Insect Physiology

Semiochemicals

David Merritt

Outline

- What are semichemicals?
- Systematic nomenclature for signalling chemicals
- Pheromones: research history
- Evolutionary origins of pheromones
- Butterfly sex pheromones
- Allomones
- Kairomones
- Synomones
- Social Insects
- Applications

Semiochemicals

= signalling chemicals: they alter the behaviour or physiology of the receiver

Pheromones	Intraspecific signalling	
Kairomones	Interspecific signalling	the responder benefits
Allomones	Interspecific signalling	the sender benefits

Interspecific chemicals can be signals that originate from a plant and affect an animal, or they can originate from one animal or plant species and affect another.

Systematic Nomenclature for Semiochemicals (= signalling chemicals)

- ***Allomones***: benefit emitter, e.g. repellent substances
- ***Kairomones***: benefit receiver, e.g. plant metabolites used to detect host-plants
- ***Synomones***: benefit both receiver and sender, e.g. floral scents

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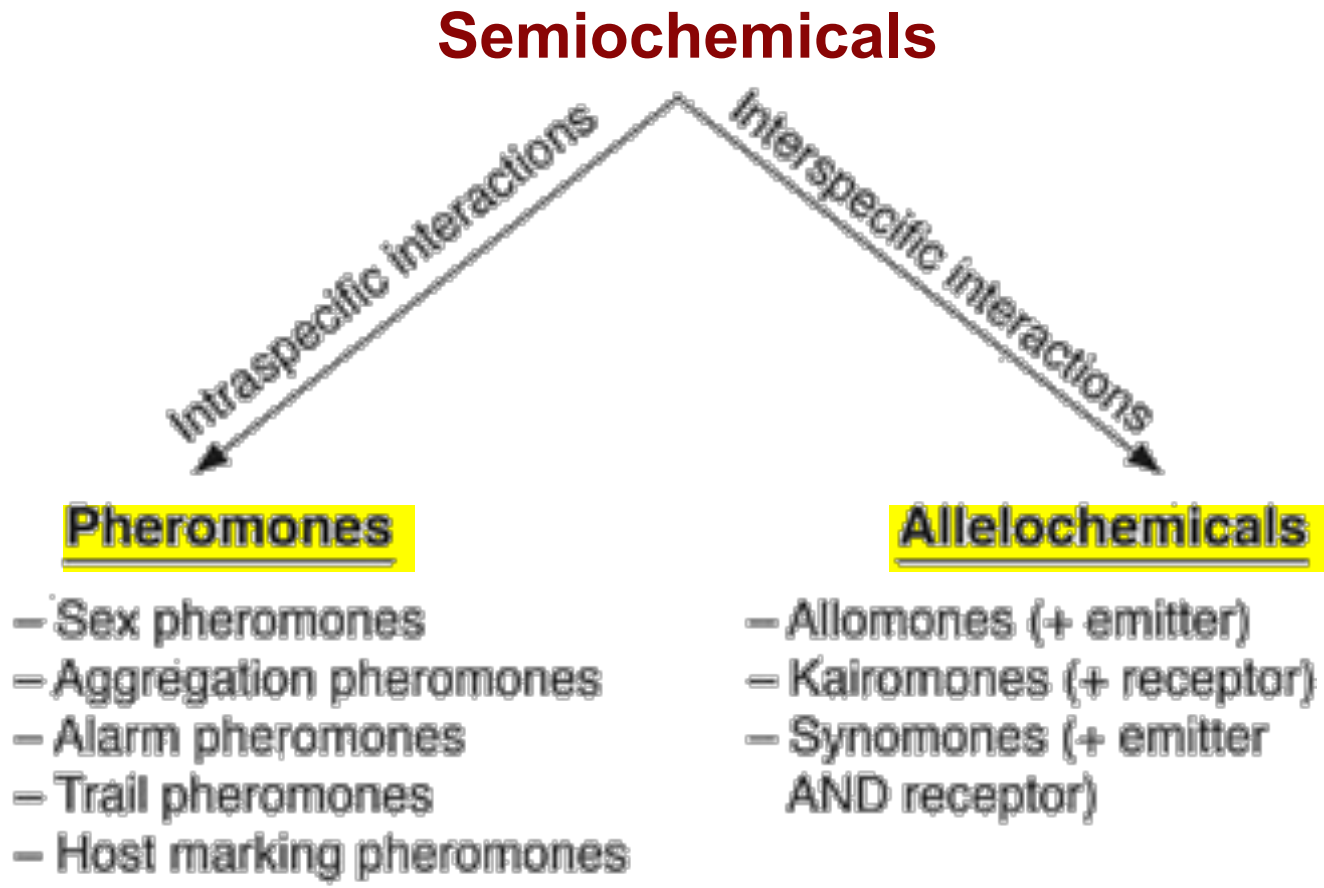


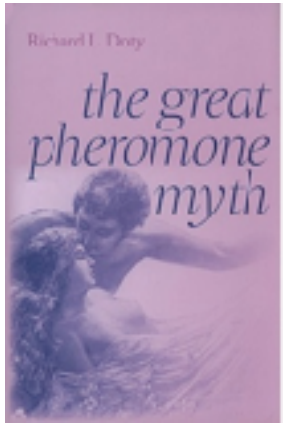
+ means benefits

What are Pheromones?

Chemical messages between animals of the same species that are sent by one and received by another individual, and trigger a response in the receiver

Classic example: Silk moth male orients towards sex pheromone sent by females

Human male pheromones allegedly controlling female hormones

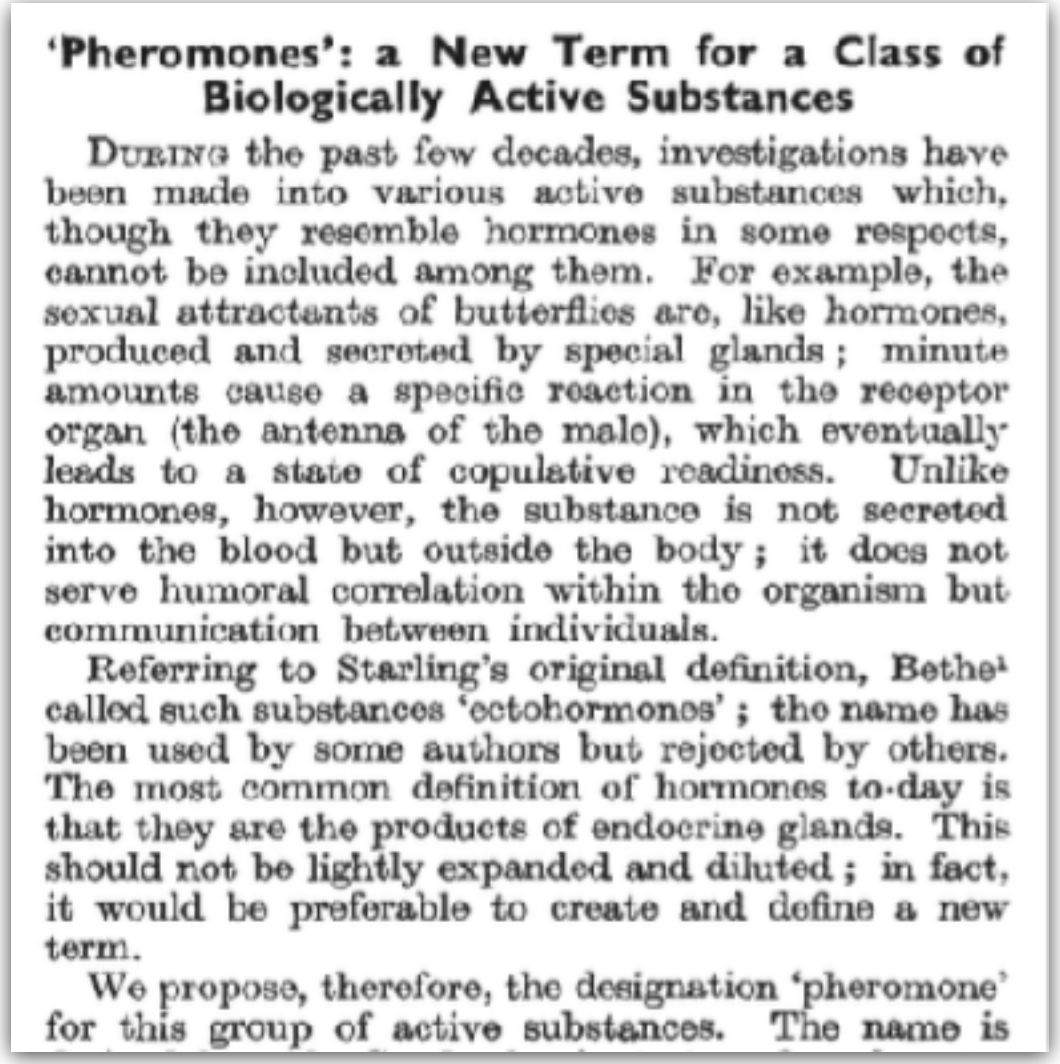


"We spend billions of pounds every year on products to remove our smells and about the same amount on perfumes to add new ones."

The search for human pheromones: the lost decades and the necessity of returning to first principles
T.D. Wyatt 2015.DOI: 10.1098/rspb.2014.2994

History of pheromone research

- The term “pheromone” was introduced by Karlson & Luescher in 1959
- Based on Greek word *pherein* (to transport) and *hormone* (to stimulate)
- First pheromone characterized: BOMBYKOL (silk moth sex pheromone) 1959
- Pheromones can be variety of different chemicals; mostly volatile chemical blends -> active over a distance
- Some are contact-based: detected by gustatory receptors



‘Pheromones’: a New Term for a Class of Biologically Active Substances

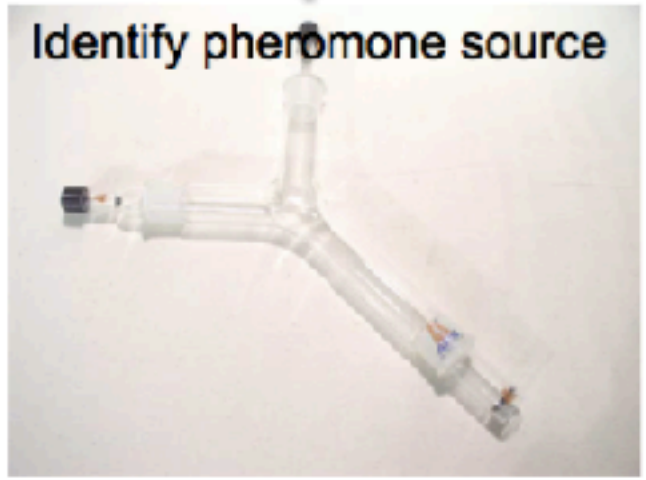
DURING the past few decades, investigations have been made into various active substances which, though they resemble hormones in some respects, cannot be included among them. For example, the sexual attractants of butterflies are, like hormones, produced and secreted by special glands; minute amounts cause a specific reaction in the receptor organ (the antenna of the male), which eventually leads to a state of copulative readiness. Unlike hormones, however, the substance is not secreted into the blood but outside the body; it does not serve humoral correlation within the organism but communication between individuals.

Referring to Starling’s original definition, Bethe[1] called such substances ‘ectohormones’; the name has been used by some authors but rejected by others. The most common definition of hormones to-day is that they are the products of endocrine glands. This should not be lightly expanded and diluted; in fact, it would be preferable to create and define a new term.

We propose, therefore, the designation ‘pheromone’ for this group of active substances. The name is

Methods of pheromone research

1



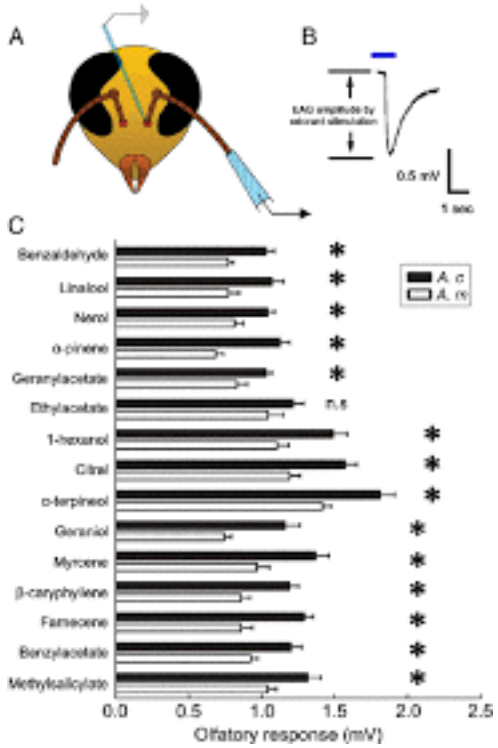
(various bioassays + histology + extractions + physiology)

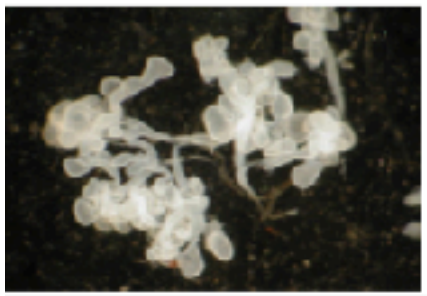
2

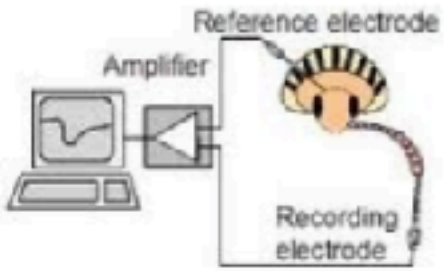
3: verification

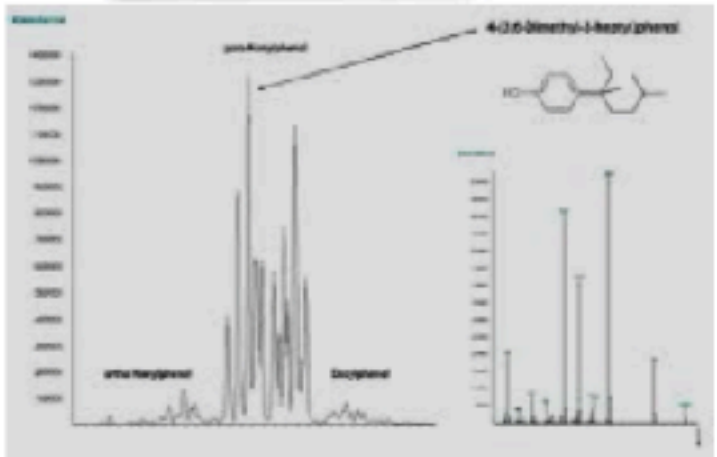
Chemical identification (GC-MS, GC-EAG)

Electroantennogram (EAG) records summed electrical potentials of all ORNs

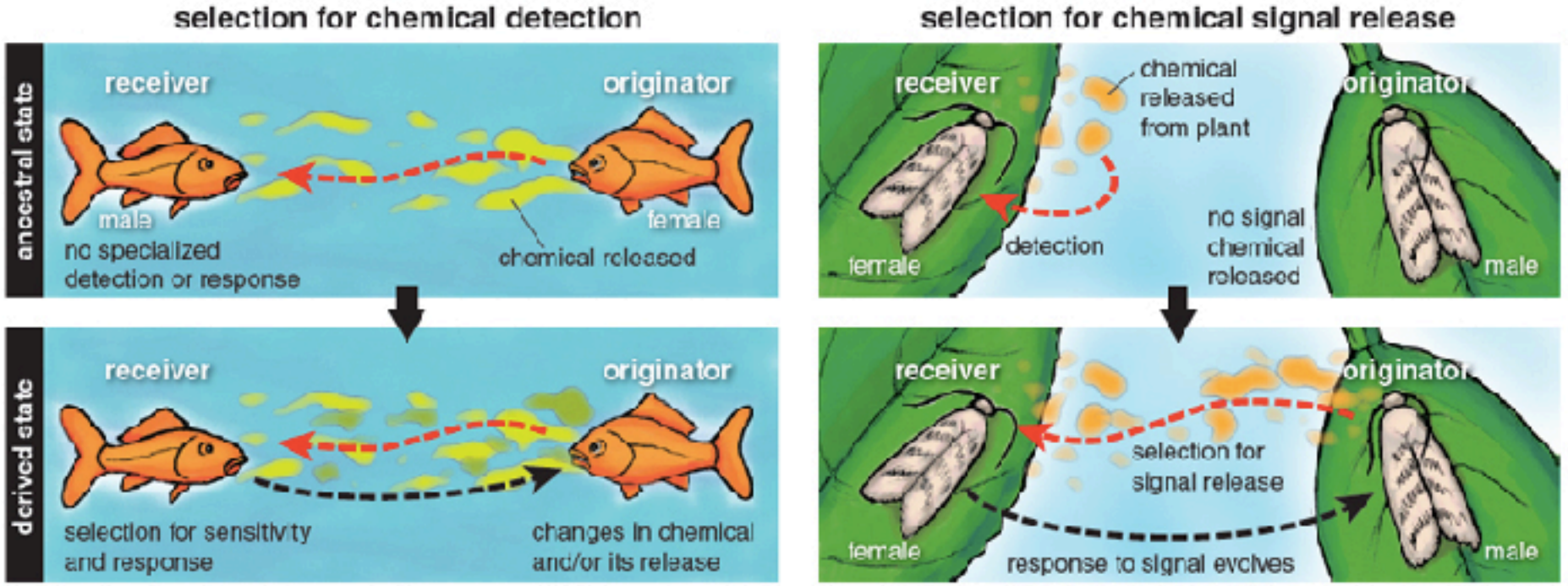








Origin of Pheromones



Release came first

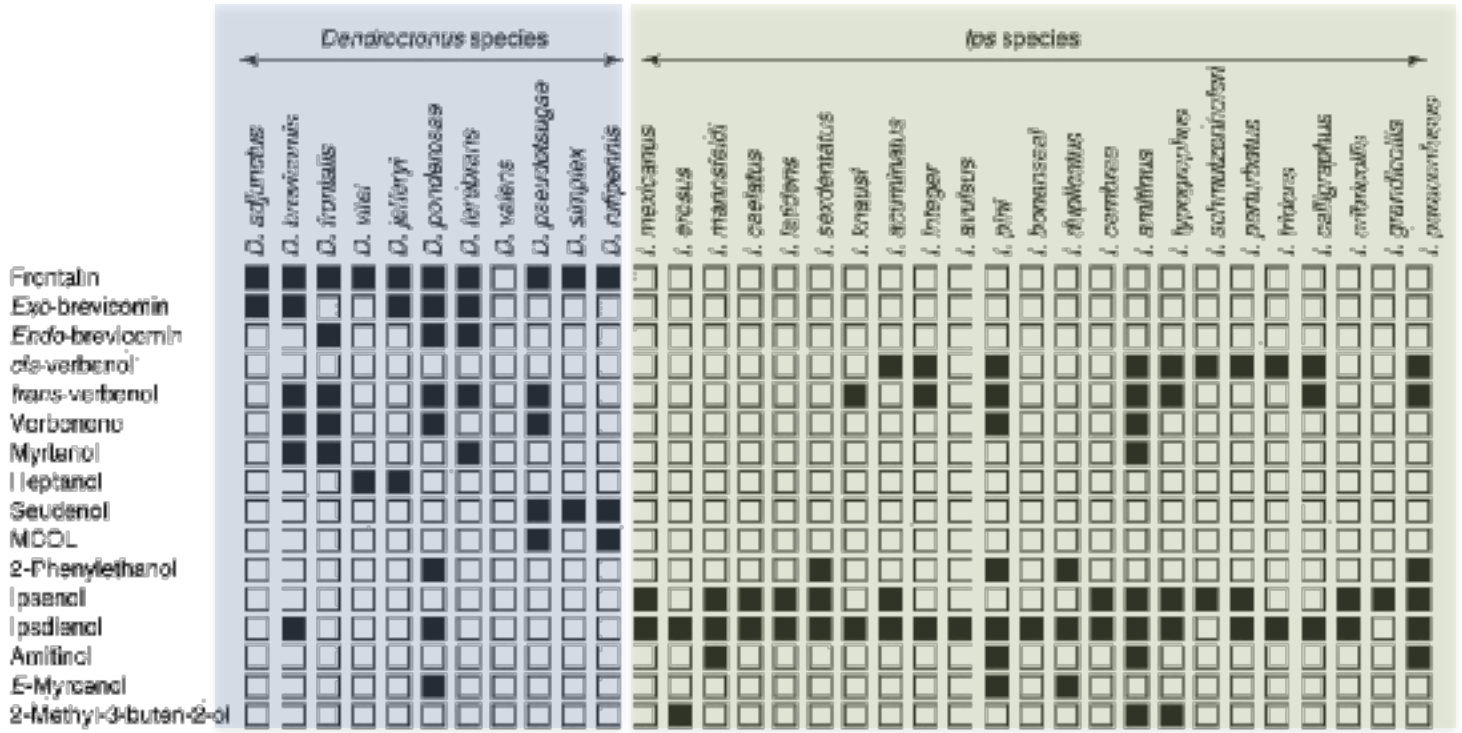
Emission came first

Pheromones can evolve in one of two ways: Either the release or the detection of the chemical evolves first. In the first instance (left), the organism releases a chemical for some other purpose and the ability to detect it then evolves—in this case, a male is able to find a female to mate with. In the latter instance (right), the ability to detect an odorant already exists for some other purpose, and then the ability to release it as a signal evolves. For example, the oriental fruit moth male evolved to release a pheromone that already attracted females, because it included molecules given off by the plant where they laid their eggs.

- Pheromones were the first signals used to communicate between the earliest forms of life (ancestral prokaryotes, eukaryotic protozoans)
- Frequently derived from excretions such as urine, faeces or plant-related dietary compounds
- Produced and secreted by diverse glands

Pheromone Components

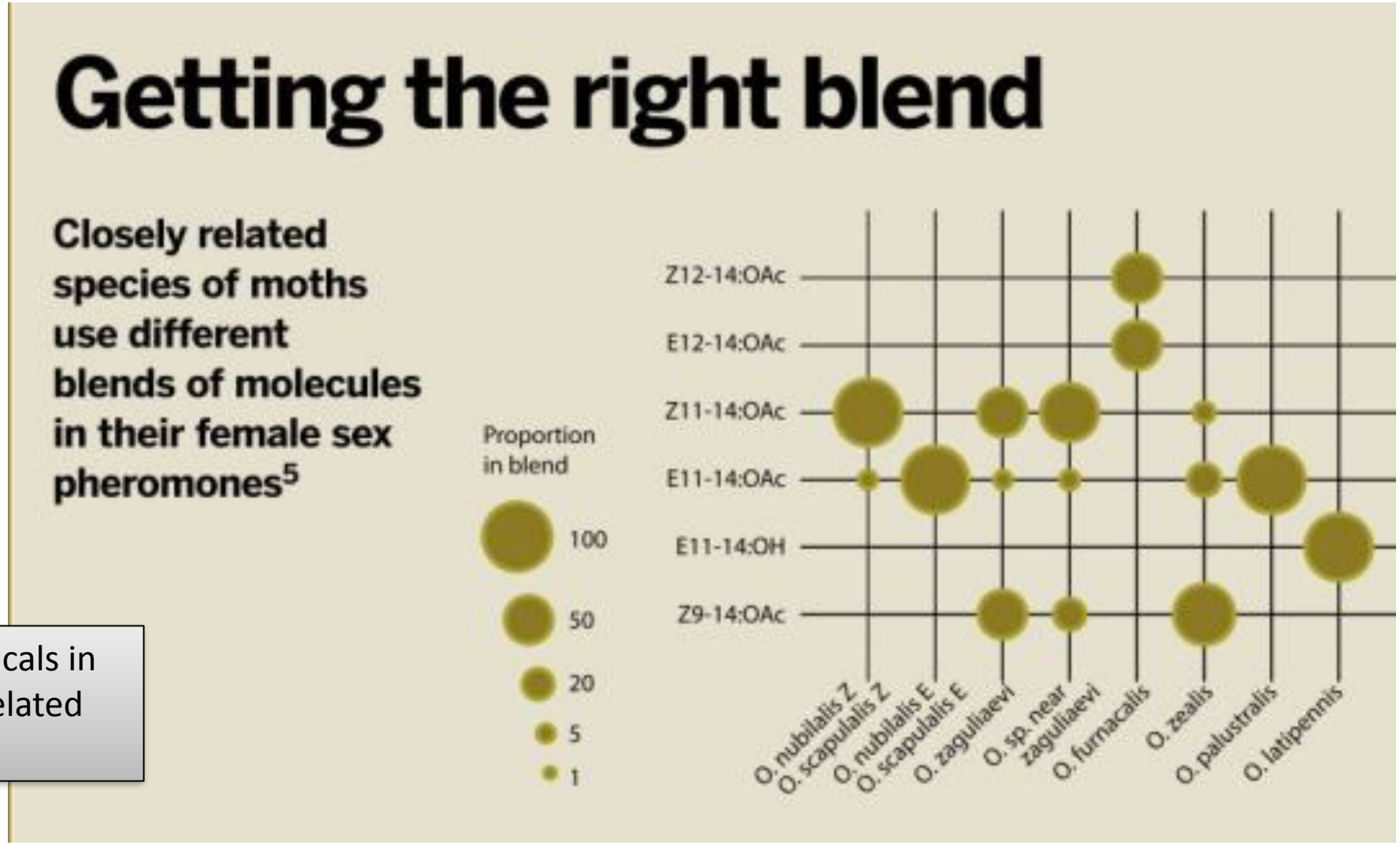
- Chemical communication remains virtually universal among all living organisms
- The main components tend to be taxon-specific



Components of aggregation pheromone in two **genera** of **beetles** Note unique and shared components in the two genera

http://dx.doi.org/10.1016/j.tree.2007.11.009

- with variation in ratios of blends between species



Different blends of chemicals in the sex pheromones of related species of moth

http://dx.doi.org/10.1016/j.tree.2007.11.009

Sex pheromones in butterflies

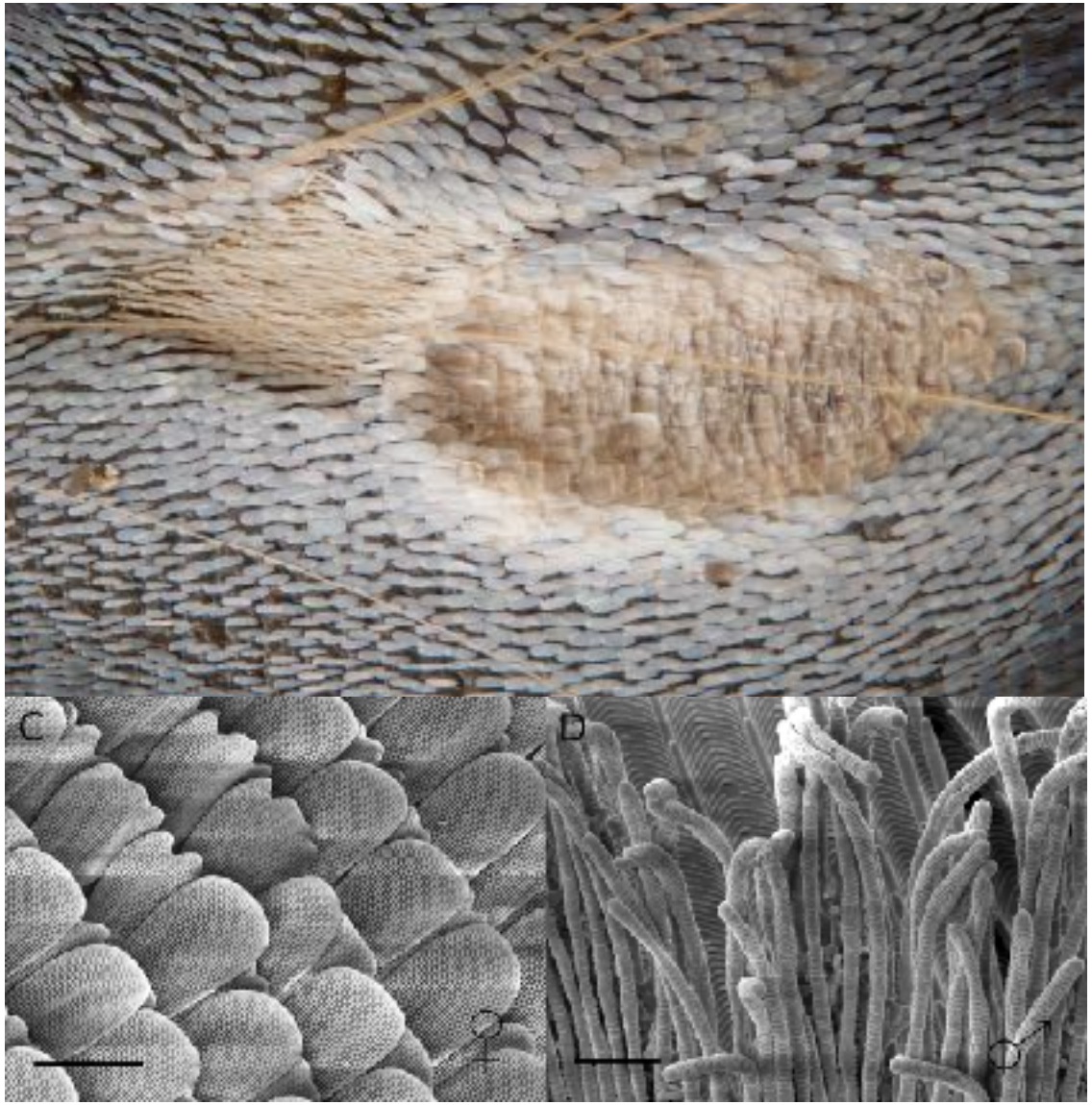
- Male Lepidoptera have hair pencils, abdominal tubular organs that can be everted by haemolymph pressure (like fingers of a glove).
- Covered with “hairs” that are modified sensilla.
- Glands open out at base of hairs.
- Males evert the hair-pencils that release the odour.
- In many species they also release cuticular particles (pheromone transfer particles [PTPs]) that are infused with the odour.

Danaus chrysippus Jee & Rani Nature Photography CC BY-SA 4.0 License

Sex pheromones in butterflies

- Some male butterlies have specialised scales (androconia) on wings
- Danaid (monarch butterfly) males androconia lie in pockets on the wing
- Inside the pocket the scales are specialised to form pocket scales and cushions with their associated cushion scales.
- TEM shows that large gland cells are closely associated with the “sensillum”
- Androconia are specialised to carry scent: they have a large surface area at the tips

By Gilles San Martin



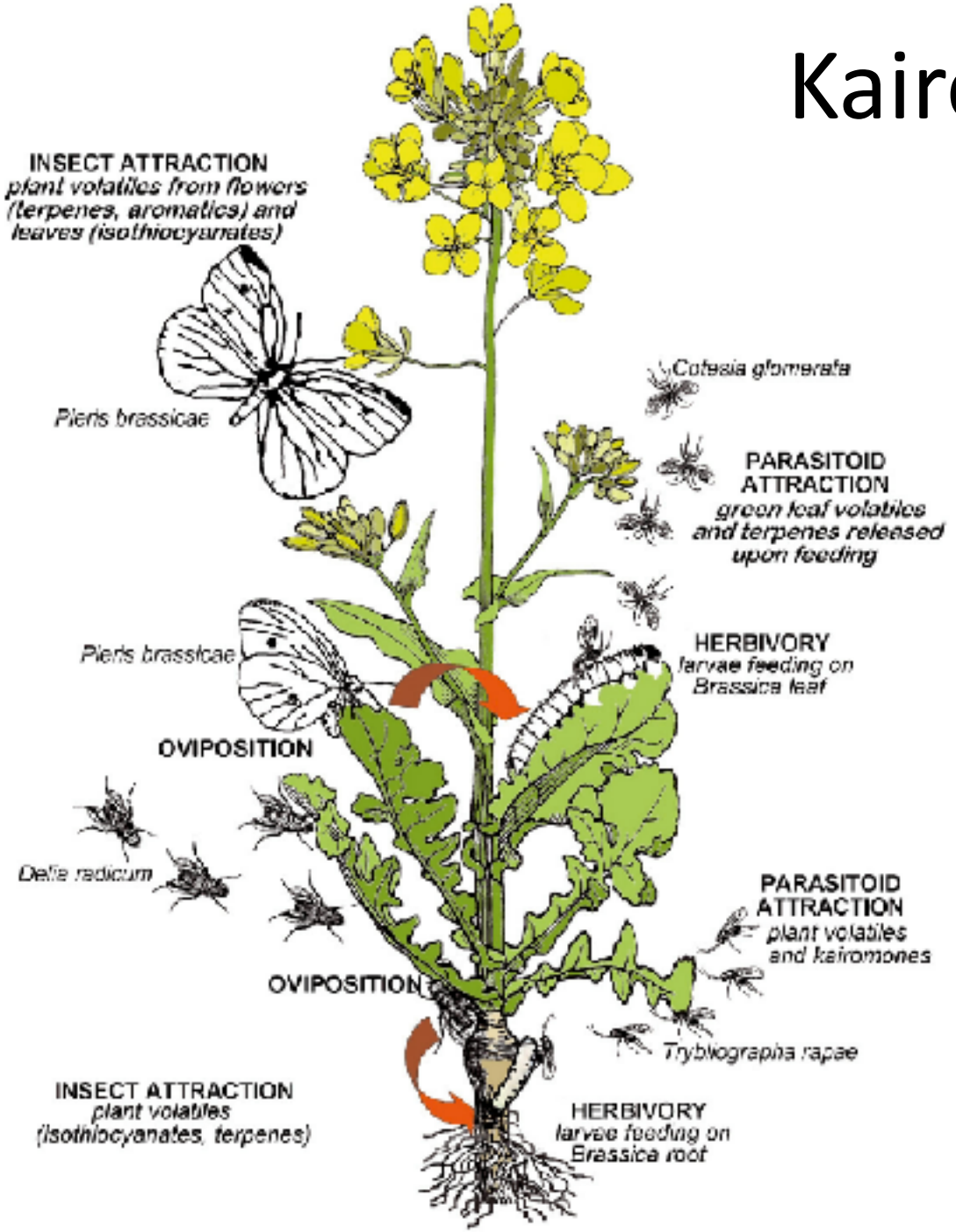
Darragh, Kathy, et al. *PeerJ* 5 (2017): e3953.

Allomones

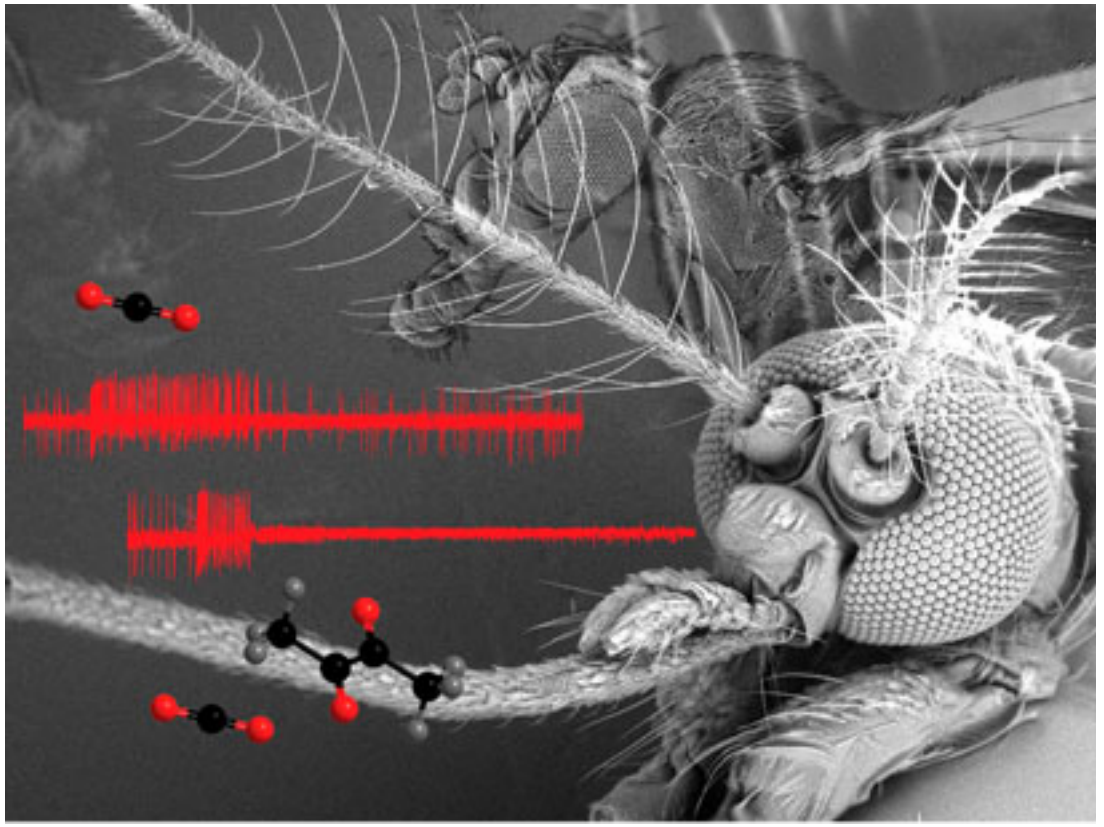
Defensive or repugnatorial

Cup moth caterpillar: Brisbane Insects

Kairomones



- Evolution of a detecting capability
- Host-related stimuli such as plant odours, breath c sweat components



Defence mechanisms of Brassicaceae: implications for plant-insect interactions and potential for integrated pest management. A review

Synomones

- Mutual development of signal and an ability to receive it
- Not all sweet flower smells: stinkhorn fungi attract carrion flies

Systematic Nomenclature for Signalling Chemicals

Releaser Pheromone

Evoke rapid behavioural response in receiving animal mediated by nervous system

Alarm
Mate recognition
Aggregation
Territorial
Oviposition
Trail following
Recruitment
Kin recognition
Nest building

Primer Pheromone

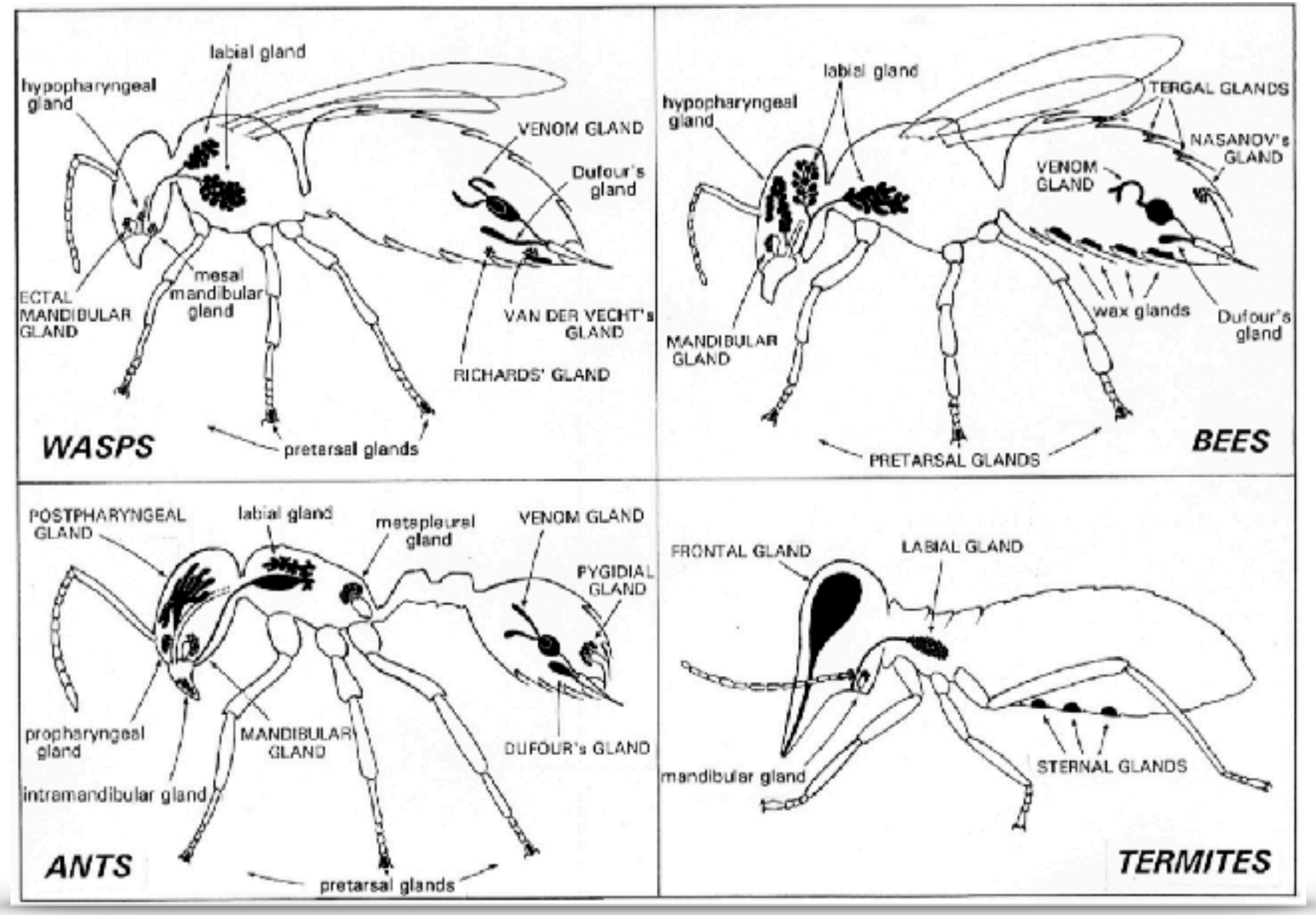
Over hours/days, they alter endocrine, reproductive, nervous systems

Sexual maturation
Development
Physiological state

Social Insects

- Social Insects make extensive use of pheromones
- All social insects use pheromones to communicate
- Requirements of the colony (alarm, defense, food)
- Control of reproduction and caste development
- Pheromones produced by diverse and novel glandular systems

Social Insects



Social Insects: Ants

- Ants, each time two individuals meet they check each other via ***antennation*** to determine relatedness
- If the wrong hydrocarbon template is detected, aggressive behaviour triggered

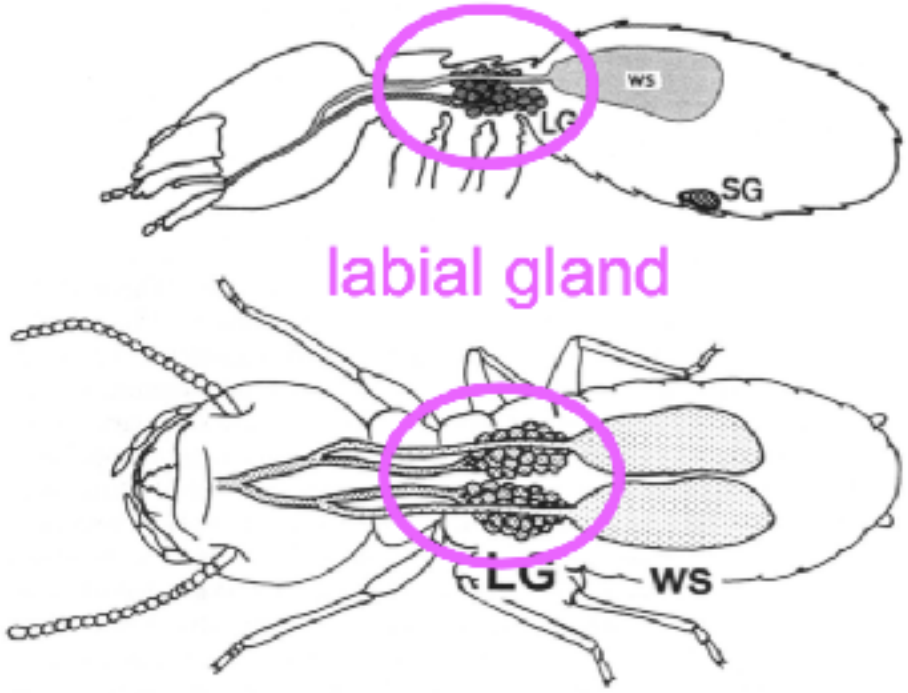
Alarm pheromones from venom and sting glands : to alert nest-mates in defense of colony and/or to alert for group attack on prey (e.g. bee hive)

- Chemistry and glandular source of pheromones well studied ("The Ants" by Hoelldobler & Wilson)
- Recruitment pheromones (trails): communication about food location and quality to nest mates

Social Insects: Termites

- Best known as pests, but they are in an ancient insect order: Isoptera, a part of Blattodea (cockroaches)
- Hemimetabolous, herbivorous insects

Unique termite phagostimulating pheromone



Termites release labial gland secretion (LGS=saliva) during chewing on food; this secretion stimulates nest mates to start feeding and chewing at the same spot.

Genomes of Blattella and termites sequenced and compared 2018

Eusocialization not associated with evolution of new genes

Ionotropic receptors are strongly expanded in the cockroach and termite genomes cf Hymenoptera

increased importance of CHC communication in termites: associated with caste differences

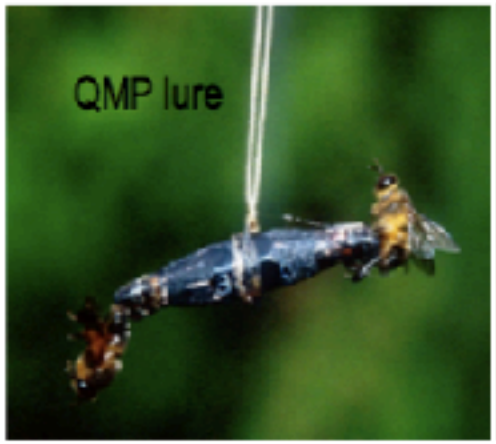
Reduction of IRs in termites cf cockroach

Higher proportion of ORs were differentially expressed between workers and queens in termites than between nymphs and adults in cockroach

Queen Mandibular Pheromone: Mating

Queen mandibular pheromone produced by the queen and fed to her attendants who share it with the rest of the colony that gives the colony the sense of being queenright.

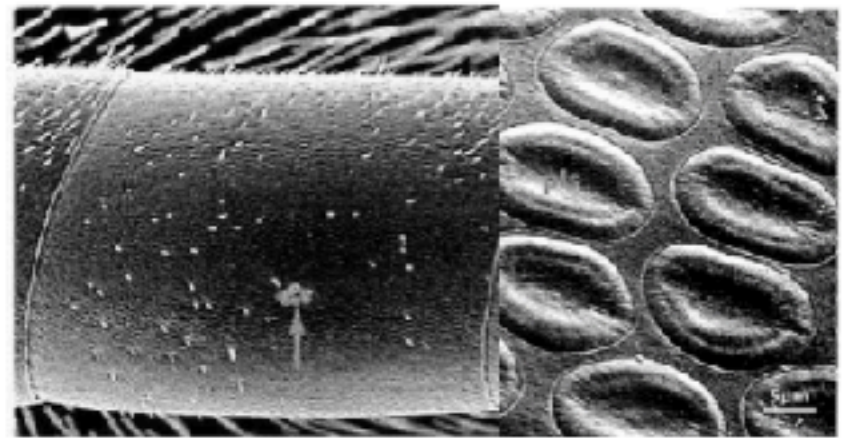
- Mature drones: daily afternoon flights
- Drone congregation areas (DCA): large numbers of drones from numerous colonies, comet-like mass
- DCA same every year associated with permanent landmarks (trees)
- Young queens on mating flights find DCAs, fly through them, releasing QMP
- Triggers frenzied chase, during which queen mates with several drones



Drones: Specialized to detect QMP

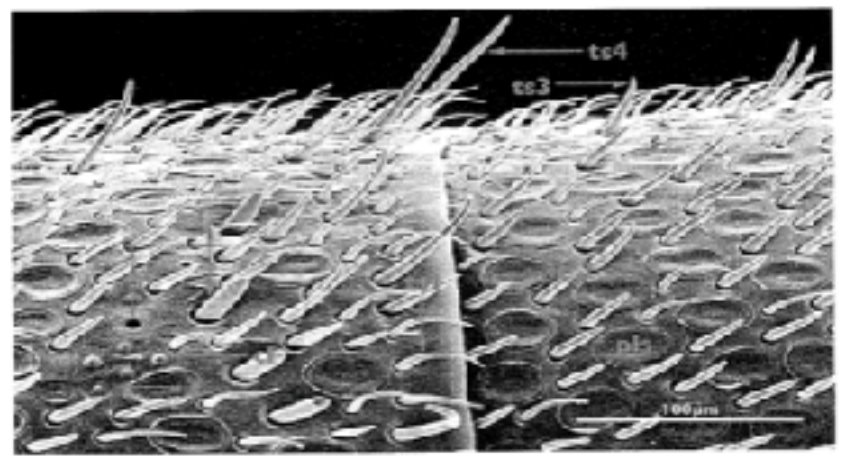
Sexual dimorphism: drones have huge eyes and 10x more olfactory sensilla on antennae

DRONE



30,000 sensilla placodea

WORKER



3,000 sensilla placodea

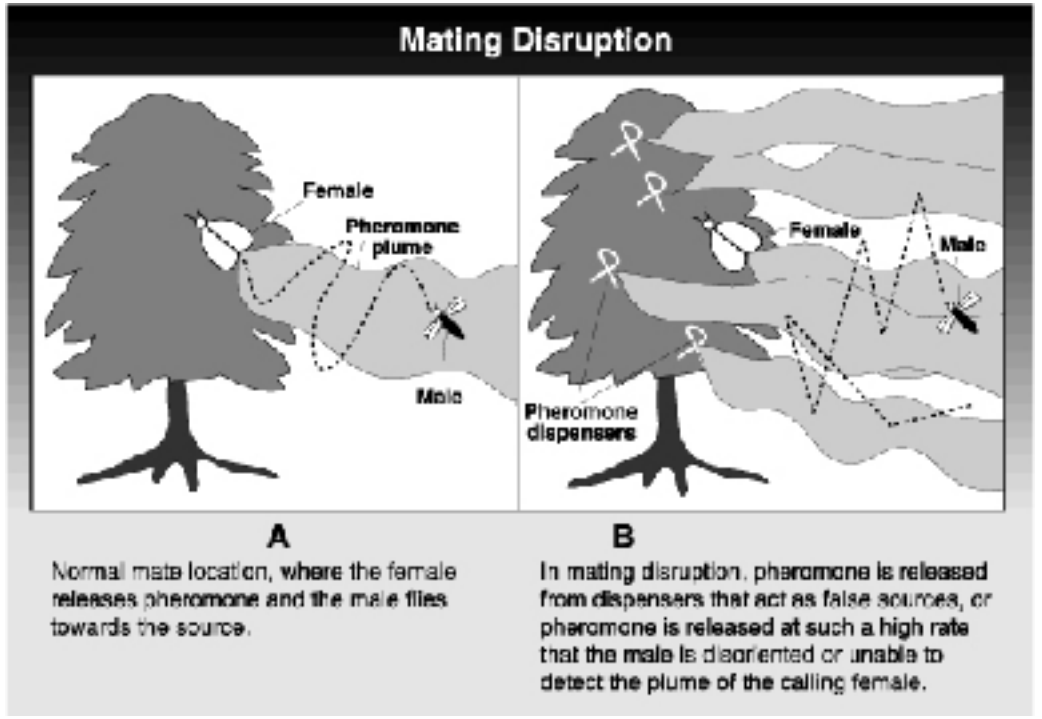
Semiochemicals in Pest Control

Advantages:
- Selective (no effect on beneficials)
- Non-toxic (delayed onset of resistance)
- Short-lived and non-polluting

Mating Disruption
- Sensory fatigue
- Competition between natural and synthetic sources
- Camouflage of natural plumes

Successfully used in control of:
- pink bollworm
- oriental fruit moth

Best when insect has:
- Short life span
- Synchronised mating period
- Short mating period.



http://jenny.tfrec.wsu.edu/opm/displaySpecies.php?pn=-80

Commercially available indian meal moth lure and sticky trap for domestic use