ICE 2025 PhD Course

International Chemical Ecology Course

Max Planck Institute for Chemical Ecology, Jena, Germany

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Chemical Ecology

- a multidisciplinary approach -

Abstracts

Insect chemical communication in the Anthropocene

Markus Knaden (MPI for Chemical Ecology, Germany)

Insects rely on olfactory cues to locate food sources and mating partners. Due to the Anthropocene, we are facing increased levels of oxidizing pollutants such as ozone and nitrogen oxides, which can degrade many of the chemical cues that insects rely on. This can lead, for example, to impaired communication between flowers and their pollinators, and inhibition of sexual communication in insects. In this talk I will present examples of how dramatic the resulting effects can be.

Application of chemical ecology principles for managing vector borne diseases

Merid Getahun (International Centre of Insect Physiology and Ecology, Kenya)

It is estimated that over a billion individuals worldwide earn their livelihoods in the livestock business across several value chains. Nevertheless, the resilience of livestock to climate shocks and productivity is strongly impacted by vector-borne diseases. Moreover, livestock serve as a reservoir for numerous zoonotic diseases that may transmit to humans, posing a pandemic risk. This presentation will examine the interaction between livestock and vectors, as well as the influence of host and vector infection with pathogens on modulating this interaction. We investigate the mechanism of vectors-livestock interaction to develop nature inspired tools (attractants, repellents, and antifeedant) that disrupt livestock vector interaction to block vector borne diseases including zoonotic transmission. Additionally, we investigate the metabolites changes due to infections to develop simple diseases diagnostic methods.

Evolutionary neuroethology in hawkmoths

Sonja Bisch-Knaden (MPI for Chemical Ecology, Germany)

The sense of smell is critical for nocturnal moths to locate feeding and oviposition sites, but these resources are often scarce and their odor bouquets may be similar to those of surrounding 'background' plants. In my talk I will show how the headspace of ecologically important and unimportant plants in the natural habitat of the hawkmoth *Manduca sexta* is detected by its antenna and encoded in the first processing center of the insect brain, the antennal lobe. Furthermore, I will present data on the evolution of a clade of odorant receptors that mediate the detection of agave flowers, one of the most valuable nectar sources of *M. sexta*.

An olfactory social language in the naked mole-rat?

<u>Mohammed A Khallaf</u> (Max Delbrück Center for Molecular Medicine, Germany)

To be announced

When it's too dark to see: chemical ecology of termites

<u>Robert Hanus</u> (Academy of Sciences of the Czech Republic)

To be announced

Navigation by visual and chemical cues

<u>Markus Knaden</u> (MPI for Chemical Ecology, Germany)

The desert ant *Cataglyphis fortis*, which inhabits the open salt pans of Tunisia, has become a model of insect navigation. The ants forage individually for dead arthropods and cover distances of more than 1.5 km in their hostile habitat before returning to an often inconspicuous nest entrance. To do so they use a path integrator, which integrates the distances and directions of their travel and always informs them about their relative position to the nest. In addition the ants can learn visual and olfactory cues and use them as landmarks. The talk will focus on the strategies ants use to speed their return to the nest before heat stress kills them.

Early days of insect chemical ecology research: World-wide mission to replace toxic insecticides with behavior-modifying chemicals

<u>Tom Baker</u> (Distinguished Professor Emeritus, Center for Chemical Ecology, Department of Entomology, Penn State University, Pennsylvania, USA)

Rachel Carson's now-classic book, "Silent Spring", was published in 1962, serendipitously during a time when the field of insect sex pheromone research was being born. At that time, only one insect sex pheromone had been identified, that of the silk moth, *Bombyx* *mori*, in 1959. Shortly after, in 1966 a second moth pheromone was identified, this one of *Trichoplusia ni*, the cabbage looper moth. The occurrence of a new-found awareness for environmental stewardship coinciding with the exciting new knowledge that there are powerful species-specific odors that can control insect behavior spawned a world-wide effort to discover and synthesize sex pheromones of pestiferous insect species. There was an inherent promise in these efforts that pheromones might provide a solution to replacing toxic insecticides with environmentally safe, non-toxic compounds that could laser-focus on controlling one pest species at a time.

Following many years of field research to duplicating the same levels of attraction of male moths to what the natural female blend could elicit, in 1978 the first commercial sex pheromone mating disruption formulation was approved by the U.S. Environmental Protection Agency. It is amazing to understand how rapidly this happened for the pink bollworm pheromone—only 12 years after the first two moth sex pheromones had been identified! Research to exploit the behavior-modifying power of insect pheromones occurred not only with regard to mating disruption, but also concerning attract-and-kill baits, mass trapping, and the monitoring of pest densities for judicious use of localized insecticide applications.

The success of this class of behavior-modifying chemicals was a result of laboriously ensuring—through exhaustive behavioral experiments in the laboratory and the field—that the natural sex pheromone signal was replicated behaviorally in the synthetic blends so that the target insects reacted as reliably and intensely as to the natural blend. Behavioral knowledge was augmented by a deep understanding of the activities within underlying olfactory pathways—"neuroecology" in its infancy. Here I emphasize that the behavioral reactions of an insect, including the underlying powers and pathways of olfaction, must be understood so that the minimal set of compounds that comprise "the signal" can be identified and used correctly and efficiently. The importance of controlled emission (dispenser) technologies and deployment strategies cannot be overstated when understanding how the successes of behavior-modifying chemicals occurred.

Behavioral conformation of insect chemical signals over the decades of pheromone research has now resulted in synthetic pheromone usage occupying ca. 25% of the insect agricultural chemicals market. Pheromones have truly delivered on the initial 1960s promise of replacing toxic insecticides. New generations of chemical ecology researchers should be aware of the effort and commitment that occurred that resulted in such effective chemical ecology tools becoming staples in the insect pest control industry. Perhaps students can learn from this history of pheromones how to keep exploring and developing unexpected new kinds of chemical ecological solutions for safer food production and improvement of the health and well-being of humans worldwide.

Locust olfactory neurecology

Bill Hansson (MPI for Chemical Ecology, Germany)

To be announced

Insect pollination and plant evolution

Florian P Schiestl (Department of Systematic and Evolutionary Botany, University of Zurich, Switzerland)

Plants need vectors in order to exchange pollen and thus achieve sexual reproduction. Those species that employ animals often use a variety of signals to attract their pollinators. Visual signals have long been assumed to be of primary importance for pollinator attraction, and only in the last decades we have discovered the beautiful diversity of chemical signals involved in plant-pollinator interactions. In my talk I will elaborate on some of the insights we have gained recently into the chemical ecology of floral fragrance, and how selection posed by pollinators shapes the evolution of those signals and other plant traits. Whereas flowers often present a reward for their pollinators, deceptive flowers don't, but attract pollinators with out-of-context signals, for example chemical compounds that insects use for mating or search for oviposition substrate. Such mimetic flowers are often pollinated in a highly specific way and chemical variation is typically involved in attraction of different specific pollinators. In the European orchid genus *Ophrys*, an example for sexual floral mimicry, alkenes and long chain esters are often important for mediating such specificity of pollinator attraction. In rewarding flowers, certain compounds can act as honest signals, i.e. those that are correlated to the sugar content of the flower reward. Such honest signals are learned by generalist pollinators and used by them to decide which flowers to visit. Phenylacetaldehyde, a very common floral scent compound, is an example of an honest signal in flowers of *Brassica rapa*, and bumblebees rapidly learn to use this signal. We have shown that this and other floral scent compounds have medium to high heritability and evolve rapidly under pollinator-mediated selection. Floral scent also impacts interactions other than pollination, for example plant-herbivore and other trophic level interactions. In a plant-herbivore-crab spider system we have shown that bee-pollinators positively select for increased scent emission, but crab spiders, that also use floral scent for finding flowers where they hunt for insects, remove this selection on scent. Crab spiders, however, feed not only on pollinators but also on herbivores, thus, when herbivore pressure is high, crab spiders are beneficial and plants are selected to attract them to herbivore-invested flowers, which is achieved by herbivore-induced floral scent emission.

You smell great - Deciphering olfactory communication in Humans

<u>Ilona Croy</u> (Friedrich Schiller University Jena, Germany)

Human interaction is characterized by how we perceive each other, and our perception is decisively determined by the signals we consciously and unconsciously send out. Typically, more in the background of the dominant senses of vision and audition, olfaction provides quite interesting information about others – eating habits, menstrual cycle, genetic match, inflammatory illness and current emotionality are all reflected in body odors. Are they? By tracing the chain of body odor communication from emitting sweat to sensing and perceiving this signal, we will clear up some myths and facts of human olfactory communication.

Insect chemical ecology in China: Bridging fundamental discoveries and practical applications

<u>Jin Zhang</u> (Nanjing Agricultural University, China)

To be announced

The effects of infections on insect chemical communications

<u>Astrid T. Groot</u> (University of Amsterdam, The Netherlands)

Health determines to a large extent how animals behave and evolve. About half of all eukaryotic species are plant-feeding insects, and their health can be impacted by many pathogens, challenging their immune system. Plant-feeding insects (and other herbivores) can also use chemical defenses of plants to protect and medicate themselves. Infections may thus result in a change in insect behaviors, including changes in food preferences, changes in mate preferences and/or changes in oviposition choices. All these short-term ecological changes can have long-term evolutionary impacts when the different life stages affect each other and/or are transmitted to the following generation(s). It is important to understand these impacts especially in this era where insect pests are increasingly controlled biologically by infecting them with viruses, bacteria and/or fungi. In this lecture, I will give an overview of the effects of infections on insect chemical communications in general and focus on some specific examples and recent research results in moths and butterflies.

From fly chemical ecology to pest management

<u>Paul Becher</u> (SLU, Alnarp, Sweden)

To be announced

Biting back: How insect herbivores resist plant chemical defenses

<u>Jonathan Gershenzon</u> (Max Planck Institute for Chemical Ecology, Germany)

To be announced

Mass spectrometry-based metabolomics in chemical ecology

<u>Georg Pohnert</u> (Friedrich Schiller University Jena, Germany)

Chemical ecology explores the roles of natural products as mediators of interactions among organisms. The search for these compounds is, however, often tedious with multiple chromatographic and analytical steps required until the active structure is identified. Over decades the so-called bioassay-guided structure elucidation, where an active extract is fractionated, and the fractions are tested for activity provided the only approach for the identification of chemical mediators. Recent advances in metabolomics now offer powerful alternative tools to explore these ecologically relevant signaling compounds. In particular, comparative metabolomics enables the detection of metabolites that are up- or downregulated during interactions and may function as pheromones, allelochemicals, or defense-related compounds. This approach overcomes key limitations of traditional bioassay-guided methods. Moreover, integrating metabolomics with other -omics technologies provides a systems-level understanding of the biosynthetic and regulatory networks involved in ecological responses. This session will introduce the concept of comparative metabolomics in chemical ecology and illustrate how it can be used to identify pheromones and induced defensive metabolites. It will focus on the experimental design, methodological challenges, and the recent progress achieved using this approach.

An inordinate fondness for symbionts: mutualist-provided defense, digestion, and desiccation tolerance in beetles

Martin Kaltenpoth (Department of Insect Symbiosis, Max Planck Institute for Chemical Ecology, Germany)

Symbiotic associations with microbes are important driving forces of evolutionary innovation. The megadiverse insect order Coleoptera, the beetles, are associated with an astounding diversity of symbionts that provide a wide range of functional benefits to their hosts. Highlighting a few selected beetle-microbe associations, I will report on novel findings of symbiont-provided antibiotic defense, microbe-enabled digestion of plant material, and symbiont-mediated adaptation to the abiotic environment. These examples are intended to show the impact of symbionts on niche expansion and diversification in beetles, but also provide insights into life-style switches from parasitism to mutualism in bacteria as well as the process of extreme genome reduction beyond the well-known intracellular symbioses.

The evolution of chemical communication in deceptive flowers, beetles, and parasitic wasps

Johannes Stökl (University of Bayreuth, Germany)

To be announced

Eating plants for defense: chemical ecology and mechanisms of sequestration in Insects

Franziska Beran (The Leibniz Institute of Vegetable and Ornamental Crops, Germany)

To be announced

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Teun Dekker (SLU, Alnarp, Sweden)

To be announced

Behaviour and chemical ecology of above-below ground multi-trophic interactions

Jared Gregory Ali (*Center for Chemical Ecology, Department of Entomology, Penn State University, Pennsylvania, USA)*

Jared Gregory Ali, Ph.D., is an Associate Professor of Entomology and Associate Chair of the Ecology Graduate Program at Penn State. He currently serves as Director of Penn State's Center for Chemical Ecology, Acting Director of the Ecology Research Institute, and holds the Dorothy Foehr Huck and J. Lloyd Huck Endowed Chair in Chemical Ecology. Dr. Ali's research centers on the complex dynamics of multitrophic interactions, spanning plant responses to herbivory, invertebrate community ecology, chemical signaling, and coevolutionary processes. His work bridges fundamental and applied science, with projects ranging from trophic cascades and above-belowground ecological linkages to chemotaxis and the evolution of plant defense strategies. A major focus of his lab is the development of sustainable pest management approaches and the conservation of beneficial insects, aligning agricultural productivity with ecological resilience. In his talk, Dr. Ali will highlight above- and belowground interactions and their relevance to modern agroecosystems.

Basic organic chemistry for chemical ecology

Sarah O'Connor *(Max Planck Institute for Chemical Ecology, Germany)*

To be announced

Insect odorant receptors: functional studies and targets for pest control

Dr Emmanuelle Jacquin-Joly (*INRAE, Versailles, France*)

Olfaction plays a fundamental role in shaping animal behavior, particularly in insects, where it is essential for key processes such as foraging, mating, and oviposition. Odor detection is mediated by olfactory sensory neurons (OSNs) housed within specialized structures known as olfactory sensilla. This process relies on the coordinated action of several protein families, with odorant receptors (ORs) at the core. These transmembrane proteins, expressed on the dendritic membranes of OSNs, bind odorant molecule(s), initiating neuronal signals that are relayed to the central nervous system.

The advent of next-generation sequencing technologies has led to a rapid expansion in the number of available insect genomes and transcriptomes, resulting in the identification of large OR gene repertoires across diverse species. However, the functional characterization of these repertoires has been accomplished in only a limited number of cases, leaving much to uncover about how insects leverage their OR toolkit to navigate complex chemical environments.

In this lecture, I will first outline the molecular mechanisms underlying OR function and present current strategies for their functional analysis using *in vitro* and *in vivo* heterologous expression systems. I will then highlight two specific case studies: (1) the functional characterization of the first large OR repertoire in the polyphagous moth *Spodoptera littoralis* (cotton leafworm), and (2) the development of a “reverse chemical ecology” (or “molecular chemical ecology”) approach that targets ORs to identify novel semiochemicals for sustainable pest control. Finally, I will briefly introduce gustatory receptors (GRs), which mediate taste perception and are other important contributors to insect chemical sensing. In particular, I will discuss the discoveries of significant GR expansions in polyphagous noctuid species, suggesting a broader role for this receptor family in ecological adaptation.

Unraveling the role of predation risk and predator chemical cues in Arthropod ecology

<u>Sara Hermann</u> (Penn State University, USA)

To be announced

Let’s spice it up! Applying chemical ecology for sustainable vegetable production

<u>Nicole M. van Dam</u> (Leibniz Institute of Vegetable and Ornamental Crops (IGZ), Germany)

In chemical ecological research, the focus is on understanding the molecular and chemical mechanisms of organismal interactions. In my research, I focus on interactions between plants and herbivores, both above and below the ground. By combining metabolomic and transcriptomic approaches with bioassays I aim to understand how plants manage the complex interaction networks they are a central member of in their natural environments. Now that more and more toxic pesticides are banned from use, crop plants are facing similar problems. This may potentially have severe impacts on food security when increases in herbivory cause severe yield losses. Here I will show how knowledge generated by (basic) chemical-ecological research can support the development of sustainable vegetable production systems. For example, metabolomic analyses combined with bioassays can identify specific metabolites conferring resistance to thrips in bell pepper plants. In addition, revealing the chemical ecology of plant-microbe-insect interactions may provide valuable information on how we use beneficial soil microbes to boost crop resistance in agro-ecosystems. Together, such measures will support the further development of new breeding and management strategies, leading to healthy and sustainable plant production systems. I am looking forward to discuss with the participants what they think chemical ecological knowledge may contribute to create resilient cropping systems that produce sufficient and healthy plant-based food for all.

Environmental impacts on volatile-mediated interactions

James Blande *(University of Eastern Finland)*

To be announced

Chemical communication in social insects

Yuko Ulrich *(Max Planck Institute for Chemical Ecology, Germany)*

Sociality is a widespread and successful ecological strategy that has enabled some social species to dominate many ecosystems. To function, animal societies rely on sophisticated communication systems, which allow members of a group to exchange information. Here, I will describe recent findings and ongoing work on the chemical bases of social organisation in an experimentally uniquely accessible social insect, the clonal raider ant *Ooceraea biroi*. In this species, unlike in other social insects, colonies are queenless and composed of workers that reproduce asexually and synchronously, leading to a remarkably simple colony social organisation. Synchronous reproduction in turn drives stereotypical behavioural cycles, in which colonies alternate between brood care phases and reproductive phases.

I will present some of my group's ongoing work combining untargeted chemical analytics and custom behavioural assays to identify putative pheromones regulating colony cycles, collective foraging, and corpse management in the clonal raider ant, towards the goal of understanding some of the basic principles of ant social organization.