SOME METHODS OF INSECT CONTROL INSPIRED BY NATURE

A wide variety of plants and animals communicate with chemical signals. These ‘pheromones’ are secreted by one individual of a species to accomplish a behavioral response or physiological change in another individual of that same species. Trees emit volatile compounds when attacked by insect predators, inducing neighboring trees to produce more toxins. Insects attract mates, send alarms, and mark trails and food sources. Mammals emit scents which attract mates or mark territory. Even female aquatic fungi and algae emit sex attractants. Because of their potential to damage food crops, insects and their pheromones have received the most attention.

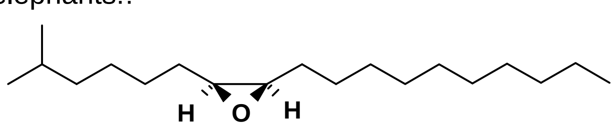
The total world population of insects is about a billion billion (10^{18}), and .01% (10^{14}!) of them are agricultural pests. Until recently, the pests were killed with broad spectrum insecticides, like DDT and malathion, which are also toxic to the other 99.9% of harmless and beneficial insects, and often to birds, other wildlife, and humans. Moreover, the persistence of insecticides like DDT in the environment has ensured that only resistant insect strains have survived, strains that require greater doses for control; higher doses also mean more damage to non-target species. Insect predators ingest the DDT along with the insect, and their predators ingest it in turn, storing it in fatty tissues. Its persistence ensures that high levels of DDT occur in non-target species like birds; DDT in high concentrations causes neurological problems and disrupts calcium metabolism, particularly egg-shell formation. Because of the resistance in pest populations, the economics of the pesticide industry, and public response to warnings like that of Rachel Carson, new pesticides like malathion were developed. These break down in nature more readily but most are also far more toxic than DDT and have killed careless farm workers. North America has seen recoveries in its bird populations, but migratory birds are often exposed to high concentrations of persistent pesticides in other parts of the world (some, like DDT, exported from the USA where they are banned). Less toxic broad spectrum insecticides are being developed, but the problem of killing non-target species like honeybees remains.

Alternate selective methods of insect control are needed; among the most successful are those relying on insect pheromones and hormones and on the plants’ natural defenses. Organic chemists and entomologists have combined forces, using the sensitivity and power of capillary GC, MS and high field NMR spectroscopy to identify very small quantities of these compounds. Advances in stereospecific synthesis, especially the Wittig reaction for making (*Z*) double bonds, have made it economical to synthesize and use these compounds on a commercially significant scale. Single species and subspecies of insect can now be controlled by their own chemistry.

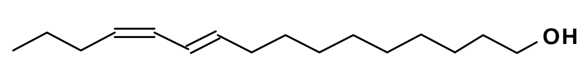
SEX PHEROMONES

Both male and female of some insects produce sex attractants. So powerful are they that the 10^{-8} g a female insect carries can attract males from miles away. Humans can often smell these pheromones, but only in much higher concentrations. Sex attractants are most commonly used as bait in traps; the trapped insects are either killed or sterilized; sterilization and release may be necessary to dilute the small population of males who escape, to ensure that they do not inseminate all of the females.

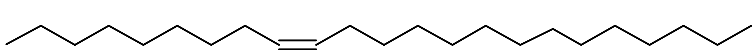
The gypsy moth (*Lymnantria dispar*), a non-native species, feeds on 500 species of vegetation and has ravaged the forests of the northeastern US. Its numbers can be estimated by the use of baited traps containing disparlure, the pheromone produced by females. More recently, trees have been sprayed with a microbial disease BT. Silkworm pheromone has been used to detect wild populations. The cabbage looper female pheromone, (*Z*)-7-dodecen-1-yl acetate, is also a female pheromone for elephants!!

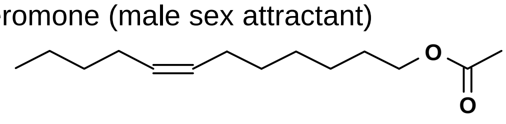


Disparlure, gypsy moth male attractant
(*Z*)-7,8-epoxy-2-methyloctadecane



Bombykol, silkworm (*Bombyx mori)*
female pheromone (male sex attractant)

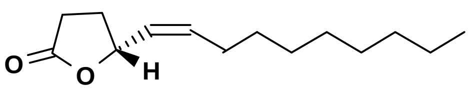




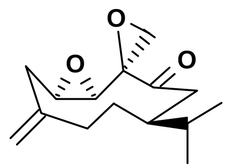
housefly (*Musca domestica*) Muscalure, male sex attractant

cabbage looper moth (*Tricholusia ni*) male sex attractant

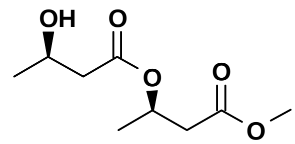
Japanese Beetle traps are familiar to most gardeners; using the traps may actually cause more local damage since the attracted beetles often feed en route to the trap. Male cockroaches have also been lured into traps with pheromones and serious fruit fly infestations have been averted with trimedlure.



Japanese beetle (*Poplilla japonica*)
Japonilure, male sex attractant

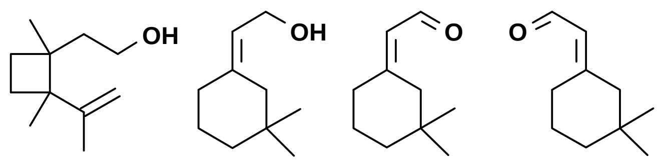


cockroach (*Periplaneta amer.*)
male sex attractant

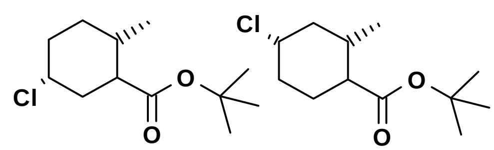


spider (*Lynyphia triangularis*)
female pheromone

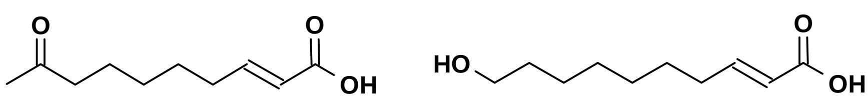
Some species require precise mixtures of compounds as sex attractants:



boll weevil (*Anthonomus grandis*)
Grandlure, female sex attractant



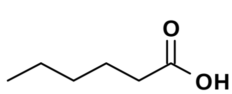
Mediterranean fruit fly (*Dacus dorsalis*)
Trimedlure, male sex attractant



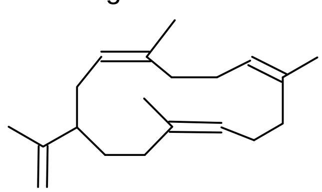
honeybee (*Apis mellifera*) queen mandibular gland pheromone:
sex attractant outside the hive, prevents production of a second queen inside the hive.

AGGREGATION AND TRAIL PHEROMONES

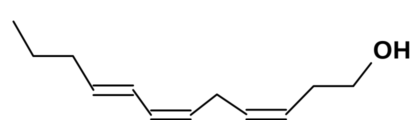
Social insects, such as ants and bees, send messages to attract other members of the species for defence or to announce a new food supply. These persistent messages can be used to lure the insects away from conflict with human goals. Termites trail markers include:



(*Zootermopsis nevaensis*)



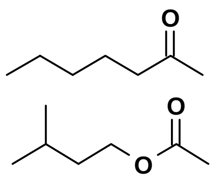
(*Nasutitermes*)



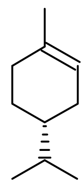
(*Reticulitermes flavioes*)

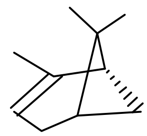
ALARM PHEROMONES

Plants and animals warn their fellows of impending danger by noise, motion and short-duration chemical messages. These pheromones can be used to deter predation.

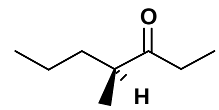


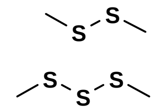
honeybee (female)
(*Apis mellifera*)





two termite species
(*Drepanotermes rubiceps)* (*Nasutitermes exitiosus*)



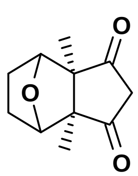


two ant species (female)
(*Atta texana*) (*Palothreus tarsatus*)

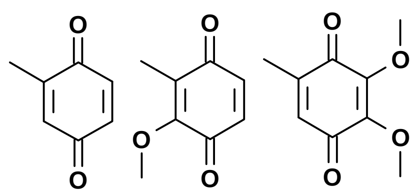
ALLOMONES

Plants and insects also send messages to other species, mostly to discourage predation. Many plants produce herbicides to inhibit the growth other plants; walnut trees are a classic example. Plants also protect themselves from insects with toxic ingredients, sometimes synthesized in response to stress. Some insects protect themselves from predation with compounds ingested from plants that few other insects will eat , e.g. monarch butterflies with milkweed. The natural materials we call antibiotics are produced by microorganisms to inhibit the growth of other species of microorganism. Skunks discourage predators effectively.

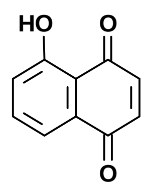
Allomones can also attract. Sea anemones emit aromatic compounds that attract symbiotic clown fish. Plants attract insects, for pollination, for example. One of my personal favorites is linalool, found in especially high concentrations in bee balm.



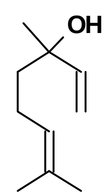
cantharidin
blister beetles
(*Lytta sp.*)



quinones
millipedes



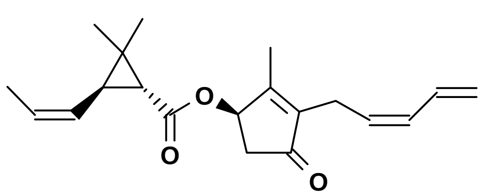
juglone
walnut leaves
(*Juglans sp.*)



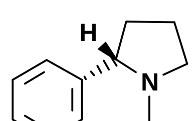
linalool
bee balm
(*Monarda didyma*)

NATURAL INSECT TOXINS FROM PLANTS

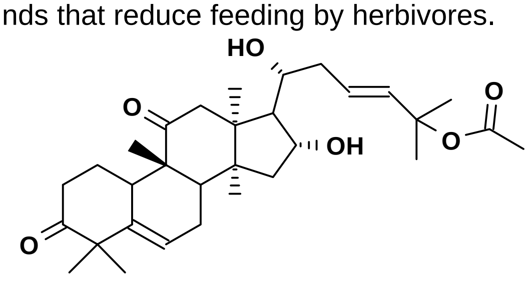
Many of the allomones are in fact toxic and many have been used by man directly or indirectly in insect control. Pyrethrins occur naturally in plants of the chrysanthemum family such as ox-eye daisy and feverfew, protecting them and their neighbors; its relatively low toxicity makes it useful in the home. Nicotine is too toxic for use as a spray, but effectively protects tobacco plants from aphids. The cucumber/squash/melon family also produce bitter compounds that reduce feeding by herbivores.



a pyrethrin
(*Chrysanthemum*)



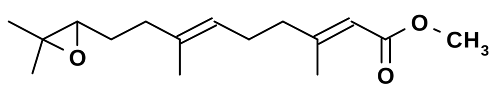
nicotine
(*Nicotiana tobaccum*)



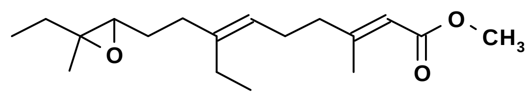
cucurbitacin B
(*Curcubitaceae*)

JUVENILE HORMONES

The complex life cycle of insects opens a variety of possibilities for controlling insects based on selective interference with their metabolism. A juvenile hormone is necessary for the juvenile stage to be maintained until it matures to adulthood. If the juvenile hormone is applied to eggs, they can be prevented from hatching. If larvae are exposed to high levels of juvenile hormone, the fail to form pupae, and never become sexually mature adults. The next generation will not be produced and the population reduced for some time.



tobacco hornworm moth hormone



cecropia moth hormone

A PERSONAL NOTE

Insects and man are often in competition for the same foods. At the same time other insects, e.g. honeybees, are essential to the production of food plants. We have the power to completely upset the balance of the earth's ecosystems, and we may already have done so. I believe that with the power, man has a responsibility to preserve and protect. Yet what can one person do? Most of us will only encounter insects we consider pests in our gardens. We can minimize the conflict (and the gardening effort) and restore the balance by planting native plants and minimizing our use of pesticides (insecticides and herbicides). This has been my approach. We can try to educate our neighbors (I try). We can insist on "organic" products or become vegetarians. As scientists we have additional opportunities. Pheromone research is full of opportunities for important contributions to science, in entomology, botany, organic chemistry and biochemistry.

The diversity of structures serving the same purpose in different species is both necessary and fascinating. Even people have pheromones! Organic chemistry students will notice the simplicity of most of the pheromones - you can even deduce the IUPAC names of nearly half of these compounds using disparlure as a model for epoxides. Designing a synthesis is not so simple because of the unconjugated *Z* double bonds which are thermodynamically unfavorable. Georg Wittig recently won the Nobel prize for inventing a reagent which converts ketones to *Z*-alkenes.

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