Public Understanding of Life Sciences / Chemical Ecology

PULS/CE 35

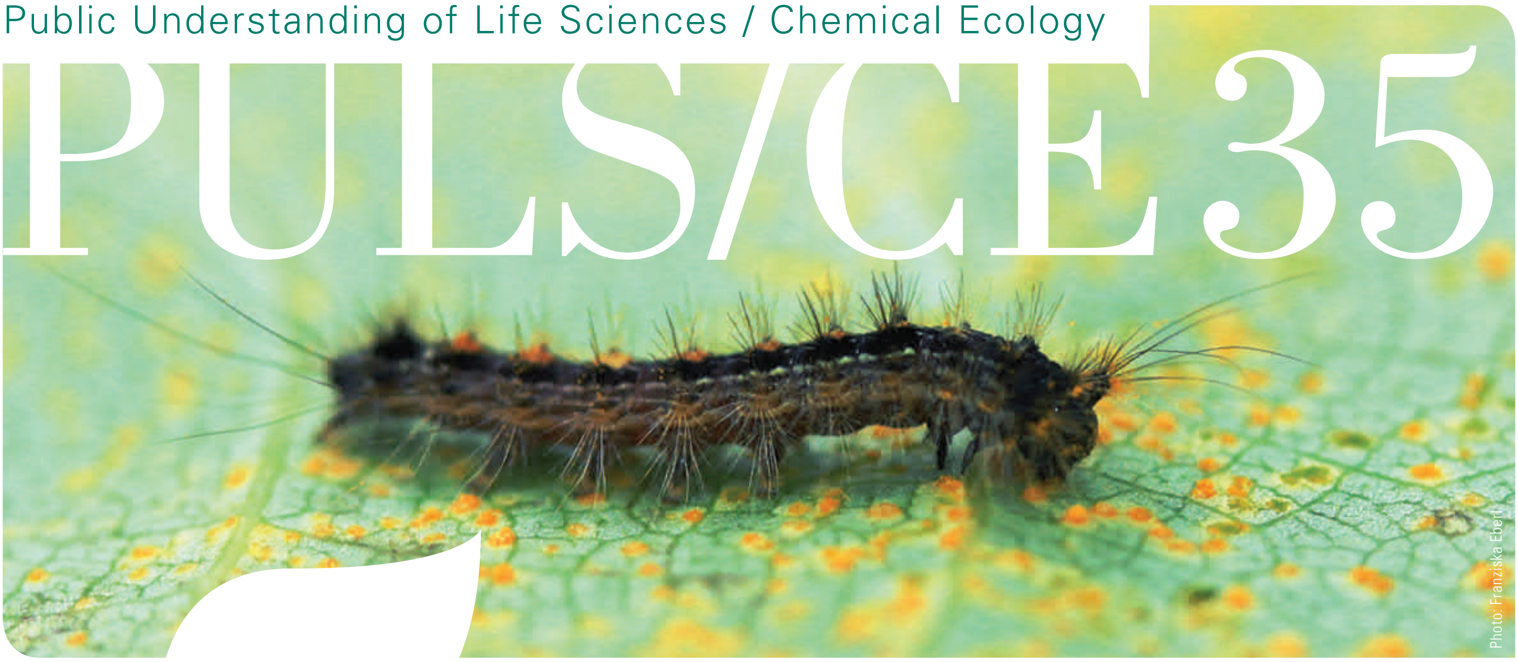


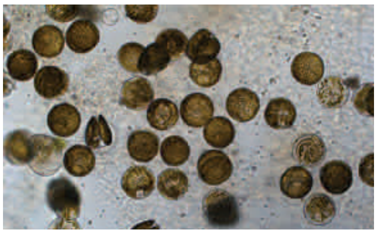
Photo: Franziska Eberl

Max Planck Institute
for Chemical Ecology

Newsletter May 2020

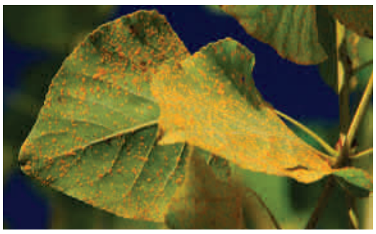
Predators have their own detoxification strategy

Plant chemical defenses affect not only herbivore growth and development but also, indirectly, consumers farther up in the food chain. A new study shows that both herbivores and their predators have developed effective mechanisms to deal with plant toxins ... **p. 3**



A manipulative marine parasite

A parasitic fungus can manipulate the metabolism of unicellular algae for its own benefit in such a way that small bioactive substances are produced, which the fungus in turn uses to propagate itself. Simultaneously, algal reproduction is inhibited, and the algal mat eventually shrinks and dies ... **p. 4**



Spores please!

Poplar leaves infected by fungi are especially tasty for caterpillars of the gypsy moth. In particular, the young larvae of this pest enhance their diet with the fungal food: they develop faster and pupate a few days earlier than caterpillars that feed on leaf tissue alone ... **p. 5**

MAX PLANCK
GESELLSCHAFT

Our institute in crisis mode

A person waiting at the Beutenberg Campus bus stop. Jena was the first city in Germany where people had to cover their noses and mouths with a face mask or shawl when entering public transport and shops or at work. The poster next to the bus shelter is pleading to show solidarity because "It's tough for all of us." Posters all over the town asked to follow the new rules, e.g. to contact the city's hotline in case of symptoms, to refrain from hoarding or to stay at home, as many of our co-workers did to work in home office. *Photo: Angela Overmeyer*

David Heckel wearing a face cover.

As I write this, Germany is slowly emerging from the restrictions imposed because of the coronavirus emergency. The last three months seem like several years, as every day has brought new developments. But the good news is that so far, our Institute has coped with the situation very well, thanks to incredible teamwork and unselfish co-operation by everybody involved.

Our first shock came when we learned that the long-scheduled meeting of the Scientific Advisory Board on 11-13 March had been cancelled. We immediately started planning for a possible shutdown of the Institute, by making priority lists of plants and insect cultures that needed to be maintained. We formalized our preparations with a Pandemic Response Plan for our Institute. We called together a Crisis Team, with representatives from all the service groups and departments. In the first meeting on 16 March, the team formulated a specific plan to deal with reduction of activities in the institute, and our response in case a co-worker would become infected with the coronavirus.

By this time, working from the home office was not only mandated by the general administration, but necessary for parents because all the schools had been closed. Service groups and most departments were divided into separate teams with non-overlapping schedules, so that possible infection of one member would not completely halt essential activities of the other team. The greenhouse was temporarily closed to non-greenhouse personnel. The IT department set up a system for accessing office desktop computers from home. The Administration was able to perform most purchasing and payroll operations from the home office. Research coordinator Karin Groten and public relations officer Angela Overmeyer constantly communicated the latest regulations of the city of Jena and the federal state of Thuringia to Institute personnel. In the meantime, Ian and Gundega Baldwin had travelled to the Utah field site to make preparations, but travel restrictions were then imposed, preventing the rest of the department from joining them. One co-worker in Jena was eventually found to have been infected by the coronavirus, 10 days after last visiting the Institute, but the person recovered and no other co-workers were infected. We are fortunate to be located in the city of Jena, which promptly adopted appropriate restrictive measurements, being the first city in Germany to mandate the wearing of masks on public transportation and in shops.

As the Institute gradually increases more research activity, I am gratified by the spirit of teamwork and cooperation that has enabled us to endure this crisis.

David G. Heckel

David Heckel, Managing Director

Predators have their own detoxification strategy

Herbivorous insects must overcome plants' chemical defenses. Glucosinolates, which are produced by all cruciferous plants, such as cabbage, broccoli and horseradish, are an example of such defensive compounds. These compounds are easily converted into toxic isothiocyanates. Therefore, some insect herbivores have evolved mechanisms to prevent the formation of isothiocyanates; these include the diamondback moth, a pest that feeds on cabbage and related species.

A research team from the Department of Biochemistry has now been able to show that the enzymatic conversion of glucosinolates is an important detoxification mechanism needed to ensure the moth's growth, survival and reproduction. Caterpillars of the diamondback moth that feed on cruciferous plants produce more of this detoxification enzyme than those that do not. In contrast, caterpillars that are no longer able to produce the enzyme are impaired in their development when they feed on plants that produce glucosinolates: their growth is inhibited and fewer survive.

Chemical analyses showed that large quantities of the toxic isothiocyanates had formed in these caterpillars. However, the formation of the enzyme may exact a cost, as larvae of the diamondback moth develop best on plants that produce no glucosinolates at all.

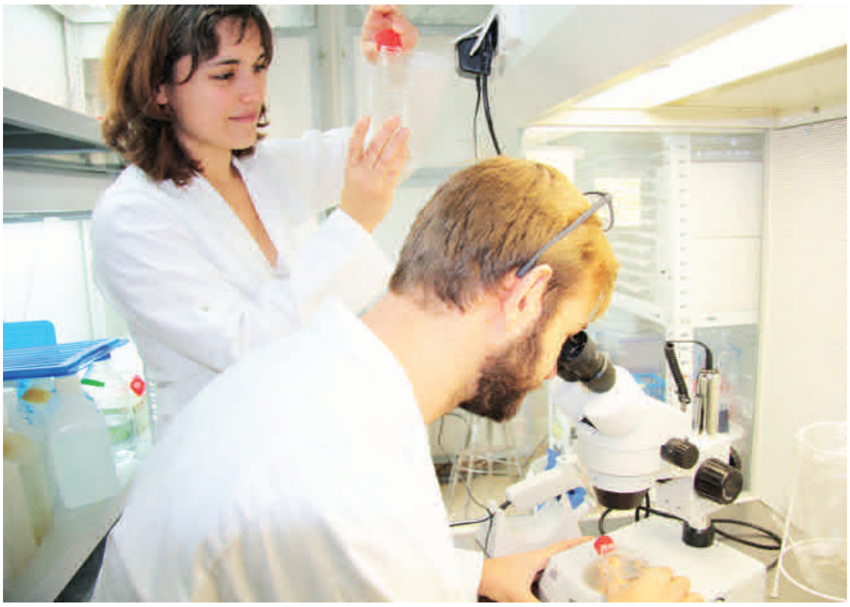
The caterpillar of the diamondback moth is part of the food chain, often falling prey to predatory insects, such as lacewing larvae. Lacewing larvae, which are voracious predators, are used as beneficial insects in biological pest control. Researchers therefore wanted to find out how the plant's defensive substances affect the predators that feed on such caterpillars. Surprisingly, lacewing larvae were completely unaffected by whether or not their prey contained toxic glucosinolates. Although lacewings do not grow as large or as quickly when they have only the toxic caterpillars as their food source, their fitness remains unaffected and their choice of prey unchanged. Further investigation revealed that lacewings are also able to detoxify the plant's defensive compounds. However, their detoxification mechanism differs from the diamondback moths'. The study shows that diamondback moths develop successfully on cabbage plants only if they are able to detoxify glucosinolates. Since predatory green lacewings are able to detoxify these substances themselves, future efforts to control the diamondback moth could take an integrated approach: selectively disrupt the moth's detoxification mechanism and, at the same time, use beneficial organisms, such as green lacewing larvae, which are clearly not affected by whether or not diamondback moths detoxify glucosinolates. [AO/KG]

In a stranglehold: A larva of the common green lacewing (*Chrysoperla carnea*, on the right) attacks a caterpillar of a diamondback moth (*Plutella xylostella*), a worldwide cabbage pest. Lacewings, which are also used as natural antagonists of the diamondback moth, are able to successfully detoxify the plant chemical defenses that they consume with their prey. *Photo: Anna Schroll*

Left below: Ruo Sun and Daniel Giddings Vassão search an *Arabidopsis* plant for insect pests, the caterpillars of the diamondback moth. The model plant also belongs to the cabbage family. *Photo: Anna Schroll*

Original publication:
Sun, R., Jiang, X., Reichelt, M., Gershenzon, J., Pandit, S. S., Giddings Vassão, D. (2019). Tritrophic metabolism of plant chemical defenses and its effects on herbivore and predator performance. **eLife**. doi:10.7554/eLife.51029

A manipulative marine parasite



Marine Vallet and Tim Baumeister study chemical interactions in plankton communities. The mostly single-cell organisms are cultivated in special containers. Combining high-resolution spectrometric methods to separate and determine small molecules from complex mixtures with microscopy, the researchers successfully identified the substances produced by a single algal cell. *Photo: Angela Overmeyer, MPI-CE*

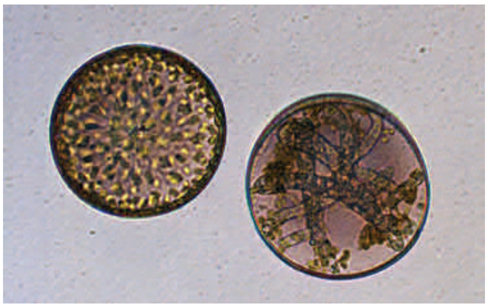
Original publication:

Vallet, M., Baumeister, T. U. H., Kaftan, F., Grabe, V., Buaya, A., Thines, M., Svatoš, A., Pohnert, G. (2019). The oomycete *Lagenisma coscinodisci* hijacks host alkaloid synthesis during infection of a marine diatom. **Nature Communications**. 10: 4938

Mass blooms of algae in oceans occur frequently. Algal mats attract many other organisms, some of which can sometimes induce the end of an entire algae population. The underlying mechanisms, however, were unknown.

Researchers led by Max Planck Fellow Georg Pohnert have now shown that a pathogenic fungus alters the metabolism of unicellular algae for its own benefit. Small bioactive substances are formed in the algae which the parasitic fungus uses for its own propagation, while the reproduction of the algae is prevented and the algal mat eventually shrinks and dies.

Egg fungi, which are known to cause many dangerous diseases, can attack marine algae. However, the relationship between the fungal microorganisms and the algae is still poorly understood. So far, little is known about why some species reproduce strongly at first and later disappear. One hypothesis is that marine microorganisms produce chemical signaling substances that are involved in defensive, mating and communicative interactions between living organisms. To identify such substances, researchers established a laboratory system in which the egg fungus Lagenisma coscinodisci infects a marine diatom under controlled conditions. They discovered that two new substances, so-called carbolines which belong to the alkaloids, are formed during the infection process. In particular, one accumulates strongly in diatoms that have been infected by the fungus. Interestingly, the carbolines only benefit the egg fungus, but damage the diatoms: They inhibit their growth, allowing the infection to spread faster in the population. As it is known that not all diatom species are equally susceptible, the scientists will investigate if and how algae defend themselves against attack by these pathogens. This is just one of many questions about how diatoms interact with their environment and which signaling substances they emit that need to be answered. [KG/AO]



Healthy (left) and infected (right) diatoms of the species *Coscinodiscus granii*: In the cell on the right, the parasitic oomycete *Lagenisma coscinodisci* has withdrawn all nutrients and modulated the algal metabolome to generate its own reproductive form, the sporangium. *Image: Marine Vallet, MPI-CE*

Spores please!

Caterpillars of the gypsy moth are known to be generalists. This means that instead of preferring certain host plants, they feed on a variety of deciduous trees and shrubs. In recent years, mass invasions of this pest have occurred repeatedly in German forests. Observing that larvae are attracted by the odor of poplar leaves infected by fungi, scientists in the Department of Biochemistry asked themselves if the caterpillars would prefer to feed on infected poplar leaves. Would they have an advantage by doing so? And if so, which chemical substances were responsible for the insects' behavior?

A gypsy moth caterpillar (*Lymantria dispar*) consumes the spores of *Melampsora larici-populina*, a rust fungus that has infested a poplar leaf. The new study shows that the insect is not only herbivorous but also fungivorous, that is, it likes to feed on nutrient-rich fungi. *Photo: Franziska Eberl, MPI-CE*

Feeding experiments, in which gypsy moth larvae were offered a choice of leaves both with and without fungal disease, showed that caterpillars clearly preferred infected leaves. In the early larval stage, they even first ingested the fungal spores on the leaf surface before consuming leaf tissue. Caterpillars that had consumed fungi developed faster and pupated earlier. Therefore, they had an advantage over their siblings who had fed only on healthy leaves. This boost is probably due to important nutrients, such as amino acids, nitrogen and B vitamins, which were concentrated in infected leaves.

The observation that an insect classified as an herbivore is actually a fungivore – at least in its early larval stage – came as a real surprise to the research team. The results suggest that microorganisms living on plants might have a much more important role in the co-evolution of plants and insects than previously thought. Further investigations will clarify how widespread fungivory is in other herbivorous insect species and what influence the combination of plant and fungal food has on the immune system of insects. It is possible that this food niche also influences the insects' own defense against their enemies, such as parasitoid wasps. The role of microorganisms in the interactions between plants and insects has long been underestimated, even overlooked. This study is an important step toward redressing that neglect. [AO/KG]

Below: Franziska Eberl. The first author of the study is this year's recipient of the Beutenberg Campus Science Award for the best dissertation. *Photo: privat*

Original publication:
Eberl, F., Fernandez de Bobadilla, M., Hammerbacher, A., Reichelt, M., Gershenzon, J., Unsicker, S., (2020). Herbivory meets fungivory: Insect herbivores feed on plant pathogenic fungi for their own benefit. **Ecology Letters**. DOI: 10.1111/ele.13506

How some plants became carnivores

Above: Alberto Dávila Lara studies the pitcher plant *Nepenthes x ventrata*. He is particularly interested in the physiology of this carnivorous plant. In Southeast Asia, where the plant is native, it has long been used in folk medicine. Interesting as a natural source of pharmaceuticals, *N. ventrata* is also an excellent model for understanding why evolution has produced similar traits in different organisms independently of each other. *Photo: Sandra Werner*

Below right: The capture mechanism of a pitcher plant works like a trapping pit. Whether nectar droplets at the edge of the pitcher help to attract weaver ants is a subject of investigation. *Photo: Alberto Dávila Lara, MPI-CE*

Insectivorous plants have evolved independently several times in the plant kingdom. They even belong to four different plant orders. Therefore, they are ideal models to study convergent evolutionary processes: the evolution of similar traits independently of each other. All carnivorous plants grow in nutrient-poor soils and they digest insects in order to compensate for this nutrient deficiency. They digest their prey under extracellular conditions, sometimes called an 'outer stomach'.

Insectivorous plants have developed different strategies to attract, capture, kill, and digest their prey, and to take up the nutrients generated by these means. Every single step has physiological, molecular, ecological and evolutionary implications that have not been deeply and thoroughly studied yet.

In order to bridge this gap, I am using the plant species *Nepenthes x ventrata*, belonging to the Caryophyllales. This species is a natural hybrid from the Philippines, representing the product of a natural cross between *Nepenthes alata* and *Nepenthes ventricosa*. I am covering three major topics in my research: 1. Understanding the adaptation of the plant's carnivory syndrome which derived from plant defense mechanisms from a physiological point of view. Carnivory is thought to have evolved from plant defense responses to herbivore attack, because plants probably use the same signaling cascade and the same genetic expression pathways. 2. Understanding prey attraction mechanisms from an ecological perspective. For this purpose, I evaluate direct interactions between animal plants. Using a multidisciplinary approach, I analyze aspects that might be involved in the attraction of the prey, for example in behavioral assays using a model prey organism, the weaver ant *Polyrhachis dives*. 3. Finally, I would like to find out how the carnivory syndrome influences the evolution of extrafloral nectar and its chemical composition. In non-carnivorous plants, this nectar, which is produced in glands outside of flowers, mediates mutualistic relationships between plants and ants: Plants offer a sugary solution to ants, and in exchange ants act as "body guards" to protect plants against herbivores. In carnivorous plants such as *Nepenthes*, extrafloral nectar may be involved in prey capture. The characterization of the chemical composition of the nectar is also addressed in order to elucidate if it functions as bait or if it is produced as an indirect plant defense.

Alberto Dávila Lara

Alberto Dávila Lara comes from Nicaragua. He is a doctoral researcher in the International Max Planck Research School, funded by the German Academic Exchange Service (DAAD). In his project in the research group Plant Defense Physiology led by Axel Mithöfer, he is studying the physiology, ecology and evolution of carnivorous pitcher plants.

IMPRS
Exploration of Ecological Interactions with Molecular and Chemical Techniques

Whether horseradish flea beetles can deter predators depends on their food plant and their life stage

Horseradish fleas use plant defense compounds, so-called glucosinolates, from their host food plants to defend themselves against predators. They store enormous amounts of these non-toxic substances in their body and, like their host plants, have an enzyme which converts the glucosinolates into toxic mustard oils.

Scientists of the Research Group Sequestration and Detoxification in Insects have found that glucosinolates are present in all life stages of the horseradish flea beetle; however, the enzyme required to convert these into toxic substances is not always active. Although flea beetle larvae can successfully fend off attack by a predator, such as a larva of the harlequin ladybird, flea beetle pupae are often predated because they do not exhibit significant enzyme activity. AO/KG]

Original publication: Sporer, T., Körnig, J., Beran, F. (2020). Ontogenetic differences in the chemical defence of flea beetles influence their predation risk. **Functional Ecology**, doi: 10.1111/1365-2435.13548

Theresa Sporer is investigating how horseradish flea beetles defend themselves against being eaten by predators by using chemical substances from their host plant. *Photo: Anna Schroll*

The larva of the horseradish flea beetle *Phyllotreta armoraciae* (left) is well-armed against its enemy, the larva of the harlequin ladybird *Harmonia axyridis* (right). *Photo: Benjamin Fabian, MPI-CE*

Sweet potato uses a single odor to warn its neighbors of insect attack

Different varieties of sweet potato grown under the same field conditions vary strikingly vis-à-vis their ability to avoid feeding damage and insect attack. Compared to the Tainong 66 variety, the Tainong 57 variety exhibited more resistance to insect pests in the field. When the plants were attacked, an odor was emitted by the wounded leaves. This odor, which is spread through the air, may be sufficient to trigger defensive mechanisms in the plants against herbivorous insects.

Scientists of the of Plant Defense Physiology Research Group have identified this odor and show that the attacked plant not only defends itself but also warns neighboring sweet potatoes that are not yet infested to "take up arms." The results are of great agricultural interest, as the cultivation of resistant varieties, such as Tainong 57, may naturally reduce the damage caused by herbivores. [KG/AO]

Original publication: Meents, A. K., Chen, S.-P., Reichelt, M., Lu, H.-H., Bartram, S., Yeh, K.-W., Mithöfer, A. (2019). Volatile DMNT systemically induces jasmonate-independent direct anti-herbivore defense in leaves of sweet potato (*Ipomoea batatas*) plants. **Scientific Reports**, 9, 17431

Group leader Axel Mithöfer and first author Anja Meents examine a sweet potato plant of the Tainong 57 variety: When attacked by insects, the leaves of this variety release an odor which puts neighboring plants on alert. *Photo: Angela Overmeyer, MPI-CE*

Catmint emits the odor nepetalactone which triggers a kind of ecstasy in sexually mature cats: They get high on sniffing catmint plants, roll on the floor and exhibit unusually playful behavior.
Photo: Phil Robinson, John Innes Centre, Norwich, UK

How a mint became catmint

Catmint, also called catnip, is known for its intoxicating effect on cats. This is due to the odor nepetalactone, a volatile iridoid produced by the plant. An international team of researchers, including Sarah O'Connor and some of her co-workers in the Department of Natural Product Biosynthesis, has now discovered through genome analysis that the ability to produce iridoids was lost in the ancestors of catmint in the course of evolution. Hence, nepetalactone biosynthesis is the result of "repeated evolution."

Nevertheless, this particular iridoid differs considerably from other compounds in this family of natural products with regards to its chemical structure, its properties and, most likely, its ecological functions. The researchers compared the genomes of two species of catmint, both of which produce nepetalactone, with the genome of the closely related medicinal plant hyssop, which produces neither nepetalactone nor any other iridoids. This comparison, the reconstruction of ancient genes, and comprehensive phylogenetic analyses enabled researchers to understand the chronology of events that led to the emergence of nepetalactone biosynthesis. [AO/KG]

Original publication: Lichman, B. R., Godden, G. T., Hamilton, J. P., Palmer, L., Kamileen, M. O., Zhao, D., Vaillancourt, B., Wood, J. C., Sun, M., Kinser, T. J., Henry, L. K., Rodriguez-Lopez, C., Dudareva, N., Soltis, D. E., Soltis, P. S., Buell, C. R., O'Connor, S. E. (2020). The evolutionary origins of the cat attractant nepetalactone in catnip. **Science Advances**, DOI: 10.1126/sciadv.aba0721

Torbjorn von Schantz, Vice-Chancellor of Lund University, Martin Stratmann, President of Max Planck Society, and Maria Knutson Wedel, Vice-Chancellor of the Swedish University of Agricultural Sciences, sign the contract for a new Max Planck Center on "next Generation Insect Chemical Ecology" (nGICE). In the background: Bill Hansson, head of the Department of Evolutionary Neuroethology and one of the nGICE co-directors.
Photo: Mårten Svensson

Researchers from Jena and Sweden study the impact of anthropogenic environmental changes on insects

Environmental changes caused by humans affect insects as well as other organisms. Therefore, the Max Planck Society, the University of Lund, and the Swedish University of Agricultural Sciences joined forces to collaborate in the new Max Planck Center "next Generation Insect Chemical Ecology" to study interactions between insects, the climate and humans. Together the scientists want to find out how climate change, greenhouse gases and air pollution influence insect chemical communication. The partnership was officially launched on January 27, 2020, in Alnarp, Sweden.

Three research groups are involved in the Max Planck Center: the Max Planck Institute for Chemical Ecology in Jena, with its Department of Evolutionary Neuroethology, the Pheromone Research Group at Lund University, and the Chemical Ecology Research Group of the Department of Plant Protection Biology at the Swedish University of Agricultural Sciences. The three partners complement each other perfectly: working with insect species as varied as herbivores (bark beetles and moths), blood eaters (mosquitoes) and the vinegar fly, the researchers involved share broad expertise. The three research organizations finance the center, each contributing EUR 500,000 per year. Seventeen young scientists hired by the Max Planck Center will work at one of the three institutions; all will benefit from the infrastructure and expertise of the other groups. [AO]

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