Public Understanding of Life Sciences / Chemical Ecology

# PULS/CE 37

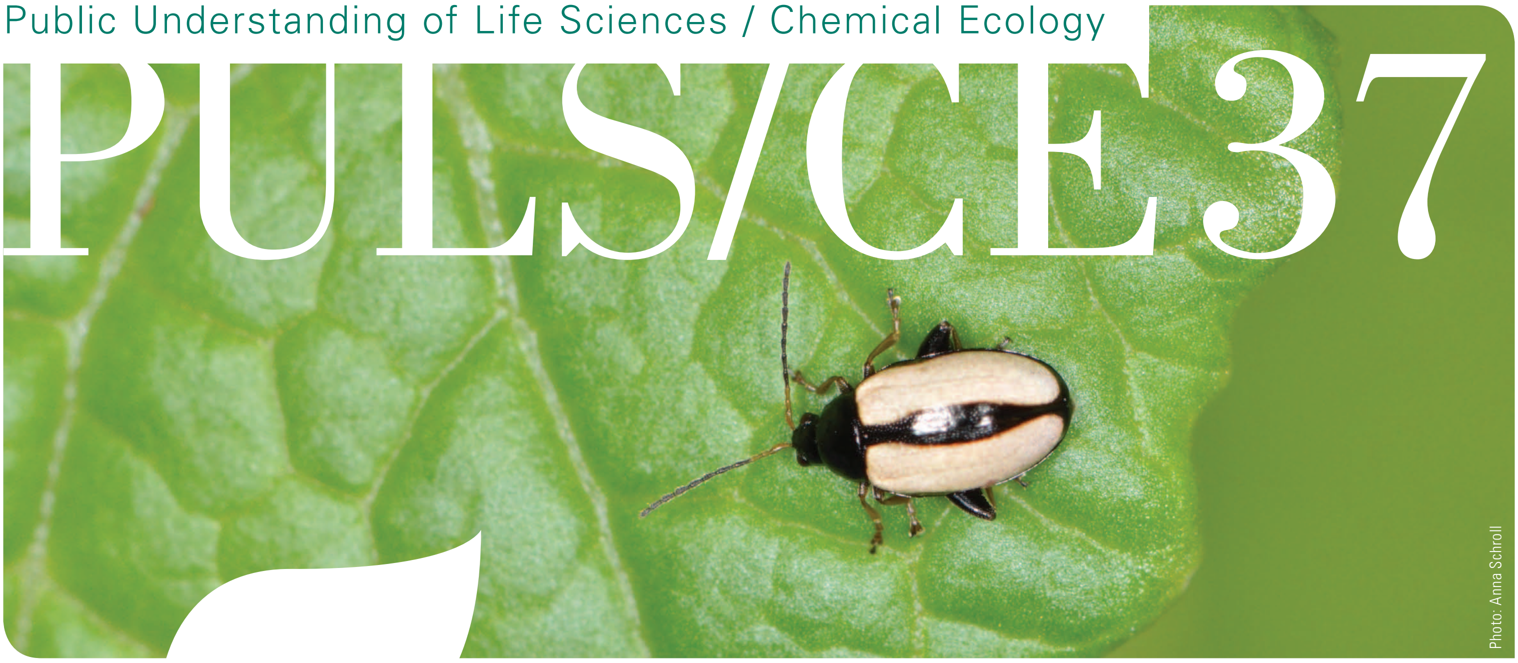


Photo: Anna Schroll

Max Planck Institute
for Chemical Ecology

Newsletter May 2021

## Chemical defense without self-poisoning

Diterpene glycosides are defense compounds plants use to fend off herbivores. The substances target specific parts of the cell membrane. To protect themselves from their own toxins and from damage to their cell membranes, tobacco plants store these chemical defenses in a non-toxic form ... **p. 3**

## Glyphosate and the Achilles heel of beetles

Glyphosate inhibits symbiotic bacteria in the saw-toothed grain beetle. As a consequence, the bacteria no longer provide important building blocks for the formation of the beetle's cuticle. The susceptibility of their microbial partners to the herbicide seems to be an insect's weak spot that has been underestimated until now ... **p. 4**

## Protected with the weapons of the food plants

Horseradish flea beetles have special transporters in their excretory system that prevent mustard oil glycosides (ingested with their food) from being excreted. This mechanism enables these beetles to store high amounts of the plant toxins in their bodies ... **p. 5**

MAX PLANCK
GESELLSCHAFT

# High commitment to integration

On May 8, 2021, Bill Hansson received the Order of Merit of the Federal Republic of Germany, the *Bundesverdienstkreuz* 1st Class, from the hands of the Thuringian Prime Minister Bodo Ramelow in Erfurt.
*Photo: Jacob Schröter/TSK*

Bill Hansson in front of the institute.
*Photo: Anna Scholl*

Science is international. Scientists speak a common language when it comes to their research. But moving to another country means you are confronted with many everyday problems for which you may be unprepared. "When I came to Germany, I didn't always know what was expected of me. That is why I saw it as one of my primary tasks, as the first foreign vice president of the Max Planck Society, to optimize the integration process for researchers from abroad," says Bill Hansson. On his initiative, a travel guide for researchers, which explained many German peculiarities, was created. At the end of Hansson's term in office, the Planck Academy began offering many personal training opportunities at various management levels, and to advance the career of young scientists.

Hansson's vice presidency was guided by the desire to internationalize research in Germany. For example, he oversaw and advised the many Max Planck partner institutions worldwide. His leadership style has also been international in nature, reflecting his Swedish origins. "When it comes to leadership, I have advocated a more Scandinavian style: lots of pauses for conversation, open communication 'per Du', less hierarchy. I call this philosophy 'leadership through kindness' and I have always found it to work well in different environments. You could also sum it up like this: Happy co-workers perform better!", says Hansson. For this reason, it was also important to him to improve the conditions for doctoral researchers, adjust their employment contracts, and equalize their vaccation entitlements.

Bill Hansson has now been awarded the Federal Order of Merit 1st Class of the Federal Republic of Germany for his service. The Prime Minister of Thuringia, Bodo Ramelow, presented the award on May 18, 2021, on behalf of President Steinmeier. In his laudatory speech, Ramelow said: "In addition to his outstanding scientific work at the Max Planck Institute in Jena as well as his achievements in the Max Planck Society, I appreciate Prof. Dr. Hansson above all for his commitment to the integration of foreign researchers in Germany, which is a matter close to his heart. By financing and initiating a unique housing project in Jena, half of whose apartments are rented to local and half to foreign scientists, Prof. Dr. Hansson is contributing last but not least to strengthening the international character of Jena as a research location. For all this, he deserves recognition and appreciation, and my very personal thanks."

We congratulate Bill Hansson wholeheartedly on this well-deserved honor.

Angela Overmeyer

PULS/CE 37

Research Highlight | Newsletter May 2021

Max Planck Institute for Chemical Ecology

# Chemical defense without self-poisoning

Many plants produce chemical defenses to protect themselves from being eaten. Still, little is known about what makes these substances toxic to the animals that consume them. Researchers from the Department of Molecular Ecology and the University of Münster wanted to find out whether the mechanisms underlying how plant toxins work are the same for herbivores and for their plant hosts, and, also, how plants manage to protect themselves against their own poisons. Their study focused on diterpene glycosides from the tobacco plant *Nicotiana attenuata*, defense substances that are found in very high concentrations in tobacco leaves. Tobacco plants that were unable to produce diterpene glycosides after two enzymes had been silenced showed conspicuous symptoms of self-poisoning: they were sick, unable to grow normally, and could no longer reproduce. Further experiments revealed that certain components of the cell membrane, so-called sphingolipids, had been attacked in these plants. Sphingolipids are found in all animals and plants, including the enemies of wild tobacco, the caterpillars of the tobacco hawkmoth *Manduca sexta*.

Accordingly, the researchers asked whether sphingolipid metabolism was the target of the diterpene glycosides. In fact, *Manduca sexta* caterpillars that had fed on plants without diterpene glycosides grew significantly better than larvae that had fed on controls, which contained the defensive chemicals. Analyses of the frass of *Manduca sexta* larvae that had ingested diterpene glycosides with their food provided further insights, as the degradation of the plant toxins during larval digestion occurs more or less in reverse order to the synthesis of the substances in the plant. Plants prevent self-harm by storing the defensive substances in a non-toxic form. However, when insects feed on plants, a part of the non-toxic molecule is cleaved off, and the chemical becomes activated or "armed." Interestingly, in both plants with incomplete diterpene glycoside biosynthesis and in feeding caterpillars, the target of the toxins is the sphingolipid metabolism.

The analysis of larval frass proved to be the key to success in this study. The scientists call this new approach "frassomics": a combination of frass (larval droppings) and metabolomics, or the analysis of all metabolites in an organism. The analysis of larval frass can provide metabolic clues about how what one organism produces is metabolized by consumer organisms.

The research goal is to gain new insights into the biosynthesis of defense substances in plants and their degradation in herbivores. Such insights will enhance our understanding of ecological interactions among plants, insects and microorganisms.

Jiancai Li collects caterpillar droppings (frass) from a tobacco plant. *Frassomics* is a new approach and a powerful tool to study plant-insect interactions. *Photo: Anna Schroll*

Left below: Tobaco hornworm *Manduca sexta*. Analysis of the larval frass shows how toxins are activated in the caterpillar and provides clues to their biosynthesis in the plant - a process like digestion reversed. *Photo: Anna Schroll*

**Original publication:**

Li, J., Halitschke, R., Li, D., Paetz, C., Su, H., Heiling, S., Xu, S., Baldwin, I. T. (2021). Controlled hydroxylations of diterpenoids allow for plant chemical defense without autotoxicity, **Science** 371 (6526), 255-260

# Glyphosate and the Achilles heel of beetles

Saw-toothed grain beetles *Oryzaephilus surinamensis* on oat flakes. Glyphosate inhibits the symbiotic bacteria of the insects that provide them with important building blocks they need for the biosynthesis of their cuticle. *Photo: Julian Kiefer, Johannes Gutenberg-Universität Mainz*

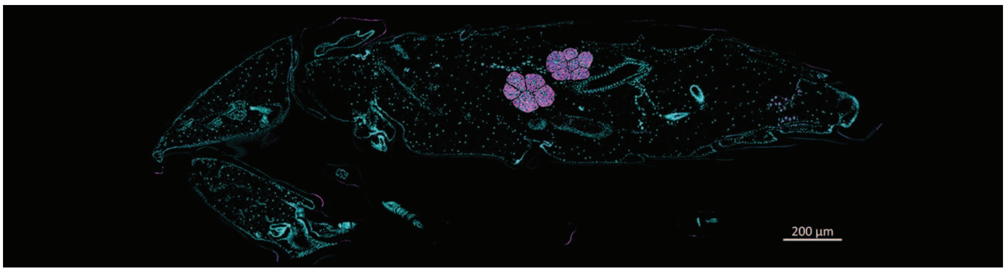
Below: The section through the pupa of a saw-toothed grain beetle shows the organs containing symbiotic bacteria. The microbial partners from the phylum Bacteroidetes are stained pink on the fluorescence *in situ* hybridization (FISH) image. *Image Tobias Engl, MPI-CE*

**Original Publication:**
Kiefer, J. S. T., Batsukh, S., Bauer, E., Hirota, B., Weiss, B. Wierz. J. C., Fukatsu, T., Kaltenpoth, M., Engl, T. (2021). Inhibition of a nutritional endosymbiont by glyphosate abolishes mutualistic benefit on cuticle synthesis in *Oryzaephilus surinamensis*. **Communications Biology**, doi: 10.1038/s42003-021-02057-6

Glyphosate is currently one of the most widely used pesticides in agriculture. It works by selectively suppressing the growth of plants by inhibiting the biosynthesis of aromatic amino acids via the so-called shikimate pathway, a metabolic pathway occurring in plants and many microorganisms. Because animals do not encode the shikimate pathway, they are thought to be unharmed by glyphosate. However, many insects engage in mutualistic interactions with symbiotic microbes and rely on the shikimate pathway of their bacterial symbionts to obtain from their partners the amino acids that are important building blocks for their protective exoskeleton (cuticle).

Researchers led by Tobias Engl from the Department of Insect Symbiosis have now shown that glyphosate negatively affects the microbial partners of the saw-toothed grain beetle *Oryzaephilus surinamensis*. Exposure to glyphosate almost completely abolished the benefits of the symbiosis between insect and bacteria for cuticle formation. First, the scientists sequenced the genome of the beetle's bacterial partner. This tiny genome contains the genetic instructions for a metabolism entirely focused on the formation of aromatic amino acids via the shikimate pathway. Interestingly, it strongly resembles the genome of the symbiotic partners of the palm weevil; although these symbionts belong to a different bacterial phylum, they are also involved in the formation of the cuticle. This observation demonstrates the importance of cuticle-supporting symbioses in beetles. As predicted, glyphosate exposure not only inhibited biosynthesis of the aromatic amino acids, but also the establishment of the symbiotic bacteria throughout the beetles' development. Any mutual benefit of the symbiosis on cuticle synthesis was completely abolished. The scientists also tested the functional benefits for the host experimentally by supplementing the beetles' diet with aromatic amino acids, as a way to compensate for the elimination of the symbionts. Using phylogenetic analyses, the authors showed that the shikimate metabolic pathways of the many symbiotic bacteria associated with different insects contain a glyphosate-sensitive enzyme. Thus, the glyphosate susceptibility of their microbial partners appears to be an Achilles heel of insects.

We are currently experiencing insect decline on a massive scale. Insect abundance is decreasing, as is insect diversity, not to mention the impact the disappearance of bees, beetles and other insects has on upper levels in the food chain. The new findings highlight the possibility that the use of the herbicide glyphosate in agriculture endangers vital symbiotic relationships between insects and microorganisms and thus may pose a serious threat to our ecosystems.



# Protected with the weapons of the food plant

Many animals use chemical defense compounds to deter predators. The ability to acquire such substances from their diet is particularly widespread in insects that feed on toxic plants, a process called sequestration. One example is the horseradish flea beetle.

Although it has long been known that this beetle can accumulate glucosinolates, how it absorbs and stores high amounts of these substances in its body was unknown. The goal of an international team led by Franziska Beran from the Research Group Sequestration and Detoxification in Insects was therefore to identify glucosinolate transporters in this insect. By narrowing down the list of 1401 candidates (all putative membrane proteins) to transporters specific for horseradish flea beetles, scientists were able to identify glucosinolate-specific transporters. These transporters are located in the excretory system of the beetles, in the so-called Malpighian tubules, which assume a role similar to that of the kidneys in vertebrates.

The scientists determined the function of these transporters using RNA interference, an approach in which the expression of a gene of interest is reduced in order to determine its function in the studied organism. Beetles in which the gene expression of several transporters localized in the Malpighian tubules had been silenced excreted more glucosinolates compared to a control group of beetles. The higher rates of glucosinolate excretion led to a decrease in the levels of defense compounds in the beetle body. The study is the first to identify transporters in the Malpighian tubules that enable an insect to accumulate plant defense compounds.

With their study, the researchers show that sequestration is a complex process and much more than just the uptake of plant metabolites into the animal's body. The sequestering insect must adapt its entire physiology to use plant defense compounds for its own defense. These adaptations are driven by challenges in its environment: predators, parasites, and pathogens. Sequestration is probably one of the most complex adaptations that herbivorous insects have evolved. It almost certainly also contributes to the evolutionary success of insects that specialize in certain host plants, such as the horseradish flea beetle.

Zhi-Ling Yang and Franziska Beran in their lab. To investigate the role of the Malpighian tubules *in situ*, the researchers needed to dissect them in an intact form. This is a very challenging task, because these tubules are only several millimeters long and also very thin and fragile. *Photo: Anna Schroll*

Below: The horseradish flea beetle *Phyllotreta armoraciae*. The pest insect is capable of sequestering large amounts of glucosinolates in its body, making itself unpalatable to predators. *Photo: Anna Schroll*

**Original Publication:**

Yang, Z.-L., Nour-Eldin, H. H., Hänniger, S., Reichelt, M., Crocoll, C., Seitz, F., Vogel, H., Beran, F. (2021). Sugar transporters enable a leaf beetle to accumulate plant defense compounds. **Nature Communications**, doi: 10.1038/s41467-021-22982-8

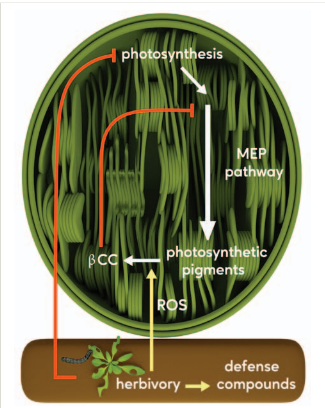
Research results suggest that decreasing hemispheric temperatures and associated ecological changes were the primary drivers of the Late Quaternary megafauna extinctions in North America. *Graphic: Hans Sell*

## Climate change likely drove the extinction of North America's largest animals

A new study by scientists in the Max Planck Research Group Extreme Events suggests that the extinction of North America's largest mammals did not result from overhunting by rapidly expanding human populations following their entrance into the Americas. Instead, the findings, based on a new statistical modelling approach, indicate that populations of large mammals fluctuated in response to climate change: drastic decreases of temperatures around 13,000 years ago initiated the decline and extinction of these massive creatures. Still, humans may have been involved in more complex and indirect ways than simple models of overhunting suggest.

**Original Publication:**

Stewart, M., Carleton, W. C., Groucutt, H. S. (2021). Climate change, not human population growth, correlates with Late Quaternary megafauna declines in North America. **Nature Communications** 12: 965




Feeding by herbivores not only causes plants to produce defense compounds, but also leads to a slowdown in growth processes. Cleavage of beta-carotene (a photosynthetic pigment) via reactive forms of oxygen (ROS = reactive oxygen species), forms beta-cyclocitral (βCC), which directly inhibits the rate-controlling enzyme of the MEP pathway located in the chloroplast. *Graphic: Kimberly Falk, Moves Like Nature*

## Chemical signal in plants reduces growth processes in favor of defense

An international team of researchers including scientists from the Department of Biochemistry has shown that plants of the thale cress *Arabidopsis thaliana* produce beta-cyclocitral when attacked by herbivores and this volatile signal inhibits the methylerythritol 4-phosphate (MEP) pathway. The MEP pathway is instrumental in plant growth processes, such as the formation of leaf pigments for photosynthesis. In addition to slowing growth processes, beta-cyclocitral also activates plant defenses against predators. Since the MEP pathway is found only in plants and microorganisms, not in animals, knowledge of a signaling molecule like beta-cyclocitral opens up new possibilities for the development of crop protection or antimicrobial agents that block this pathway. When plants are attacked, they may need to stop growth processes in order to release sufficient resources for their defense. Beta-cyclocitral signaling is a mechanism that controls precisely this shift in resources. Beta-cyclocitral, or a more stable derivative, could therefore be applied to crops to stimulate defenses during a pest outbreak. Further studies will investigate whether beta-cyclocitral increases insect resistance in crops, such as tomatoes, and whether it interacts with other already known defense signals.

**Original Publication**

Mitra, S., Estrada-Tejedor, R., Volke, D. C., Phillips, M. A., Gershenzon, J., Wright, L. (2021). Negative regulation of plastidial isoprenoid pathway by herbivore-induced β-cyclocitral in *Arabidopsis thaliana*. **Proceedings of the National Academy of Sciences of the United States of America** 118 (10) e2008747118

## Defensive symbiosis leads to gene loss in bacterial partners

To protect their offspring from detrimental mold fungi in the warm, moist conditions of their underground brood chambers, females of the European beewolf *Philanthus triangulum* secrete a substance from their antennae that contains symbiotic bacteria of the genus *Streptomyces*. These produce a cocktail of various antibiotic substances, which the beewolf larvae then spin into their cocoons. This defensive symbiosis, which has existed for more than 68 million years, ensures the protection of beewolf offspring against harmful microorganisms. In a new study, scientists from the Department of Insect Symbiosis and the University of Mainz, together with an international research team, were able to show that these beneficial bacteria are losing genetic material that is no longer needed. The genome of these bacteria is of great interest for understanding the process of genome erosion and for elucidating how cooperation and the mutual benefit between symbiotic bacteria and their host insects have evolved over long periods of time.

**Original Publication:**
Nechitaylo, T. Y., Sandoval-Calderón, M., Engl, T., Wielsch, N., Dunn, D. M., Goesmann, A., Strohm, E., Svatoš, A., Dale, C., Weiss, R. B., Kaltenpoth, M. (2021). Incipient genome erosion and metabolic streamlining for antibiotic production in a defensive symbiont. **Proceedings of the National Academy of Sciences of the United States of America** 118 (17) e2023047118

A European beewolf hatching from its cocoon, which is protected against pathogens with antibiotics. The antibiotic agents are produced by the insects's bacterial symbionts. Genetic analyses revealed that the metabolism of the microbial partner is mainly directed towards the production of antibiotics. *Photo: Martin Kaltenpoth, MPI-CE*

## Researchers identify the gene that controls the mating preference of male European corn borers for the female sex pheromone

During mating, the pheromone signal sent by a female must be preferred by a male of the same species in order to make sure that like mates with like. An international research team involving the Department of Entomology has now has discovered which gene expressed in the brain of the male European corn borer moth controls his preference for the sex pheromone produced by females. The relevant variants of this gene are found not in the parts of the gene that code for a protein but, rather, in those parts that presumably determine how much of the protein is produced. This, in turn, affects the neuronal circuits that run from the insects' antennae to the brain. The researchers found anatomical differences in males, including the connections of olfactory sensory neurons in different parts of the insect brain, and linked these to the males' attraction to females of different strains within the species. For the first time, the female pheromone signaling gene and the gene for the preference for that particular pheromone cocktail in males were identified in a moth. This discovery gives scientists the opportunity to measure how closely pheromone-based mate choice is linked to the evolution of species. [Tufts University]

**Original Publication:** Unbehend, M., Kozak, G. M., Koutroumpa, F., Coates, B. S., Dekker, T., Groot, A. T., Heckel, D. G., Dopman, E. B. (2021). bric à brac controls sex pheromone choice by male European corn borer moths. **Nature Communications**, 12:2818

Male (above) and female (below) of the European corn borer *Ostrinia nubilalis*. The moth has been used as a model organism for studying speciation since researchers discovered that there are E and Z strains of the pest insect that produce different pheromones. *Photo: Melanie Unbehend, MPI-CE*

Yuko Ulrich will join the institute as the new Lise Meitner group leader. She studies the social behavior of populations of the clonal raider ant *Ooceraea biroi*. She is particularly interested in how the social organization of organisms affects the dynamics of diseases. *Photo: private*

## Yuko Ulrich to lead first Lise Meitner Group at the Institute

Led by Yuko Ulrich, the first Lise Meitner Group will commence work at the institute in August. The young biologist successfully applied for the Max Planck Society's Lise Meitner Excellence Program. This program, named after an exceptional woman in science, Lise Meitner (1878-1968), specifically promotes top international female researchers by offering independence in the form of their own research group and access to excellent research equipment. In addition, recipients will have the prospect of receiving a permanent W2 position with a group at a Max Planck Institute if a positive evaluation is made within five years. The long-term goal is to increase the pool of female candidates who can become directors at a Max Planck institute. Yuko Ulrich investigates how the social organization of organisms affects disease dynamics. Her study system is the clonal raider ant *Ooceraea biroi*. These ants, which do not have a queen, consist only of workers. They reproduce asexually, virtually cloning themselves: each ant lays eggs, and their eggs are genetic clones of themselves. In her research, Yuko Ulrich takes an experimental approach, combining lab experiments with ants and computerized behavioral analyses with molecular approaches. She wants to find out how diseases spread and whether the social organization of a group can prevent or reduce the transmission of pathogens.

M. A. Khallaf. *Photo: Anna Schroll*

## Mohammed A. Khallaf to receive the Beutenberg Campus Science Award for the the best doctoral thesis in the field

Mohammed A. Khallaf from the Department of Evolutionary Neuroethology will be awarded the 2021 Beutenberg Campus prize for the best doctoral thesis in the field. Beutenberg Campus e.V. honors outstanding work by young researchers in life sciences and physics. Last year, he received his doctorate with a "summa cum laude" for his excellent doctoral thesis "Wired for love: Evolutionary neurobiology of sexual communication in *Drosophila*." The prize is endowed with 1000 euros.

Franziska Eberl. *Photo: Anna Schroll*

## Franziska Eberl to be awarded the Otto Hahn Medal

This year, the Max Planck Society is once again honoring young scientists for outstanding achievements during their doctorate. Franziska Eberl will also receive one of the coveted Otto Hahn Medals, which are endowed with 7500 euros. For her dissertation in the Department of Biochemistry, she studied the chemical ecology of a tripartite relationship: the interactions between trees, herbivorous insects, and fungal pests. Franziska Eberl is now a postdoctoral researcher investigating the influence of different light spectra and intensities on the growth and phytochemistry of various plant species. She also coordinates the profile line LIFE at Friedrich Schiller University, which encompasses research in the life sciences and medicine.



**Impressum:** PULS/CE is published semi-annually and can be downloaded free of charge on the homepage of the MPI for Chemical Ecology and is distributed electronically as PDF to subscribers. A print version will be sent on request.
Editor: MPI-CE, Jena • Managing Director: Prof. Dr. Jonathan Gershenzon (viSdP). Editorial Staff: Dr. Karin Groten, Research Coordination • Angela Overmeyer, M.A., Information and Communication • Emily Wheeler, Editing
ISSN: 2191-7507 (Print), 2191-7639 (Online)