has been sharing future visions of research – using drones to monitor invasive insects in the UK (Tonya Lander), creating wild life corridors in the UK landscape (Lindsay Turnbull), and enhancing pigeon pea production in India (Phil Poole) – with our supporters. It has also been a pleasure to celebrate the successes of individuals – for example the merit promotion to full professor this year of both Robert Scotland and Dmitry Filatov in recognition of their science and their contribution to the work of the Department.

Alumni and donors play an important part in enabling us to carry out our research but also to deliver a diverse and engaging Biological Sciences degree to our undergraduates. We look forward to meeting you at our Department of Plant Sciences events in London in 2017 and 2018 as we move towards the 400th Anniversary of Plant Science in Oxford.

Professor George Ratcliffe will take over as Head of Department on 1 October 2107. George is a biochemist and a world leader in metabolic flux analysis who uses a diversity of approaches to understand plant metabolism. George's leadership and vision will guide the Department into the third decade of the century – I hope that he has as much fun as I have had. The Department's future is in great hands.

Ben Sheldon
Head of Zoology Department

I took over as Head of Department in October 2016 following five years of wise and successful leadership from Peter Holland. I am honoured and a little humbled to have this opportunity.

The past year has been one of challenges as well as continued successes. As with all parts of the higher education sector we face uncertainty over Brexit: many of our staff and students are citizens of EU countries, and in many years Europe has been our largest single funder. We await details of how education, research and immigration policy will develop in response to this cataclysmic political event, but we are confident that world-class science and education will continue in the Department.

There are many successes to celebrate. Applications for the undergraduate degree continue to soar, and we continue to attract very high quality graduate students. Graduate student funding has been greatly enhanced by the departmental graduate scholarships funded by the sale of two major spin-out companies (*Natural Motion* and *Oxitec*) founded in the department. Several members of the department have won prestigious awards, including the Scientific Medal of the Zoological Society (Kevin Foster), election to the Academy of Medical Sciences (Martin Maiden), and the Young Investigator award of the American Society of Naturalists (Lucy Aplin). Charles Godfray recently led a major team to win a £5M grant from the Wellcome Trust to study the link between food security and environmental change.

However, there is no doubt about the event that dominates our lives at the moment. The Department of Zoology had to leave the Tinbergen Building, its home for nearly half a century, at very short notice in February, to enable asbestos found in the building to be dealt with. The University has reassured the Department that it does not believe that there has been any health risk to regular users of the building.

The closure of our building brought out the best in Oxford. Colleges and other Departments opened their doors to us and made us feel very welcome, so that we all had somewhere to sit within days. Over the next few weeks, we found a slightly more permanent solution, such that the department is now settled until the end of this year in three main hubs - New Radcliffe House in the Radcliffe Observatory Quarter, at Wytham Field Station and in laboratory space in the main science area.

Thanks to the amazing response of our teaching staff in Zoology and Plant Sciences, ably supported by administrative staff in the two departments, teaching the Biological Sciences degree has gone on uninterrupted throughout the whole period. We are working to ensure that our new cohort starting in October will have the same excellent experience of an Oxford biology degree as they would have expected before the closure of the Tinbergen.

For many of our staff and research students, the Tinbergen closure has had a massive and immediate impact that we are doing our best to mitigate. However, we are now starting to look forward to the future, and seeing positives in this catastrophic event. The haven given to our staff in different departments, and the mingling of research groups in our temporary homes, has led to new collaborations with colleagues across the sciences in Oxford. We will build on these links and the ideas they have generated into the future. The closure has also provided the impetus for the revitalisation of the Wytham Field Station, to a vibrant hub which will play a full role in the department's future.

We are now starting to plan for our long-term future as a department. This shake-up gives us the opportunity to rethink what it means to be an excellent department, leading the development of the subject in the 21st century, and over the next months we will be formulating ideas for a new home that facilitate and support our research and teaching vision for the future. With several new appointments in the pipeline, this is a time for us to look forward with a positive vision. As alumni and friends of the Zoology Department we would love for you to be part of this conversation. If you have thoughts or suggestions please get in touch.

A wolf in fox's clothing

Rat catchers on the roof of Africa; remarkably successful in their niche but threatened by shrinking habitats and disease.

Although hunting for small prey on their own, Ethiopian wolves live in large family packs, which protect their home ranges and care for their offspring communally

Ethiopia is the home of Lucy, our ancestor. Her discovery 3.2 million years ago confirmed this northern stretch of the Great Rift Valley as the cradle of humankind. From here humans crossed a land bridge northward to conquer the world, but many remained and shaped the land of Ethiopia over hundreds of thousands of years, particularly through herding livestock and farming.

Crossing a land bridge from Eurasia in a reverse route the ancestors of Ethiopian wolves, closely related to grey wolves and coyotes, came to the horn of Africa about 700,000 years later, as the land warmed up and the ice of the last glaciation receded.

The continent's new immigrants would remain there, refining their skills at hunting rodents on the Afroalpine plateaux, developing longer limbs, muzzles and smaller set-apart teeth until they were masters of the Afroalpine – efficient, lean, killing machines of mole rats, grass rats and hyrax. Increasingly resembling more a red fox (albeit three times the size) than their lupine ancestor.

I began studying the behavioural ecology of Ethiopian wolves in the Bale Mountains in the late 1980s, when I joined the Zoology Department as a graduate student. There were never many wolves because of their limited habitat - probably a few thousand at best, and today there are fewer than 500 alive in a handful of mountain enclaves, making the Ethiopian wolf the rarest canid species in the world - four times rarer than the panda bear – and Africa's most endangered carnivore.

It is not for lack of food that their numbers are small. Their Afroalpine environments harbour a particularly high rodent biomass, some 3,000kg of rats per km2 in some meadows, comparable to large herbivore biomass in several protected grasslands of East Africa. It is an amazing resource for wolves, other carnivores and many raptors. Although solitary foragers, the wolves live in large family packs that patrol and tandem-mark small communal territories protecting rich food patches, attaining high densities unusual for a carnivore the size of a German shepherd.

In a way these wolves are victims of their own success. They evolved to thrive as specialists of the Afroalpine grassland. But because of the warming continent, and the pressure of humans, now they are restricted to tiny mountain pockets and the pressure continues ever upwards. This environment is also a resource for cattle and goat herders, and the peril they bring by way of disease carried by the shepherds' dogs. The dogs are there to protect the herds from wild predators. Ethiopian wolves do not prey on such large animals, but it doesn't stop dogs interacting with wolves and inevitably transmitting rabies and canine distemper virus to their wild relatives.

Whenever rabies strikes three quarters of a wolf population may perish, and small populations are at risk of local extinction. Social canids have the ability to reproduce well, and litters of six or seven puppies in a good year might deliver a thirty percent growth following an outbreak, with the wolves' demography showing accentuated peaks and troughs. This led our research to focus on the demographic impacts of disease, and to develop prophylaxis to protect these rare animals. This includes vaccinating dogs coexisting with wolves, or the wolves themselves during epizootics. However, in recent years we have been moving away from a reactive vaccination approach to a pro-active one, using an oral vaccine. This could enable us to prevent or lessen the impact of future outbreaks and build some immunity in the populations.

Specialised creatures require special management, and we have to take all factors into account, particularly humans. The highlands of Ethiopia are human dominated, and there is no viable conservation approach without taking the local communities into account. Our team's work is never done. These animals are inherently rare and they are going to remain rare. Unless we succeed with our conservation efforts they are going to get rarer still.

Claudio Sillero

Electrosensing in fish

Gnathonemus petersii, *the weakly electric elephantnose fish*

What is it like to be a bat? The philosopher Thomas Nagel posed this question as part of a thought experiment about perception and consciousness. His interest was in how an animals' sensory apparatus influences the way that it might experience the world; in this particular case, how information filtered through echolocation might affect a bat's perception. In parallel to a philosophical approach, the science of sensory ecology seeks to understand what information is obtained through different sensory systems, how it is obtained and processed and why the information is useful. My group explore these mechanistic and functional questions that are key to animals' survival and success.

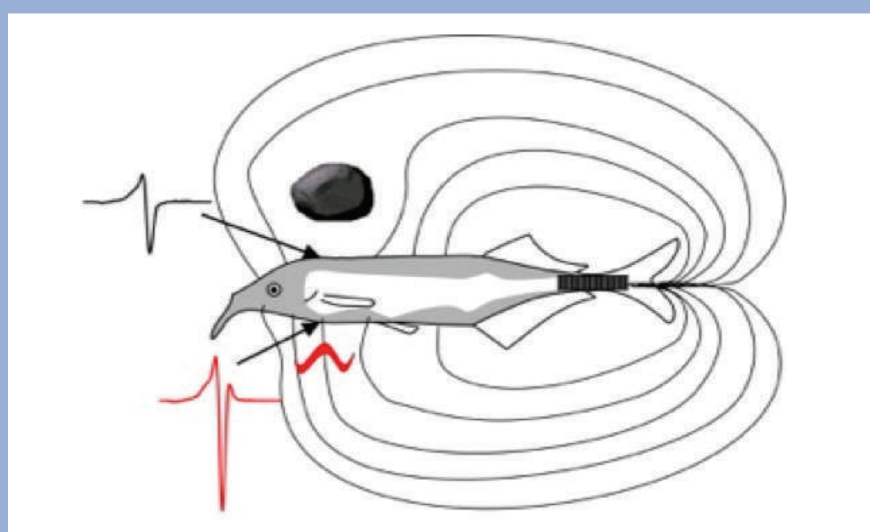
Together with Gerhard von der Emde in Bonn, Germany, we are investigating electrosensing in the fantastically named weakly electric elephantnose fish, *Gnathonemus petersii*. These fish are able to detect and discriminate objects by a process called active electrolocation. Individual fish produce weak electric pulses from an electric organ located in the caudal peduncle (just in front of the tail) that is controlled by a pacemaker nucleus in the central nervous system. These electric organ discharges generate a three-dimensional electric field around the animal, which is then perceived by the fish using special cutaneous electroreceptor organs. A nearby object distorts the field lines, which results in an electric image being produced across the population of mechanosensory-based receptors on the fish; analogous to a visual image produced on a retina, although with very different properties. Electric images provide a wealth of fine scale spatial information about objects including shape, size and location and also information about their electrical properties such as resistance and capacitance, which can inform the fish whether these objects are living or dead (useful if you are deciding whether to eat something or not!).

Objects and environments contain inherently multimodal information, therefore animals are likely to use information from multiple sensory channels to analyse features of their environment and to guide behaviour. A fundamental question in sensory biology is how multiple sensory systems operate together to produce an appropriate behavioural response. Together with the elephantnose fish's visual sense (which is fascinating in its own right, shaped by many adaptations that have evolved to deal with the animals' crepuscular lifestyle), the active electric sense has provided a wonderful system in which to explore how senses interact. Electric fish can discriminate between objects of different shapes by sight alone, or by using their active electric sense on its own and they can weight these senses independently, depending on their reliability. Strikingly, the fish spontaneously transfer the features of the object between their visual and electric senses. In other words, they can reliably identify objects using their electric sense when they had only ever seen them before, and by sight when their only previous experience of the object was electric. This suggests that objects are represented in a generic form independent of the specific sensory system used. Perhaps a form of Platonic Ideal in a fish!

Ultimately, our work offers insight into the way information is perceived, processed and represented in the brain and hence sheds light on how animals behave and interact with the world that they inhabit.

Theresa Burt de Perera

Electric organ discharges generate a three-dimensional electric field around the fish. These field lines are perturbed by close-by objects. A conducting object, such as a worm, condenses the field lines on the skin; whereas a non-conducting object, like a stone, spreads the field lines. From von der Emde, G. (2006). Non-visual environmental imaging and object detection through active electrolocation in weakly electric fish. Journal of Comparative Physiology A, 192(6), 601-612.



How fish respond to the loss of predators

Tim Coulson walking/swimming to the field site where we study guppies in their natural environment

Ecological change happens quickly, with fluctuations in the size of animal and plant populations measured in days, months or years. Evolution happens much more slowly, on the scale of centuries and millennia. Biologists had held this view of nature for many decades, but in the last few years they have realised that evolution happens on timescales we can observe, and that ecological and evolutionary change can occur simultaneously. Although this was an exciting discovery, it raised a significant challenge – ecological theory needed extending to incorporate evolutionary dynamics, and vice versa. My group and I have been addressing this challenge by developing new theory and applying it to understand joint ecological and evolutionary change in free-living populations of animals.

In the lowlands of Trinidad, guppies coexist with a number of predatory fish that prey upon them. Guppies found in these streams live fast and die young: they reach sexual maturity at a young age and small size, they produce large litters of small offspring, and they die young, usually as a meal for a predator. Guppies living in these lowland streams are agile swimmers, are often found in shoals and feed primarily on freshwater invertebrates. Both males and females are rather drab.

If you walk upstream, you soon reach the mountains of Northern Trinidad. At this point waterfalls appear that have acted as barriers to guppy predators; the streams above these waterfalls do not contain populations of the pike cichlids and wolf fish that eat guppies. In some of these predator-free streams there are populations of guppies, and they differ from their lowland ancestors. They have a much slower life history, they are slower swimmers, have a more omnivorous diet, and are more likely to be found alone rather than in a shoal. Males are often more brightly coloured than their lowland cousins. The low predation guppies found above waterfalls are genetically different to those found in the lowland reaches. What is remarkable is that this evolution is repeatable: the high predation phenotype has evolved into the low predation form on multiple occasions.

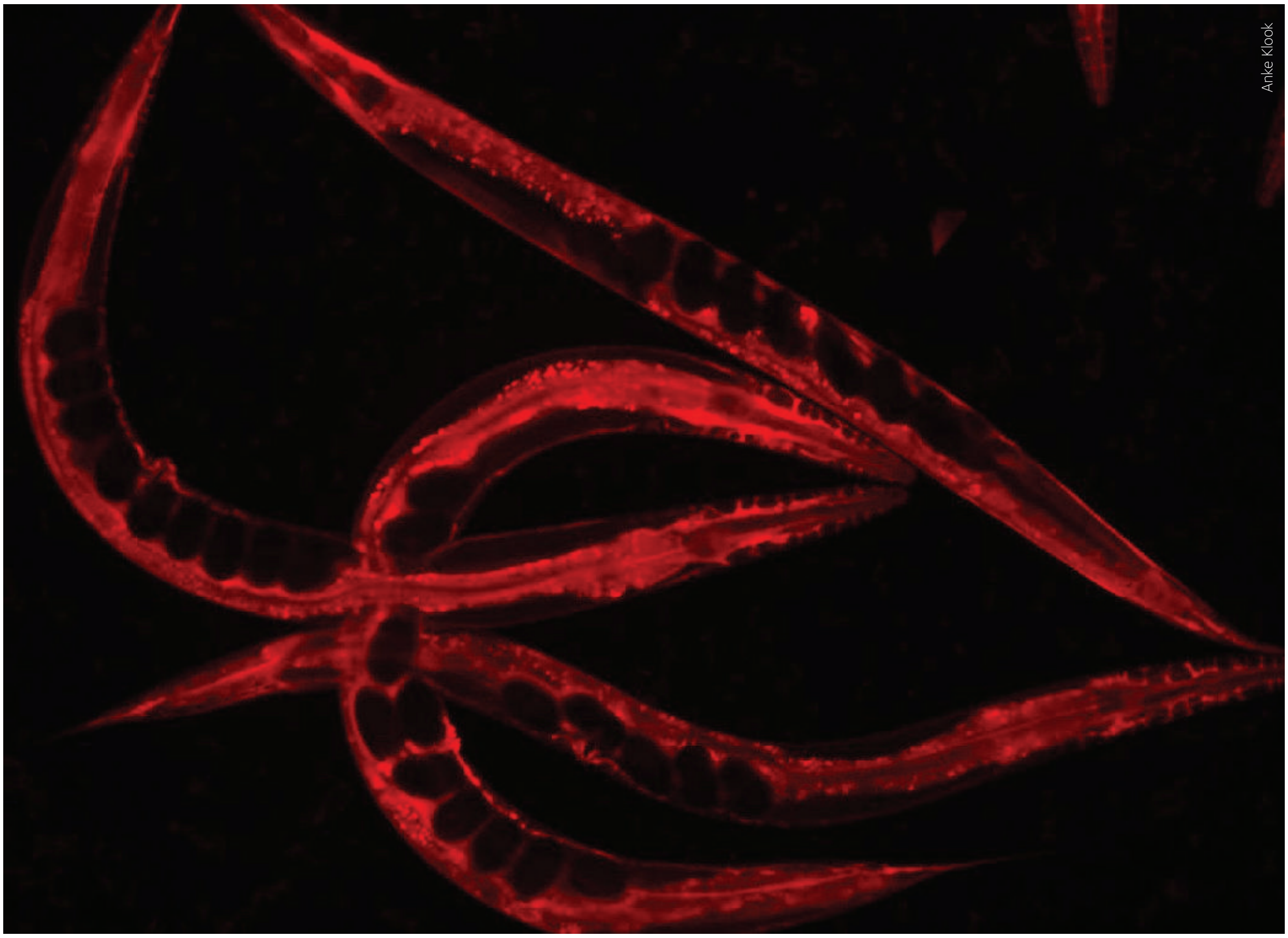
In collaboration with researchers at the University of California at Riverside and Florida State University we are running an experiment to understand the evolutionary journey from the high predation phenotype to the low predation one. Nearly ten years ago we identified four experimental mountain streams that did not contain guppies. Into each of these experimental streams we introduced 100 high predation guppies, each of which was marked with a unique tattoo. Each month, researchers return to the streams capturing as many guppies as they can. Any unmarked guppies are tattooed and a scale taken for genetic work. We now have the life histories of 80,000 guppies as they evolve to life in their new environment. Our data are collected by teams of intern undergraduate and graduate students who each spend three months in Trinidad working on the system.

We have taken these guppy data and used them to parameterise models to pick apart the causes and consequences of releasing guppies from predation. Predictions from these models have led to us running a number of experiments in 16 artificial streams we have constructed in Trinidad to test our theories. Our work has revealed that a relaxation in predation pressure leads directly to the evolution of slower swimming speeds and brighter colouration in males. Life history evolution, in contrast, is driven by an indirect effect of removing predators. In the absence of predators, the guppy populations grow in size until they are limited by food availability rather than by predation. Increased competition between guppies for food results in the evolution of a more omnivorous diet as freshwater invertebrates become significantly less abundant at high guppy densities. In addition, the change in mortality attributable to the release from predation selects for a slower life history. Finally, competition with the only other fish species in the mountain stream, Hart's killifish, also appears to contribute to some of the changes we see, with current work exploring how killifish influence guppy ecology and evolution and vice versa.

We have shown that by altering the predation regime of guppies we see rapid ecological change, with populations rapidly increasing in size. These changes, coupled with the loss of predation, result in the evolution of a wide variety of different traits over the course of about 20 generations. Guppies in our experimental streams have not yet reached the end of their evolutionary journey, although rates of evolution appear to be slowing. Our teams of interns continue to collect the mark-recapture data that is so useful for us, while gaining valuable field skills that many of them so desire.

Tim Coulson

Microbes that protect



Caenorhabditis elegans *worm colonised by bacterial pathogens*

Virtually all multi-cellular organisms, including us humans, are home to multitudes of microbes. These microbes can be harmful or of no consequence. However, over a century ago, it was observed that some can be beneficial by providing their hosts with a strong barrier against infection by parasites. 'Protective microbes' are now known to be widespread components of plant, animal, and human microbiota. For example, North American fruit flies can inherit bacteria whose toxins suppress infecting nematode parasites, and cocoa trees in Central America can acquire fungi which fight off foliar pathogens. These protective traits also make microbes attractive candidates for disease control. They form the basis of the probiotics industry and therapeutic approaches such as 'faecal transplants' whereby the gut microbial communities from healthy individuals are transplanted to ill patients. These beneficial microbes are thus of clear environmental and clinical significance.

My research group at the University of Oxford has shown that microbes living inside nematode worms (*Caenorhabditis elegans*) can evolve within days to possess this protective power. Worms were protected against infection by virulent, opportunistic parasites (e.g., *Staphylococcus aureus*), including some antibiotic-resistant superbugs. The short timescale presents the possibility of the evolution of microbe-mediated protection within the lifetime of a longer-lived host, such as a human or tree. My group then asked whether microbe-mediated protection could force parasites to change tactics, similar to how parasites have evolved resistance to antibiotics. Intriguingly, protective microbes caused a rapid decline in disease severity as parasites evolved to be less virulent. Much of this work is relevant to human health and disease as we conduct our studies with human parasites. Thus, if applied in a disease control context, our results suggest that microbes could be used to cure infections in the short-term and also guide parasite evolution in a favourable direction over the long-term.

One of our goals now is to assess how the host immune system copes with these friendly foreigners. Although *C. elegans* are relatively simple worms, they have a well-described innate immune response to parasites. As a starting point, we will evolve worm hosts to determine whether protective microbes can 'take-over' from the host immune response as the primary antagonist to parasites. If so, host immunity against particular parasites could become redundant over evolutionary time. Such a finding would reveal more about the impacts of the microbes that protect us. They could be more significant to host biology and evolutionary history than previously realised.

Kayla King

Student projects

How does the breeding phenology of birds respond to a changing climate?

Emily Simmonds, St Cross College

An advance in the timing of breeding across many species has been a widely observed response to warming temperatures. I study how great tits in Wytham woods time their breeding to best match with the peak abundance of winter moth caterpillars. I use field techniques to investigate how current matching is achieved, such as deploying thermometers within nests to identify the onset of incubation. I also use mathematical models to predict how synchrony between the tits and their prey may change into the future, under different climate change scenarios. My research should give us an insight into what the future great tit population could look like. My DPhil research is funded by NERC.

Control of rhizoid development by microRNAs

Anna Thamm, Linacre College

During plant development cells divide and differentiate into specialised cell types by selectively activating and inactivating specific genes. MicroRNAs play decisive roles in controlling gene expression. My DPhil project aims to characterise the function of a microRNA that is part of a genetic network controlling the development of the rooting cells (rhizoid cells) in the model liverwort *Marchantia polymorpha*. To this aim, I am using the targeted genome editing technique CRISPR/Cas9 to suppress the expression of that microRNA and thus to investigate its role within the genetic network. The results of my DPhil will increase our knowledge of how microRNAs control genetic networks and hence cell differentiation.

Population dynamics and interactions of a symbiont-aphid-parasitoid system

Luke Howard, St Anne's College

Hamiltonella defensa is an endosymbiont found in many aphid populations around the world. It provides its host aphid with a greater resistance against one of its largest enemies: the parasitoid. Even though it provides such an obvious benefit, the symbiont is never fixed in aphid populations. In my project, I attempted to investigate why this is the case by creating a mathematical population model. I coded and ran simulations of my model in Mathematica to explore the relationships between each population. Analysis of my model implied that there is a strong effect of aphid density-dependence that is preventing *H. defensa* from reaching fixation. It also suggested that there may be an influence of spatial or temporal fluctuations in parasitoid populations.

Reducing the impacts of ash dieback on ecosystems

Louise Hill, Linacre College

Ash dieback is an invasive fungal pathogen of ash trees, which was accidentally introduced into Europe around 1990 and spread to the UK in 2012. It is expected to kill a large proportion of ash trees, Britain's third most common broadleaved tree, with major knock-on effects on woodland ecosystems. My research looks at this crisis from the perspective of the ecosystem, to ask what the wider impacts may be and whether we could lessen them through management. I am using modelling and experimental techniques to produce recommendations for evidence-based conservation, aiming to retain as many ash-like characteristics in woodlands as possible.

Uncovering the function of a novel regulator of chloroplast biogenesis

William Broad, Wolfson College

Plastids, the organelles which include chloroplasts, are a defining feature of plant cells. They fulfil critical functions in all plant tissues, including photosynthesis, environmental perception, signalling, and the synthesis of molecules of dietary importance. The structure and function of plastids is defined in part by their proteome. As plastids import >95 % of their ~3000 proteins from the cytosol, studying the regulation of their protein import machinery gives insights into the differentiation of plastid function. Using molecular and genetic techniques, I am developing an understanding of a gene, implicated in chloroplast biogenesis, which I have found to profoundly influence the protein import components.

Oxford Botanic Garden – a garden of science

*Painting of the fanged pitcher plant (*Nepenthes bicalcarata*) showing its swollen tendril in which ants brood*

I returned to Oxford in 2015 with a vision to transform Oxford Botanic Garden and Arboretum (OBGA) into a world class University Botanic Garden. Central to this vision is science: collections at a university botanic garden must be used for research and tell scientific stories about plants for education and public engagement; they must also be maintained to the highest standards of horticulture, arboriculture, and curation. I applied this formula at the University of Bristol Botanic Garden (where I was Director from 2002–2015) to create a new Botanic Garden where plant science is central, and both research and teaching flourish. Here at Oxford, with a dedicated team of staff and enthusiastic support from the Friends and other benefactors, we are applying this formula to the oldest botanic garden in Britain.

Our challenge is to become more like Harvard's Arnold Arboretum (arguably the world's premier University Botanic Garden) by embedding scientific excellence in our strategic plan. Realising this objective will take time and significant investment in new glasshouses, in a visitor centre at the Arboretum, and in new research, teaching and public engagement facilities. However work is already well underway to reinvigorate and enhance the collections through acquisition of new material, reconfiguration of beds and displays, and creative interpretation. The newly reconfigured 'vegetable beds' now showcase 'Plants that Changed the World' – a seasonal assemblage of edible, medicinal and fibre plants that have been central to the evolution of human civilisation.

'Plants that Changed the World' is a key element of 'plants and people', one of four core themes in our collections strategy, the others being 'evolution and taxonomy', 'biodiversity and conservation' and 'heritage and landscape'. The latter relates to the Oxford Herbaria with their world class plant collections assembled over nearly 400 years of Oxford botany, and to the rich ecological landscape at the Arboretum. This theme celebrates the historical and contemporary links with the Department of Plant Sciences. This relationship will be showcased by the new 'Herbarium Room', which will be a 'shop window' for the botanical treasures of the Herbaria.

High quality interpretation is critical for communicating the science behind the collections, and this requires new interpretation boards, plant labels, and digital links. Perhaps the most challenging task will be interpretation of the former 'Family Beds', which we are reconfiguring as 'Order Beds' according to the latest DNA-based classification of flowering plants by the Angiosperm Phylogeny Group (APG). To do this we are presenting the Orders in a 'linear' fashion according to how they would appear in a herbarium structured according to APG. This will preserve the historical look of the walled garden, with its distinctive rectangular beds, in a contemporary scientific format.

We are also building a portfolio of research projects at OBGA and strengthening current research links with Plant Sciences. My long-standing research project on the evolution of Oxford ragwort (*Senecio squalidus*) has just received more funding from NERC and our work on evolution and speciation in whitebeams (Sorbus) is in collaboration with Kew. The recent appointment of Dr Chris Thorogood as Head of Science and Public Engagement brings further research opportunities to the Garden – Chris has worked extensively on the evolution of parasitic plants, notably broomrapes (*Orobanche*) and carnivorous *Nepenthes* pitcher plants. The arrival of Dr Guillaume Chomicki later this year, as a Glasstone Fellow in Plant Sciences, heralds the return of research on ant plants – plants with a mutualistic association with ants. Research on these fascinating plants was pioneered by Dr Camilla Huxley in the 1970s and '80s and her collection is preserved at the Botanic Garden awaiting a research renaissance under Dr Chomicki. The outlook for science and research is bright.

Simon Hiscock

Left: *Plants that changed the world at the Oxford Botanic Garden*

Plant growth and mechanics: much edgier than we thought

A fundamental challenge in biology is to explain how organisms develop the intricate anatomical forms we observe in nature. This is a truly complex process that requires co-ordination across scales from the molecular (e.g. the arrangement of polymers in a cell wall) to the multicellular (e.g. the co-ordination of cell growth across an organ). My lab studies the intracellular mechanisms that facilitate the development of higher-order multicellular plant form. Recent work has uncovered a unique aspect of these mechanisms, showing that plant cells have a remarkable capacity to identify their own geometrical features and that this ability is important for organising cell growth during organ formation.

The overall shape of any organism is determined by the size, shape, and arrangement of its component cells. In this respect, plants exhibit a number of distinctive features. Young plant cells of developing organs adopt strikingly polyhedral shapes that are determined by the rigid cell wall that is assembled around each cell. Higher order anatomical form is generated principally by controlling the growth vectors of individual cells: a cell may, for example, grow equally in all directions to increase in size without any change in shape or it may elongate in one direction only. It has long been recognised that to do this, polyhedral cells must be able to identify and then selectively weaken their cell walls at particular geometric faces. Little is known about how this happens.

We have identified a new and previously unrecognised feature of the mechanisms involved. We discovered that young plant cells are able to identify not only their cell faces but also their geometric edges, i.e. the intersections between faces. By studying the processes that contribute to the assembly and modification of cell walls, we found that a unique population of intracellular transport vesicles is targeted specifically to the geometric edges of cells. Time-lapse microscopy showed that when this intracellular transport pathway is genetically disrupted, cells continue to grow but lose their capacity to control growth direction so organ formation is grossly perturbed (Figure 1). This intracellular mechanism is controlled by a protein that seems to have appeared first in the earliest aquatic ancestors of land plants.

Cell edges are points of high mechanical stress so we propose that the edge-directed transport pathway modulates the mechanics of cell walls at cell edges. To test this we need a much better understanding of the mechanics of cell expansion as well as improved methods for measuring mechanical properties at subcellular resolution. In collaboration with Prof. Sonia Contera (Physics) we are using dynamic atomic force microscopy (AFM) to map the mechanical properties of cell walls at nanometre resolution. Crucially, this analysis reveals the loss modulus (Figure 2), which is the critical determinant of cell growth, whereas all previous AFM measurements have documented only the elasticity of the wall. To understand how these mechanical parameters influence cell growth in the context of multicellular tissues, we are collaborating with Prof. Antoine Jérusalem (Engineering Science) to use his finite-element modelling framework to produce 3-dimensional mechanical models of cell and tissue growth. Previous models are confined to artificial 2-dimensional simulations or to small expansions that represent cell elasticity rather than cell growth. We hope that our combined efforts will provide insights into the ways in which activities at the subcellular scale are co-opted into the higher order control of cell and organ growth.

Ian Moore

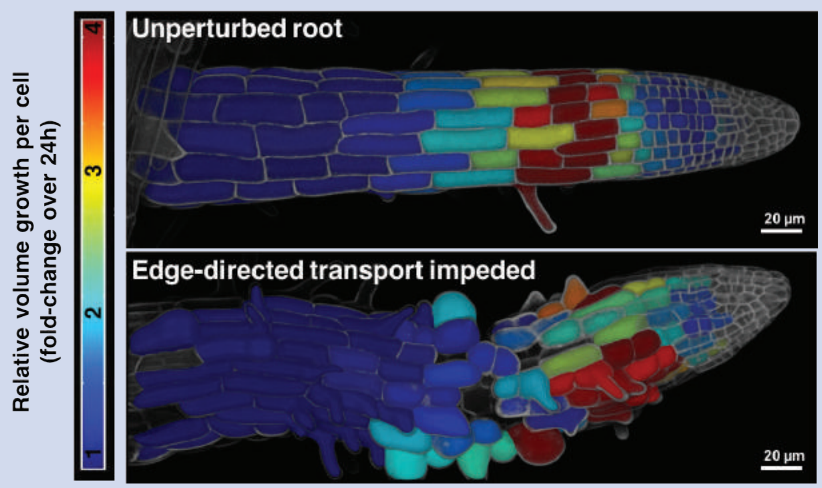
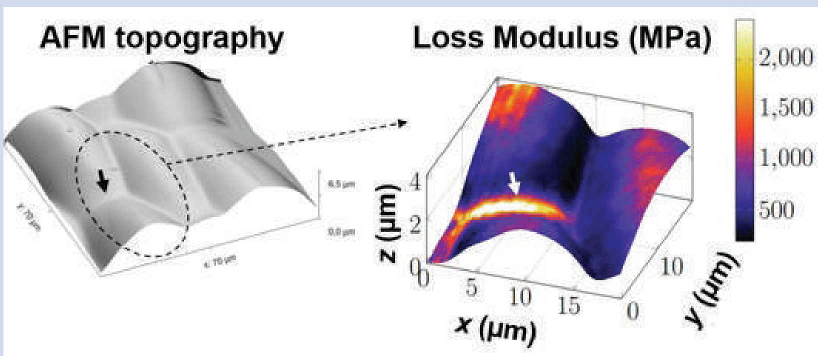


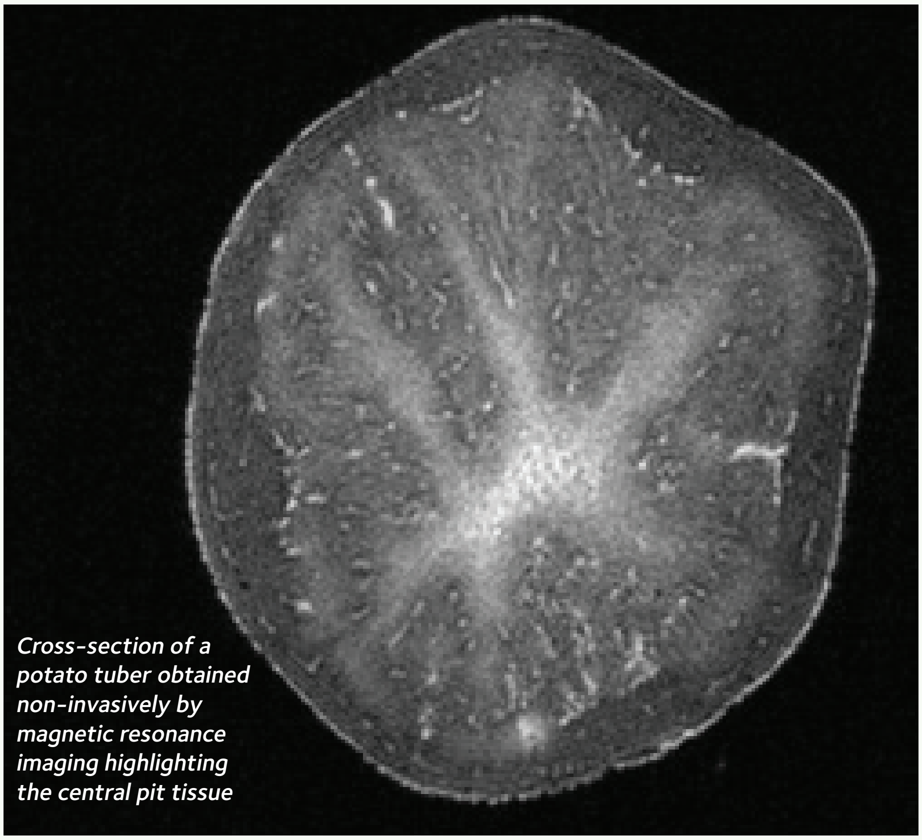
Figure 1 (above): *Images of roots with cells colour-coded by their relative growth over a 24h period. New cells are formed at the tip then grow principally in one direction to form an elongated structure* (top); *when transport to cell edges is inhibited, cells grow more isotropically and root structure is perturbed.*

Figure 2 (below): *Measurements of cell topology* (left) *and the loss modulus* (right), *a measure of viscoplastic deformability in cell walls. This parameter varies in strength at cell faces and at different edges depending on the principal orientation of organ growth* (Jacob Seifert and Sonia Contera, unpublished).



Increasing the quality of fruit and veg

As consumers, we expect our fruit and vegetables to look good and taste good but also to be cheap and in plentiful supply all year round. Growers are faced with the unenviable challenge of producing high quality, uniformly sized produce, whilst maximising yields per hectare and reducing costs. A further problem for growers is that many crops have only a single harvest each year, meaning that long-term storage of the crop is required to meet year-round demand. Fulfilling these consumer demands is often at the expense of flavour and nutritional quality.



Cross-section of a potato tuber obtained non-invasively by magnetic resonance imaging highlighting the central pit tissue

The research in my lab focuses on plant metabolic networks – the thousands of interconnected biochemical reactions that lead to the biosynthesis of all the molecular components required to build cells and tissues. The flavour and nutritional quality of fruit and vegetables is a direct consequence of the activity of their metabolic networks. For example, as tomato fruit ripen, they accumulate specific flavour metabolites. This compositional change makes the fruit more palatable for animals, facilitating seed dispersal, as well as affecting the taste of the tomato in your lunchtime salad or sandwich.

Working with scientists at Syngenta, we have identified the underlying metabolic basis for the accumulation of two amino acids – glutamate and aspartate – that are important for the acidic tang without which tomatoes would be blandly sweet. Through the efforts of a D.Phil. student and a postdoc over a six-year period of research, we established that the accumulation of these two amino acids in ripe fruit was affected by the activity of a transporter protein that ferries them into the large central vacuole of tomato fruit cells. By genetically increasing the expression of the gene encoding this transporter protein, we were able to increase aspartate five-fold and glutamate two-fold, huge increases considering that these were already the two most abundant amino acids in ripe fruit.

We also work with the related Solanaceae crop, potato. Here the problem is not flavour, but storage-related degradation. To maintain year-round supply, UK potatoes are stored for up to thirteen months in vast refrigerated facilities to prevent sprouting and to maintain skin condition. Because of this prolonged storage, more potato crop losses are now experienced in-store than in-field. A significant proportion of these in-store losses is caused by the disorder "Blackheart" which causes brown discoloration in the centre of affected tubers. This is not the result of a pathogen but rather is thought to be due to the activity of an enzyme, polyphenol oxidase, in the same process that causes browning of cut fruit like apples and bananas. Manor Fresh, a specialist supplier of vegetables to UK retailers, is funding a D.Phil. student in my lab, Lottie Chapman, to find out more about the biochemical events that lead to Blackheart. We have discovered that the central pith tissues suffer a metabolic energy deficit prior to the onset of Blackheart and are working to establish whether this is the underlying cause of the disorder.

The work in our lab highlights the importance of metabolism for the quality of fruit and vegetables. By working alongside industry, we hope that our discoveries will be used to generate new varieties and to develop new agronomic practices that will lead to more nutritious and better-tasting food on your plate.

Lee Sweetlove

A time-course of Blackheart development in potato

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