

PULS/CE 33



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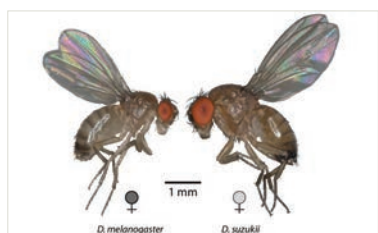
Max Planck Institute
for Chemical Ecology

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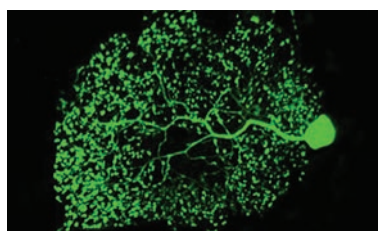
Multifunctional defenses

Cereals use chemical defenses to directly fend off lepidopteran larvae and also to regulate indirect defense mechanisms against aphids. Scientists identified the “switch” between these different functions as a methyltransferase enzyme ... **p. 3**



No super-Drosophila

Vinegar flies of the genus *Drosophila* have either excellent vision or an increased olfactory sensitivity, but not both at the same time. In other words, they have developed more sensitive odor perception at the cost of poor vision or vice versa. The size of their sensory organs is related to their mate and host selection behavior ... **p. 4**



Tasty or putrid?

Vinegar flies can process conflicting odors in the brain by minimizing the perception of positive odors through noxious odors. Therefore the flies avoid attractive odor sources when a repellent odor is added to the mix. This behavior protects them from moldy food and foodborne pathogens ... **p. 5**



MAX-PLANCK-GESELLSCHAFT



A farewell and a new start



Outgoing director Wilhelm Boland (in the middle with his wife Marie-Luise, right) and his successor Sarah O'Connor (left) during the break of the Emeritus Symposiums on April 12, 2019. Meanwhile, a wind quintet made up of members of the institute (below from left to right: Grit Kunert, Robert Winkler, Michael Reichelt, Diana Mewes and Benjamin Bartels) surprised the professor emeritus, who is still leading a small research group, with a serenade. Photos: Angela Overmeyer

Dear Readers!

In 2017, we celebrated the 20th anniversary of our institute. This year, we had the first farewell symposium for one of the founding directors: On the verge of retirement, Prof. Wilhelm Boland was celebrated and honored by many of his long-time colleagues, his former PhD students and postdocs from all over the world, and also by co-workers from the administration, the IT group and building services, many of whom have also been part of the institute for 20 years and actively involved in its establishment. His outstanding scientific contributions and his close relationship to Friedrich Schiller University were acknowledged with appreciation in welcoming addresses and lectures by, among others, the former rector of the Jena university Klaus Dicke, as well as Erika Kothe and Axel Brakhage, with whom Boland launched the "Jena School for Microbial Communication," a graduate school which has been

funded by the Excellence Initiative of the German Research Foundation since 2007. Wilhelm Boland's achievements in promoting young scientists are also remarkable: Today, eight of his former group leaders hold professorships in German-speaking countries. Many international talents, some of whom still have strong links to the institute as leaders of Max Planck Partner Groups, are the heads of their own research group or are professors.

Over the next decade, at intervals of two to three years, all of the founding directors will gradually retire. Their retirement will ultimately mark the end of the start-up phase of the institute, a period of extremely high scientific productivity. However – to somewhat alter Hermann Hesse's famous line of poetry – a promising beginning dwells in each farewell: Sarah O'Connor, who has just received the prestigious Perkin Prize for Organic Chemistry (see page 8), will take up her post as Director of the Department of Natural Product Biosynthesis starting in July of this year. The remodeling work in her wing of the institute is in full swing, and the first two doctoral students have already started their research in Jena. Most of Sarah O'Connor's research group will move here in July, so that new momentum will be brought to our institute. The search for a potential successor of David Heckel has already started. Much will change over the next ten years, and these changes will bring new opportunities and challenges. Nevertheless, we will always look back with pride on the achievements of the first 20 years of our young institute.

Karin Groten





Multifunctional defenses

In nature, plants are exposed to a multitude of enemies that feed on their leaves, stems and roots, or drink their sap. In response to these threats, plants produce secondary metabolites to prevent herbivores from feeding. These defensive substances can be used in a multifunctional manner, as a team of researchers led by Tobias Köllner from the Department of Biochemistry and Matthias Erb from the University of Bern found out. They characterized the function of benzoxazinoids in wheat using previous insights about the benzoxazinoids' defensive functions in maize, in which a methyltransferase acts as a functional switch. The enzyme "decides" whether benzoxazinoids are sufficiently toxic to protect the plant from caterpillar herbivory, or whether a less toxic form of the compound induces the production of callose, a cell sealant that makes it difficult for aphids to suck phloem sap. When the scientists introduced the maize switch into wheat and permanently activated it, the transgenic wheat plants were no longer able to "choose" between toxin production and defense regulation; instead, the plants constantly produced the toxic form of the benzoxazinoids. These plants allowed for Köllner and Erb's team to analyze how switching

between toxin production and defense regulation affects wheat resistance to lepidopteran larvae and aphids. Moreover, the scientists were able to identify and analyze the corresponding switch in wheat. Surprisingly, in both species, the genes responsible for switching between their toxic and regulative forms are only distantly related, although both maize and wheat produce benzoxazinoids via the same conserved core biosynthetic pathway. The two cereal species likely evolved this switch independently during the course of evolution. Scientists call the phenomenon that different species evolve a solution for the same problem independently from each other "convergent evolution." That two grasses which produce the same defensive substances evolved the corresponding switch for their use independently of each other may be evidence that the ability to use benzoxazinoids for different functions has evolved relatively recently. This also highlights how important it is for plants to be able to adapt defense responses specifically to different herbivores. Plants of the cabbage family also use defensive substances for callose regulation, suggesting that this type of multifunctionality is widespread in the plant kingdom.



The researchers would now like to find out how benzoxazinoids control other defensive processes. They are particularly interested in discovering whether there are receptors for benzoxazinoids. If so, these could well be classified as specialized hormones, thus further blurring the boundary between plant toxins and defense regulators. Ultimately, this research could contribute to answering why plants use toxins to regulate defenses in addition to classical plant hormones. [AO/KG]



Right above: When wheat is attacked by aphids, the plant produces a less toxic form of benzoxazinoids, which regulates callose production. Callose makes it difficult for aphids to take up plant sap. Image: Beibei Li and Tobias Züst, University of Bern, Switzerland

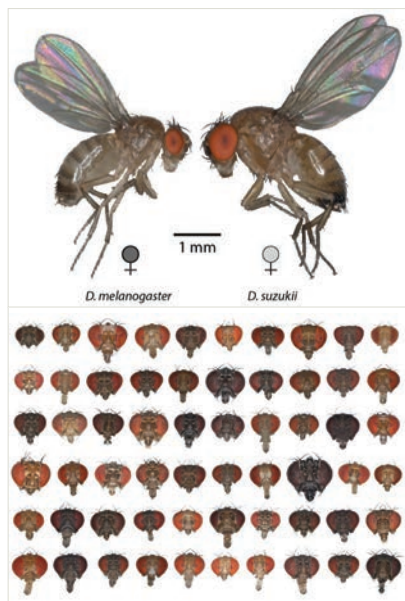
Left below: Wheat plants which overexpress a maize methyltransferase gene cannot regulate their defense adequately and become susceptible to aphid attack. Photo: Beibei Li, University of Bern, Switzerland

Original publication: Li, B., Förster, C., Robert, C. A. M., Züst, T., Hu, L., Machado, R. A. R., Berset, J.-D., Handrick, V., Knauer, T., Hensel, G., Chen, W., Kumlehn, J., Yang, P., Keller, B., Gershenzon, J., Jander, G., Köllner, T. G., Erb, M. (2018). Convergent evolution of a metabolic switch between aphid and caterpillar resistance in cereals. **Science Advances** 4:eaat6797





No super-*Drosophila*



A comparison of vinegar flies: Above: *Drosophila melanogaster* female and *Drosophila suzukii* female. The significantly larger eyes of *D. suzukii* are striking. This pest insect also relies on visible cues to find its food.

Below: Morphology of 60 further *Drosophila* species. Images: Ian Keeseey, aus: Keeseey et al. 2019.

Above right: Two of authors of the study, Markus Knaden (left) and Ian Keeseey (right), in the fly lab performing behavioral assays with vinegar flies.

Photo: Anna Schroll

Original publication: Keeseey et al. (2019) Inverse resource allocation between vision and olfaction across the genus *Drosophila*. **Nature Communications** 10:1162

In vinegar flies of the genus *Drosophila*, the size of the sensory organs reflects the preferences related to selecting a host plant or a mate. Large-nosed flies are more likely to be attracted by smell, while large-eyed flies follow visual cues.

Scientists in the Department of Evolutionary Neuroethology observed these different behaviors in earlier studies on the black-bellied vinegar fly *Drosophila melanogaster* and the cherry vinegar fly *Drosophila suzukii*, a relatively new pest in Central Europe: when foraging, *D. melanogaster* flies were more likely to be attracted by the smell of food alone; in *D. suzukii*, vision also played an important role. These behavioral preferences were also reflected in the different sizes of the respective sensory organs. Based on this observation, the scientists hypothesized that the variation in vision and olfaction is the result of a so-called trade-off. The biological definition of the term describes how, in adapting to the environment, a beneficial change in one trait is linked to a detrimental change in another. In the case of the genus *Drosophila*, such a trade-off seems to take place in the expression of visual and olfactory organs.

In order to test their trade-off hypothesis, the researchers examined the forms and functions of eyes and antennae as well as the associated visual and olfactory brain structures of a total of 62 *Drosophila* species. And indeed, large-eyed species had small noses or antennae, while species with larger antennae had proportionally smaller eyes. The scientists observed species that had invested primarily in vision, species where vision and olfaction were about equal,



and species that rely primarily on their olfactory sense, but none of the species studied had both large eyes and large antennae. The reason why animals have either a well-developed olfactory system or well-developed vision might be that in embryonic development both sensory organs emerge from the same structure and the number of nuclei is limited. The competition for resources, which determines which of the two sensory organs is more pronounced, thus takes place at a very early stage of development.

With their study, the scientists want to open new avenues in the so-called Eco-Evo-Devo research. This research field is based on the assumption that concepts of ecology (eco), evolution (evo) and developmental biology (devo) are tightly linked, and an understanding of ecological relationships requires evolutionary and developmental knowledge and vice versa. Although genomic data are available for many species, knowledge of their ecology is often lacking. Understanding trade-offs in genetic model organisms provides a path for determining the mechanisms underlying how ecology and evolution shape the natural world. [AO/KG]





Tasty or putrid?

Vinegar flies are exposed to odor mixtures when navigating in the natural environment. These mixtures often consist of odors which are both attractive and repellent, such as a source of food contaminated with toxic bacteria. The decision to approach or avoid is extremely important for the survival and reproduction of the insect. But so far, little is known about how different odors with opposing values in a mixture are processed simultaneously in the brain.

In a new study, scientists from the Research Group Olfactory Coding and the Department of Evolutionary Neuroethology aimed to investigate how odor mixtures of opposite valence, that is, a mix of odors that are attractive and repellent, are processed and perceived. The researchers succeeded in elucidating the neural mechanism that enables the vinegar fly *Drosophila melanogaster* to evaluate such conflicting situations in order to make the best decision.

In an experiment, vinegar flies were exposed to artificial odor mixtures, each containing an attractive and repellent odor, in defined ratios. By analyzing the brain activity of the flies exposed to these opposing odor mixtures using functional imaging techniques, the scientists were able to show that a repellent component in an odor mixture specifically inhibits the odor channels for attractants. The scientists also identified the underlying neuronal mechanism and the specific neurons involved. They were able to show that glomeruli – spherical functional

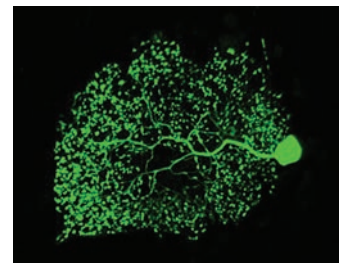


units in the olfactory center – that respond to attractive odors are linked via certain inhibitory neurons to the repellent-specific glomeruli. However, not all odor mixtures show the same inhibitory effect. An exception is geosmin, the typical smell of toxic bacteria or mold. Geosmin is recognized in the fly brain by only one receptor type, and thus only a highly specific glomerulus is activated. Similarly specialized pathways have been described only for the detection of sex pheromones, carbon dioxide and iridomyrmecin, the latter of which is the specific smell of a parasitic wasp that infests vinegar flies.

The scientists assume that such a specific, inhibitory cross-talk in the olfactory center of the fly's brain also occurs in other olfactory systems, such as the olfactory bulb of mammals, and therefore perhaps also in humans. Such a mechanism could help protect not only flies but also humans to recognize and avoid, for example, contaminated food that emits pleasant as well as bad odors.

[KG/AQ]

Silke Sachse, head of the Olfactory Coding group, discussing with her PhD student Ahmed Mohamed, first author of the study. Photo: Anna Schroll



Fluorescence staining of a local interneuron which mediates inhibition between glomeruli that respond to repellent or attractive odors. Image: Benjamin Fabian, MPI-CE

Original publication: Mohamed et al. (2019). Odor mixtures of opposing valence unveil inter-glomerular cross-talk in the *Drosophila* antennal lobe.

Nature Communications 10:1201





Huw Groucutt on an archaeological survey in Dho'far, in the South of the Arabian peninsula. His main research area for the past decade has been the prehistory of Arabia. This is a fascinating part of the world that was most of the time hyper-arid, and probably uninhabitable for early humans. But periodically the area saw much precipitation as monsoonal rains moved into the area. Each time this happened, humans also moved into the area.

Huw Groucutt is trying to understand how human populations responded to decreasing rainfall.

Photo: Eleanor Scerri, MPI-SHH

Selected Publications:

Groucutt et al. (2018). *Homo sapiens* in Arabia by 85,000 years ago. **Nature Ecology & Evolution** 2, 800-809.

Groucutt et al. (2015). Rethinking the dispersal of *Homo sapiens* out of Africa. **Evolutionary Anthropology** 24, 149-164.

Extreme events and their consequences

In February 2019, archaeologist Huw S. Groucutt joined our institute as a new Max Planck Research Group leader. Groucutt, who grew up in South Wales (UK), is establishing a research group to study extreme events in biological, societal and earth systems. The interdisciplinary approach of his research is reflected by the fact that the Extreme Events group is one of the first interdisciplinary research groups in the Max Planck Society: It collaborates with all three Jena Max Planck Institutes – Chemical Ecology, Biogeochemistry, and the Science of Human History – and is part of all three scientific sections in the society: the Biology and Medicine, the Chemistry, Physics and Technology Section, and the Humanities. We had the opportunity to ask Huw Groucutt a few questions:

Why and when did you decide to become an archaeologist?

I grew up in the Black Mountains in South Wales (UK). The area is full of historic and prehistoric remains. I was fascinated by the stories of things like the Abergavenny Massacre in 1175 and the struggle of local tribes against the invading Romans. I was also interested in the natural landscape and used to spend a lot of time walking, rock climbing and caving. Archaeology seemed to fuse my interest in the past with something more scientific than history. So I went to study archaeology at the University of Sheffield in 2004. I quickly became interested in human evolution and completed a master's degree in paleoanthropology at Sheffield, my PhD in archaeological science at the University of Oxford, a postdoc position on an ERC project and then a British Academy postdoctoral fellowship at the University of Oxford.

What are you currently studying?

My new research project, based at the MPI-CE is a very exciting advance for me. The newly established Extreme Events Research Group is an independent Max Planck research group which I am leading. It will explore the notion of extreme events across multiple aspects and from different angles. In my past research I have explored things like how human societies responded to sudden changes in climate. With this new project I will be exploring all kinds of different areas and systems, from dinosaurs to modern politics. It's a challenging and exciting new direction, and I look forward to the coming years of research.

What do you find most fascinating in your research field?

I find my research field fascinating for several reasons. Firstly, I love all the mysteries. When I excavate stone tools hundreds of thousands of years old, I always think 'who made these?'. And that question applies both in terms of individuals, but also social structures. And often we don't even know which species of human made particular archaeological assemblages, so the whole thing like is like a big detective story: working out what happened, when it happened, the context in which it happened. But I think beyond those kinds of aspects it is fascinating how archaeology, and paleoanthropology more broadly, cuts to the heart of the 'human condition'. People are often very quick to jump to claims about 'human nature', but they tend to not know very much about human evolution. Over the millions of years of human evolution there have been various types of humans – from *Paranthropus* which had huge teeth and muscle attachment due to its specialization on low quality food, to *Homo floresiensis*,





the diminutive 'hobbits' which lived on Flores. There have been multiple types of human, and I think that is really important when we think about things like human nature. Finally, I find it fascinating to think about the environmental and ecological context of human evolution. In the humanities, researchers often strongly emphasize 'human uniqueness', as if humans are somehow immune to their contexts. I think that environmental and ecological changes played a prominent role in human evolution. Reconstructing the ecologies and environments in which humans evolved is also highly relevant for modern societies. Understanding past changes can provide important lessons for the future in an era of rapid climate change.

Which are your most exciting discoveries?

There are two really which I think are equally exciting. They are scientifically important but they are also iconic. The first is the tusk and other bones of an extinct kind of elephant (*Palaeoloxodon recki*) dating to about 500,000 years ago, in the middle of what is today a desert in Saudi Arabia. Finds like this have revealed a huge amount about the context in which early humans migrated into Arabia – both in terms of the local ecology and environment, but also biogeographically in terms of the evolutionary histories of various species. My second favorite discovery is the intermediate phalanx (middle finger bone) we discovered at another site in Arabia called Al Wusta. This bone dates to about 90,000 years ago, and through a detailed analysis of 3D shape we were able to show that this fellow belonged to our species *Homo sapiens*. This was very exciting because the textbooks say that our species did not leave Africa (aside from a short holiday to Levantine forests on the doorstep of Africa) until less than 50,000 years ago. Yet here they were, tens of thousands of years earlier in the middle of what is today a desert. The Al Wusta site shows a short wet phase, when rainfall increased,



and as well as the human fossil we found things like hippo fossils and microscopic organisms called diatoms showing that it was a freshwater lake. But between these small lakes was a semi-arid and highly seasonal grassland environment. It is through combining these different kinds of findings that we can make sense of the human story. And that one small fingerbone is currently still the only human fossil from Arabia (more than 3,000,000 km²) dating to more than a few thousand years ago.

What are you looking forward to, now that you head this new research group in Jena?

I look forward to working with colleagues from various disciplines to explore the definition, detection, impacts and prediction of extreme events. I hope to find out more about totally new areas of science about which I know very little. I am also excited about learning more about Germany.

Huw Groucutt points to a layer containing animal fossils and human-made stone tools in an ancient lakebed in the Nefud Desert in the northern Arabian peninsula, dating to more than 150,000 years ago. With his interdisciplinary Max Planck Research Group Extreme Events he wants to compare the dynamics of extreme events in totally different settings and systems in order to answer the question whether the notion of 'extreme events' can be generalized, or whether each system follows its own logic. His research goal is to find out whether extreme events can be defined in such a way that the definition applies to dinosaur extinctions as much as to modern political upheavals. Photo: Eleanor Scerri, MPI-SHH





As soon as a tobacco plant starts producing defensive substances, a very hungry tobacco hornworm has to look for a new feeding place.

Photo: Pia Backmann

Ingenious techniques in neighborhood disputes

Plants cannot run away from animals which eat them, but many species have their own ways of defending themselves; they produce chemicals which allow plants to push back at hungry caterpillars. In this way, wild tobacco plants (*Nicotiana attenuata*) strike back at the larvae of the tobacco hawk moth (*Manduca sexta*). A new study by researchers from the iDiv research center, the University of Jena, the Helmholtz Centre for Environmental Research, and the Max Planck Institute for Chemical Ecology, shows that a plant may benefit

from putting up with these herbivores for a few days before starting its defense. In this way, the caterpillars move to a neighboring plant when and only when they are mature enough to be really good eaters, thus giving the first plant an advantage in intraspecific competition. [T. Turrini, iDiv]

Original publication: Backmann et al. (2019): Delayed Chemical Defense: Timely Expulsion of Herbivores Can Reduce Competition with Neighboring Plants. **The American Naturalist** 193:1, 125-139.



Close-up of the giant duckweed *Spirodela polyrrhiza*. Its low mutation rates contribute to low genetic diversity.

Photo: Klaus J. Appenroth

Duckweed: low mutation rate and genetic diversity

Plant researchers from the Department of Biochemistry and the University of Münster were able to measure the mutation rate of duckweed, i.e., how many mutations accumulate per generation experimentally under outdoor conditions. The result: Low genetic diversity in this plant was accompanied by an extremely low mutation rate. The researchers suspect that the enormous population size of the giant duckweed, and therefore the large possibilities of selection over the course

of evolution, has minimized the number of mutations. This low number in turn corresponds to low genetic diversity. The study provides new insights into why and how genetic diversity differs among different species. [S. Ronge, WWU Münster]

Original publication: Xu et al. (2019). Low genetic variation is associated with low mutation rate in the giant duckweed. **Nature Communications** 10:1243

Sarah O'Connor receives the Perkin Prize for Organic Chemistry

As the Royal Society of Chemistry announced, Sarah O'Connor, the new director of the Department of Natural Product Biosynthesis, will be awarded the renowned Perkin Prize for Organic Chemistry. The Society thereby honors her achievement in elucidating the biosynthetic pathways of complex organic compounds in plants. Many secondary plant compounds are interesting and promising medical agents.

For instance, O'Connor also studies the biosynthesis of vincristine, an anti-cancer drug, which is produced by the Madagascar periwinkle *Catharanthus roseus*. She is proud to be the first woman to receive this prestigious chemistry award. The Perkin Prize, for sustained originality and achievement in research in any area of organic chemistry, is endowed with 5,000 pounds.

<https://www.rsc.org/>



Sarah O'Connor. © Sebastian Reuter

