Middlebury

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Greetings, Alumni College Students!

Welcome to my Insects in a Chemical World course. Thank you for your interest, and I look forward to meeting you at Bread Loaf in early September. I took an insect chemical ecology course in Sweden back in 2011, and it inspired me to shift my research focus. I'm excited to share this world with you as we discuss both the basic and applied science surrounding insects and chemicals!

We can think about this topic on a small and familiar scale, the agroecosystem of an apple orchard. Currently fresh blossoms are emitting a floral bouquet of odors to attract pollinators. Codling moth males are chasing the sex pheromone of the female, while farmers try to disrupt mating by placing dispensers of the same pheromone around the orchard. Aphids gathered on the young branches are cloning themselves and sending alarm pheromones to their colony when ladybirds are about. And these important signals are just a small part of the ever-changing profusion of other molecules in the orchard. How does an insect navigate the chemical landscape and filter out the noise?

To prepare for the class, I'd like you to read the following:

- *Extraordinary Insects* by Anne Sverdrup-Thygeson 2019 (ISBN: 0008316376)
- "The Great Peacock" by Jean-Henri Fabre from *The Life of the Caterpillar* 1916 (PDF)
- "Mating Disruption" by Jay F. Brunner and Alan Knight from *WSU Tree Fruit* 1993 (PDF)

Extraordinary Insects is a great book to begin to understand insects, their behavior, and their ecological importance. The book contains many delightful vignettes of many insect species and is available at several book retailers. "The Great Peacock," written by Jean-Henri Fabre, a French entomologist and pioneer in insect behavior, is one of the very first accounts of insect pheromonal communication. And the "Mating Disruption" article takes you into the modern day with the agricultural application of insect pheromone research. With the class having this foundation knowledge, I look forward to a rich discussion, both in the classroom and the field.

I look forward to meeting you soon, and enjoy the insects of summer!

Sincerely,

Greg Pask
Assistant Professor of Biology

Chapter XI. The Great Peacock

34-43 minutes

Jean-Henri Fabre *The Life of the Caterpillar*

The Peacock Butterfly Caterpillar

IT WAS a memorable evening. I shall call it the Great Peacock evening. Who does not know the magnificent Moth, the largest in Europe, clad in maroon velvet with a necktie of white fur? The wings, with their sprinkling of grey and brown, crossed by a faint zig-zag and edged with smoky white, have in the centre a round patch, a great eye with a black pupil and a variegated iris containing successive black, white, chestnut and purple arcs.

No less remarkable is the caterpillar, in colour an undecided yellow. On the top of thinly-scattered tubercles, crowned with a palisade of black hairs, are set beads of turquoise blue. His stout brown cocoon, so curious with its exit-shaft shaped like an eel-trap, is usually fastened to the bark at the base of old almond-trees. The caterpillar feeds on the leaves of the same tree.

Well, on the morning of the 6th of May, a female emerges from her cocoon in my presence, on the table of my insect-laboratory. I forthwith cloister her, still damp with the

humours of the hatching, under a wire-gauze bell-jar. For the rest, I cherish no particular plans. I incarcerate her from mere habit, the habit of the observer always on the look-out for what may happen.

It was a lucky thought. At nine o'clock in the evening, just as the household is going to bed, there is a great stir in the room next to mine. Little Paul, half-undressed, is rushing about, jumping and stamping, knocking the chairs over like a mad thing. I hear him call me:

„Come quick!“ he screams. „Come and see these Moths, big as birds! The room is full of them!“

I hurry in. There is enough to justify the child's enthusiastic and hyperbolical exclamations, an invasion as yet unprecedented in our house, a raid of giant Moths. Four are already caught and lodged in a bird-cage. Others, more numerous, are fluttering on the ceiling.

At this sight, the prisoner of the morning is recalled to my mind.

„Put on your things, laddie,“ I say to my son. „Leave your cage and come with me. We shall see something interesting.“

We run downstairs to go to my study, which occupies the right wing of the house. In the kitchen I find the servant, who is also bewildered by what is happening and stands flicking her apron at great Moths whom she took at first for Bats.

The Great Peacock, it would seem, has taken possession of pretty well every part of the house. What will it be around my prisoner, the cause of this incursion? Luckily, one of the two windows of the study had been left open. The approach is not blocked.

We enter the room, candle in hand. What we see is unforgetable. With a soft flick-flack the great Moths fly around the bell-jar, alight, set off again, come back, fly up to the ceiling and down. They rush at the candle, putting it out with a stroke of their wings; they descend on our shoulders, clinging to our clothes, grazing our faces. The scene suggests a wizard's cave, with its whirl of Bats. Little Paul holds my hand tighter than usual, to keep up his courage.

How many of them are there? About a score. Add to these the number that have strayed into the kitchen, the nursery and the other rooms of the house; and the total of those who have arrived from the outside cannot fall far short of forty. As I said, it was a memorable evening, this Great Peacock evening. Coming from every direction and apprised I know not how, here are forty lovers eager to pay their respects to the marriageable bride born that morning amid the mysteries of my study.

For the moment let us disturb the swarm of wooers no further. The flame of the candle is a danger to the visitors, who fling themselves into it madly and singe their wings. We will

resume the observation tomorrow with an experimental interrogatory thought out beforehand.

But first let us clear the ground and speak of what happens every night during the week that my observation lasts. Each time it is pitch dark, between eight and ten o'clock, when the Moths arrive one by one. It is stormy weather, the sky is very much overcast and the darkness is so profound that even in the open air, in the garden, far from the shadow of the trees, it is hardly possible to see one's hand before one's face.

In addition to this darkness there is the difficulty of access. The house is hidden by tall plane-trees; it is approached by a walk thickly bordered with lilac- and rose-trees, forming a sort of outer vestibule; it is protected against the mistral by clumps of pines and screens of cypresses. Clusters of bushy shrubs make a rampart a few steps away from the door. It is through this tangle of branches, in complete darkness, that the Great Peacock has to tack about to reach the object of his pilgrimage.

Under such conditions, the Brown Owl would not dare leave the hole in his olive-tree. The Moth, better-endowed with his faceted optical organs than the night-bird with its great eyes, goes forward without hesitating and passes through without knocking against things. He directs his tortuous flight so skilfully that, despite the obstacles overcome, he arrives in a state of perfect freshness, with his big wings intact, with not a scratch upon him. The darkness is light enough for him.

Even if we grant that it perceives certain rays unknown to common retin?, this extraordinary power of sight cannot be what warns the Moth from afar and brings him hurrying to the spot. The distance and the screens interposed make this quite impossible.

Besides, apart from deceptive refractions, of which there is no question in this case, the indications provided by light are so precise that we go straight to the thing seen. Now the Moth sometimes blunders, not as to the general direction which he is to take, but as to the exact spot where the interesting events are happening. I have said that the children's nursery, which is at the side of the house opposite my study, the real goal of my visitors at the present moment, was occupied by the Moths before I went there with a light in my hand. These certainly were ill-informed. There was the same throng of hesitating visitors in the kitchen; but here the light of a lamp, that irresistible lure to nocturnal insects, may have beguiled the eager ones.

Let us consider only the places that were in the dark. In these there are several stray Moths. I find them more or less everywhere around the actual spot aimed at. For instance, when the captive is in my study, the visitors do not all enter by the open window, the safe and direct road, only two or three yards away from the caged prisoner. Several of them come in downstairs, wander about the hall and at most reach the staircase, a blind alley barred at the top by a closed door.

These data tell us that the guests at this nuptial feast do not make straight for their object, as they would if they derived their information from some kind of luminous radiation, whether known or unknown to our physical science. It is something else that apprises them from afar, leads them to the proximity of the exact spot and then leaves the final discovery to the airy uncertainty of random searching. It is very much like the way in which we ourselves are informed by hearing and smell, guides which are far from accurate when we want to decide the precise point of origin of the sound or the smell.

What are the organs of information that direct the rutting Moth on his nightly pilgrimage? One suspects the antennae, which, in the males, do in fact seem to be questioning space with their spreading tufts of feathers. Are those glorious plumes mere ornaments, or do they at the same time play a part in the perception of the effluvia that guide the enamoured swain? A conclusive experiment seems to present no difficulty. Let us try it.

On the day after the invasion, I find in the study eight of my visitors of the day before. They are perched motionless on the transoms of the second window, which is kept closed. The others, when their dance was over, about ten o'clock in the evening, went out as they came in, that is to say, through the first window, which is left open day and night. Those eight persevering ones are just what I want for my schemes.

With a sharp pair of scissors, without otherwise touching the Moths, I cut off their antennae, near the base. The patients take hardly any notice of the operation. Not one moves; there is scarcely a flutter of the wings. These are excellent conditions: the wound does not seem at all serious. Undistraught by pain, the Moths bereft of their horns will adapt themselves all the better to my plans. The rest of the day is spent in placid immobility on the cross-bars of the window.

There are still a few arrangements to be made. It is important in particular to shift the scene of operations and not to leave the female before the eyes of the maimed ones at the moment when they resume their nocturnal flight, else the merit of their quest would disappear. I therefore move the bell-jar with its captives and place it under a porch at the other end of the house, some fifty yards from my study.

When night comes, I go to make a last inspection of my eight victims. Six have flown out through the open window; two remain behind, but these have dropped to the floor and no longer have the strength to turn over if I lay them on their backs. They are exhausted, dying. Pray do not blame my surgical work. This quick decreptitude occurs invariably, even without the intervention of my scissors.

Six, in better condition, have gone oft. Will they return to the bait that attracted them yesterday? Though deprived of their antennae, will they be able to find the cage, now put in another place, at a considerable distance from its original position?

The cage is standing in the dark, almost in the open air. From time to time, I go out with a lantern and a Butterfly-net. Each visitor is captured, examined, catalogued and forthwith

let loose in an adjoining room, of which I close the door. This gradual elimination will enable me to tell the exact number, with no risk of counting the same Moth more than once. Moreover, the temporary gaol, which is spacious and bare, will in no way endanger the prisoners, who will find a quiet retreat there and plenty of room. I shall take similar precautions during my subsequent investigations.

At half past ten no more arrive. The sitting is over. In all, twenty-five males have been caught, of whom only one was without antennae. Therefore, of the six on whom I operated yesterday and who were hale enough to leave my study and go back to the fields, one alone has returned to the bell-jar. It is a poor result, on which I dare not rely when it comes to asserting or denying that the antennae play a guiding part. We must begin all over again, on a larger scale.

Next morning I pay a visit to the prisoners of the day before. What I see is not encouraging. Many are spread out on the floor, almost lifeless. Several of them give hardly a sign of life when I take them in my fingers. What can I hope from these cripples? Still, let us try. Perhaps they will recover their vigour when the time comes to dance the lovers' round.

The twenty-four new ones undergo amputation of the antennae. The old, hornless one is left out of count, as dying or close to it. Lastly, the prison-door is left open for the remainder of the day. He who will may leave the room, he who can shall join in the evening festival. In order to put such as go out to the test of searching for the bride, the cage, which they would be sure to notice on the threshold, is once more removed. I shift it to a room in the opposite wing, on the ground-floor. The access to this room is of course left free.

Of the twenty-four deprived of their antennae, only sixteen go outside. Eight remain, powerless to move. They will soon die where they are. Out of the sixteen who have left, how many are there that return to the cage in the evening? Not one! I sit up to capture just seven, all newcomers, all sporting feathers. This result would seem to show that the amputation of the antennae is a rather serious matter. Let us not draw conclusions yet: a doubt remains and an important one.

„A nice state I'm in!“ said Mouflard, the Bull-pup, when his pitiless breeder had docked his ears. „How dare I show my face before the other Dogs?“

Can it be that my Moths entertain Master Mouflard's ap prehensions? Once deprived of their fine plumes, dare they no longer appear amidst their rivals and a-wooing go? Is it bashfulness on their part or lack of guidance? Or might it not rather be exhaustion after a wait that exceeds the duration of an ephemeral flame? Experiment shall tell us.

On the fourth evening, I take fourteen Moths, all new ones, and imprison them, as they arrive, in a room where I intend them to pass the night. Next morning, taking advantage of their daytime immobility, I remove a little of the fur from the centre of their corselet. The

silky fleece comes off so easily that this slight tonsure does not inconvenience the insects at all; it deprives them of no organ which may be necessary to them later, when the time comes to find the cage. It means nothing to the shorn ones; to me it means the unmistakable sign that the callers have repeated their visit.

This time there are no weaklings incapable of flight. At night the fourteen shaven Moths escape into the open. Of course the place of the cage is once more changed. In two hours, I capture twenty Moths, including two tonsured ones, no more. Of those who lost their antennae two days ago, not one puts in an appearance. Their nuptial time is over for good and all.

Only two return out of the fourteen marked with a bald patch. Why do the twelve others hang back, although supplied with what we have assumed to be their guides, their antennary plumes? Why again that formidable list of defaulters, which we find nearly always after a night of sequestration? I perceive but one reply the Great Peacock is quickly worn out by the ardours of pairing-time.

With a view to his wedding, the one and only object of his life, the Moth is gifted with a wonderful prerogative. He is able to discover the object of his desire in spite of distance, obstacles and darkness. For two or three evenings, he is allowed a few hours wherein to indulge his search and his amorous exploits. If he cannot avail himself of them, all is over: the most exact of compasses fails, the brightest of lamps expires. What is the use of living after that? Stoically we withdraw into a corner and sleep our last sleep, which is the end of our illusions and of our woes alike.

The Great Peacock becomes a Moth only in order to perpetuate his species. He knows nothing of eating. While so many others, jolly companions one and all, flit from flower to flower, unrolling the spiral of their proboscis and dipping it into the honeyed cups, he, the incomparable faster, wholly freed from the bondage of the belly, has no thought of refreshment. His mouth-parts are mere rudiments, vain simulacra, not real organs capable of performing their functions. Not a sup enters his stomach: a glorious privilege, save that it involves a brief existence. The lamp needs its drop of oil, if it is not to be extinguished. The Great Peacock renounces that drop, but at the same time he renounces long life. Two or three evenings, just time enough to allow the couple to meet, and that is all: the big Moth has lived.

Then what is the meaning of the staying away of those who have lost their antennae?

Does it show that the absence of these organs has made them incapable of finding the wire bell in which the prisoner awaits them? Not at all. Like the shorn ones, whose operation has left them uninjured, they prove only that their time is up. Whether maimed or intact, they are unfit for duty because of their age; and their non-return is valueless as evidence. For lack of the time necessary for experimenting, the part played by the antennae escapes us. Doubtful it was and doubtful it remains.

My caged prisoner lives for eight days. Every evening she draws for my benefit a swarm of visitors, in varying numbers, now to one part of the house, now to another, as I please. I catch them, as they come, with the net and transfer them, the moment they are captured, to a closed room, in which they spend the night. Next morning, I mark them with a tonsure on the thorax.

The aggregate of the visitors during those eight evenings amounts to a hundred and fifty, an astounding number when I consider how hard I had to seek during the following two years to collect the materials necessary for continuing these observations. Though not impossible to find in my near neighbourhood, the cocoons of the Great Peacock are at least very rare, for old almond-trees, on which the caterpillars live, are scarce in these parts. For two winters I visited every one of those decayed trees at the lower part of the trunk, under the tangle of hard grasses in which they are clad, and time after time I returned empty-handed. Therefore my hundred and fifty Moths came from afar, from very far, within a radius of perhaps a mile and a half or more. How did they know of what was happening in my study?

The perceptive faculties can receive information from a distance by means of three agents: light, sound and smell. Is it permissible to speak of vision in this instance? I will readily admit that sight guides the visitors once they have passed through the open window. But before that, in the mystery out of doors! It would not be enough to grant them the fabulous eye of the Lynx, which was supposed to see through walls; we should have to admit a keenness of sight which could be exercised miles away. It is useless to discuss anything so outrageous; let us pass on.

Sound is likewise out of the question. The great fat Moth, capable of sending a summons to such a distance, is mute even to the most acute hearing. It is just possible that she possesses delicate vibrations, passionate quivers, which might perhaps be perceptible with the aid of an extremely sensitive microphone; but remember that the visitors have to be informed at considerable distances, thousands of yards away. Under these conditions, we cannot waste time thinking of acoustics. That would be to set silence the task of waking the surrounding air.

There remains the sense of smell. In the domain of our senses, scent, better than anything else, would more or less explain the onrush of the Moths, even though they do not find the bait that allures them until after a certain amount of hesitation. Are there, in point of fact, effluvia similar to what we call odour, effluvia of extreme subtlety, absolutely imperceptible to ourselves and yet capable of impressing a sense of smell better-endowed than ours? There is a very simple experiment to be made. It is a question of masking those effluvia, of stifling them under a powerful and persistent odour, which masters the olfactory sense entirely. The too-strong scent will neutralize the very faint one.

I begin by sprinkling naphthaline in the room where the males will be received this evening. Also, in the bell-jar, beside the female, I lay a big capsule full of the same stuff. When the visiting-hour comes, I have only to stand in the doorway of the room to get a

distinct smell of gas-works. My artifice fails. The Moths arrive as usual, they enter the room, pass through its tarry atmosphere and make for the cage with as much certainty of direction as though in unscented surroundings.

My confidence in the olfactory explanation is shaken. Besides, I am now unable to go on. Worn out by her sterile wait, my prisoner dies on the ninth day, after laying her unfertilized eggs on the wirework of the cage. In the absence of a subject of experiment, there is no more to be done until next year.

This time I shall take my precautions, I shall lay in a stock so as to be able to repeat as often as I wish the experiments which I have already tried and those which I am contemplating. To work, then; and that without delay.

In the summer, I proclaim myself a buyer of caterpillars at a sou apiece. The offer appeals to some urchins in the neighbourhood, my usual purveyors. On Thursdays, emancipated from the horrors of parsing, is the weekly holiday in French schools.--Translator's Note. they scour the fields, find the fat caterpillar from time to time and bring him to me clinging to the end of a stick. They dare not touch him, poor mites; they are staggered at my audacity when I take him in my fingers as they might take the familiar Silk-worm.

Reared on almond-tree branches, my menagerie in a few days supplies me with magnificent cocoons. In the winter, assiduous searches at the foot of the fostering tree complete my collection. Friends interested in my enquiries come to my assistance. In short, by dint of trouble, much running about, commercial bargains and not a few scratches from brambles, I am the possessor of an assortment of cocoons, of which twelve, bulkier and heavier than the others, tell me that they belong to females.

A disappointment awaits me, for May arrives, a fickle month which brings to naught my preparations, the cause of so much anxiety. We have winter back again. The mistral howls, tears the budding leaves from the plane-trees and strews the ground with them. It is as cold as in December. We have to light the fires again at night and resume the thick clothes which we were beginning to leave off.

My Moths are sorely tried. They hatch late and are torpid. Around my wire cages, in which the females wait, one to-day, another to-morrow, according to the order of their birth, few males or none come from the outside. And yet there are some close at hand, for the plumed gallants resulting from my harvest were placed out in the garden as soon as they were hatched and recognized. Whether near neighbours or strangers from afar, very few arrive; and these are only halfhearted. They enter for a moment, then disappear and do not return. The lovers have grown cold.

It is also possible that the low temperature is unfavourable to the tell-tale effluvia, which might well be enhanced by the warmth and decreased by the cold, as happens with scents. My year is lost. Oh, what laborious work is this experimenting at the mercy of the sudden changes and deceptions of a short season!

I begin all over again, for the third time. I rear caterpillars, I scour the country in search of cocoons. When May returns, I am suitably provided. The weather is fine and responds to my hopes. I once more see the incursions which had struck me so powerfully at the beginning, at the time of the historic invasion which first led to my researches.

Nightly the visitors turn up, in squads of twelve, twenty or more. The female, a lusty, big-bellied matron, clinging firmly to the trellis-work of the cage. She makes no movement, gives not so much as a flutter of the wings, seems indifferent to what is going on. Nor is there any odour, so far as the most sensitive nostrils in the household can judge, nor any rustle perceptible to the most delicate hearing among my family, all of whom are called in to bear evidence. In motionless contemplation she waits.

The others, in twos or threes or more, flop down upon the dome of the cage, run about it briskly in every direction, lash it with the tips of their wings in continual movement. There are no affrays between rivals. With not a sign of jealousy in regard to the other suitors, each does his utmost to enter the enclosure. Tiring of their vain attempts, they fly away and join the whirling throng of dancers. Some, giving up all hope, escape through the open window; fresh arrivals take their places; and, on the top of the cage, until ten o'clock in the evening, attempts to approach are incessantly renewed, soon to be abandoned and as soon resumed.

Every evening the cage is moved to a different place. I put it on the north side and the south, on the ground-floor and the first floor, in the right wing and fifty yards away in the left, in the open air or hidden in a distant room. All these sudden displacements, contrived if possible to put the seekers off the scent, do not trouble the Moths in the least. I waste my time and ingenuity in trying to deceive them.

Recollection of places plays no part here. Yesterday, for instance, the female was installed in a certain room. The feathered males came fluttering thither for a couple of hours; several even spent the night there. Next day, at sunset, when I move the cage, all are out of doors. Ephemeral though they be, the newest comers are ready to repeat their nocturnal expeditions a second time and a third. Where will they go first, these veterans of a day?

They know all about the meeting-place of yesterday. One is inclined to think that they will go back to it, guided by memory, and that, finding nothing left, they will proceed elsewhither to continue their investigations. But no: contrary to my expectations, they do nothing of the sort. Not one reappears in the place which was so thickly crowded last night; not one pays even a short visit. The room is recognized as deserted, without the preliminary enquiry which recollection would seem to demand. A more positive guide than memory summons them elsewhere.

Until now the female has been left exposed, under the meshes of a wire gauze. The visitors, whose eyes are used to piercing the blackest gloom, can see her by the vague

light of what to us is darkness. What will happen if I imprison her under an opaque cover? According to its nature, will not this cover either set free or arrest the tell-tale effluvia?

Physical science is to-day preparing to give us wireless telegraphy, by means of the Hertzian waves. Can the Great Peacock have anticipated our efforts in this direction? In order to set the surrounding air in motion and to inform pretenders miles away, can the newly-hatched bride have at her disposal electric or magnetic waves, which one sort of screen would arrest and another let through? In a word, does she, in her own manner, employ a kind of wireless telegraphy? I see nothing impossible in this: insects are accustomed to invent things quite as wonderful.

I therefore lodge the female in boxes of various characters. Some are made of tin, some of cardboard, some of wood. All are hermetically closed, are even sealed with stout putty. I also use a glass bell-jar standing on the insulating support of a pane of glass.

Well, under these conditions of strict closing, never a male arrives, not one, however favourable the mildness and quiet of the evening. No matter its nature, whether of metal or glass, of wood or cardboard, the closed receptacle forms an insuperable obstacle to the effluvia that betray the captive's whereabouts.

A layer of cotton two fingers thick gives the same result. I place the female in a large jar, tying a sheet of wadding over the mouth by way of a lid. This is enough to keep the neighbourhood in ignorance of the secrets of my laboratory. No male puts in an appearance.

On the other hand, make use of ill-closed, cracked boxes, or even hide them in a drawer, in a cupboard; and, notwithstanding this added mystery, the Moths will arrive in numbers as great as when they come thronging to the trellised cage standing in full view on a table. I have retained a vivid recollection of an evening when the recluse was waiting in a hat-box at the bottom of a closed wall-cupboard. The Moths arrived, went to the door, struck it with their wings, knocked at it to express their wish to enter. Passing wayfarers, coming no one knows whence across the fields, they well knew what was inside there, behind those boards.

We must therefore reject the idea of any means of information similar to that of wire-less telegraphy, for the first screen set up, whether a good conductor or a bad, stops the female's signals completely. To give these a free passage and carry them to a distance, one condition is indispensable: the receptacle in which the female is contained must be imperfectly closed, so as to establish a communication between the inner and the outer air. This brings us back to the probability of an odour, though that was contradicted by my experiment with naphthaline.

My stock of cocoons is exhausted and the problem is still obscure. Shall I try again another year, the fourth? I abandon the thought for the following reasons: Moths that mate at night are difficult to observe if I want to watch their intimate actions. The gallant

certainly needs no illuminant to attain his ends; but my feeble human powers of vision cannot dispense with one at night. I must have at least a candle, which is often extinguished by the whirling swarm. A lantern saves us from these sudden eclipses; but its dim light, streaked with broad shadows, does not suit a conscientious observer like myself, who wants to see and to see clearly.

Nor is this all. The light of a lamp diverts the Moths from their object, distracts them from their business and, if persistent, gravely compromises the success of the evening. The visitors no sooner enter the room than they make a wild rush for the flame, singe their fluff in it and thenceforth, frightened by the scorching received, cease to be trustworthy witnesses. When they are not burnt, when they are kept at a distance by a glass chimney, they perch as close as they can to the light and there stay, hypnotized.

One evening, the female was in the dining-room, on a table facing the open window. A lighted paraffin-lamp, with a large white-enamel shade, was hanging from the ceiling. Two of the arrivals alighted on the dome of the cage and fussed around the prisoner; seven others, after greeting her as they passed, made for the lamp, circled about it a little and then, fascinated by the radiant glory of the opal cone, perched on it, motionless, under the shade. Already the children's hands were raised to seize them.

„Don't," I said. „Leave them alone. Let us be hospitable and not disturb these pilgrims to the tabernacle of light."

All that evening, not one of the seven budged. Next morning, they were still there. The intoxication of light had made them forget the intoxication of love.

With creatures so madly enamoured of the radiant flame, precise and prolonged experiment becomes unfeasible the moment the observer requires an artificial illuminant. I give up the Great Peacock and his nocturnal nuptials. I want a Moth with different habits, equally skilled in keeping conjugal appointments, but performing in the day-time.

Before continuing with a subject that fulfils these conditions, let us drop chronological order for a moment and say a few words about a late-comer who arrived after I had completed my enquiries, I mean the Lesser Peacock (Attacus pavonia minor, LIN.). Somebody brought me, I don't know where from, a magnificent cocoon loosely wrapped in an ample white-silk envelope. Out of this covering, with its thick, irregular folds, it was easy to extract a case similar in shape to the Great Peacock's, but a good deal smaller. The fore-end, worked into the fashion of an eel-trap by means of free and converging fibres, which prevent access to the dwelling while permitting egress without a breach of the walls, indicated a kinswoman of the big nocturnal Moth; the silk bore the spinner's mark.

And, in point of fact, towards the end of March, on the morning of Palm Sunday, the cocoon with the eel-trap formation provides me with a female of the Lesser Peacock, whom I at once seclude under a wire-gauze bell in my study. I open the window to allow

the event to be made known all over the district; I want the visitors, if any come, to find free entrance. The captive grips the wires and does not move for a week.

A gorgeous creature is my prisoner, in her brown velvet streaked with wavy lines. She has white fur around her neck; a speck of carmine at the tip of the upper wings; and four large, eye-shaped spots, in which black, white, red and yellow-ochre are grouped in concentric crescents. The dress is very like that of the Great Peacock, but less dark in colouring. I have seen this Moth, so remarkable for size and costume, three or four times in my life. It was only the other day that I first saw the cocoon. The male I have never seen. I only know that, according to the books, he is half the size of the female and of a brighter and more florid colour, with orange-yellow on the lower wings.

Will he come, the unknown spark, the plume-wearer on whom I have never set eyes, so rare does he appear to be in my part of the country? In his distant hedges will he receive news of the bride that awaits him on my study table? I venture to feel sure of it; and I am right. Here he comes, even sooner than I expected.

On the stroke of noon, as we were sitting down to table, little Paul who is late owing to his eager interest in what is likely to happen, suddenly runs up to us, his cheeks aglow. In his fingers flutters a pretty Moth, a Moth caught that moment hovering in front of my study. Paul shows me his prize; his eyes ask an unspoken question.

„Hullo!“ I say. „This is the very pilgrim we were expecting. Let's fold up our napkins and go and see what's happening. We can dine later.“

Dinner is forgotten in the presence of the wonders that are taking place. With inconceivable punctuality, the plume-wearers hasten to answer the captive's magic call. They arrive one by one, with a tortuous flight. All of them come from the north. This detail has its significance. As a matter of fact, during the past week we have experienced a fierce return of winter. The north wind has been blowing a gale, killing the imprudent almond-blossoms. It was one of those ferociouus storms which, as a rule, usher in the spring in our part of the world. To day the temperature has suddenly grown milder, but the wind is still blowing from the north.

Now at this first visit all the Moths hurrying to the prisoner enter the enclosure from the north; they follow the movement of the air; not one beats against it. If their compass were a sense of smell similar to our own, if they were guided by odoriferous particles dissolved in the air, they ought to arrive from the opposite direction. If they came from the south, we might believe them to be informed by effluvia carried by the wind; coming as they do from the north, through the mistral, that mighty sweeper of the atmosphere, how can we suppose them to have perceived, at a great distance, what we call a smell? This reflux of scented atoms in a direction contrary to the aerial current seems to me inadmissible.

For a couple of hours, in radiant sunshine, the visitors come and go outside the front of the study. Most of them search for a long while, exploring the wall, flitting along the

ground. To see their hesitation, one would think that they were at a loss to discover the exact place of the bait that attracts them. Though they have come from very far without mistake, they seem uncertain of their bearings once they are on the spot. Nevertheless, sooner or later they enter the room and pay their respects to the captive, without much importunity. At two o'clock all is over. Ten Moths have been here.

All through the week, each time at noonday, when the light is at its brightest, Moths arrive, but in decreasing numbers. The total is nearly forty. I see no reason to repeat experiments which could add nothing to what I already know; and I confine myself to stating two facts. In the first place, the Lesser Peacock is a day insect, that is to say, he celebrates his wedding in the brilliant light of the middle of the day. He needs radiant sunshine. The Great Peacock, on the contrary, whom he so closely resembles in his adult form and in the work which he does as a caterpillar, requires the dusk of the early hours of the night. Let him who can explain this strange contrast of habits.

In the second place, a powerful air-current, sweeping the other way any particles capable of instructing the sense of smell, does not prevent the Moths' arriving from a direction opposite to that of the odoriferous flux, as our physics imagine it.

If I am to go on with my observations, I want a day Moth; not the Lesser Peacock, who made his appearance too late, at a time when I had nothing to ask him, but another, no matter whom, provided that he be quick at discovering nuptial feasts. Shall I find this Moth?

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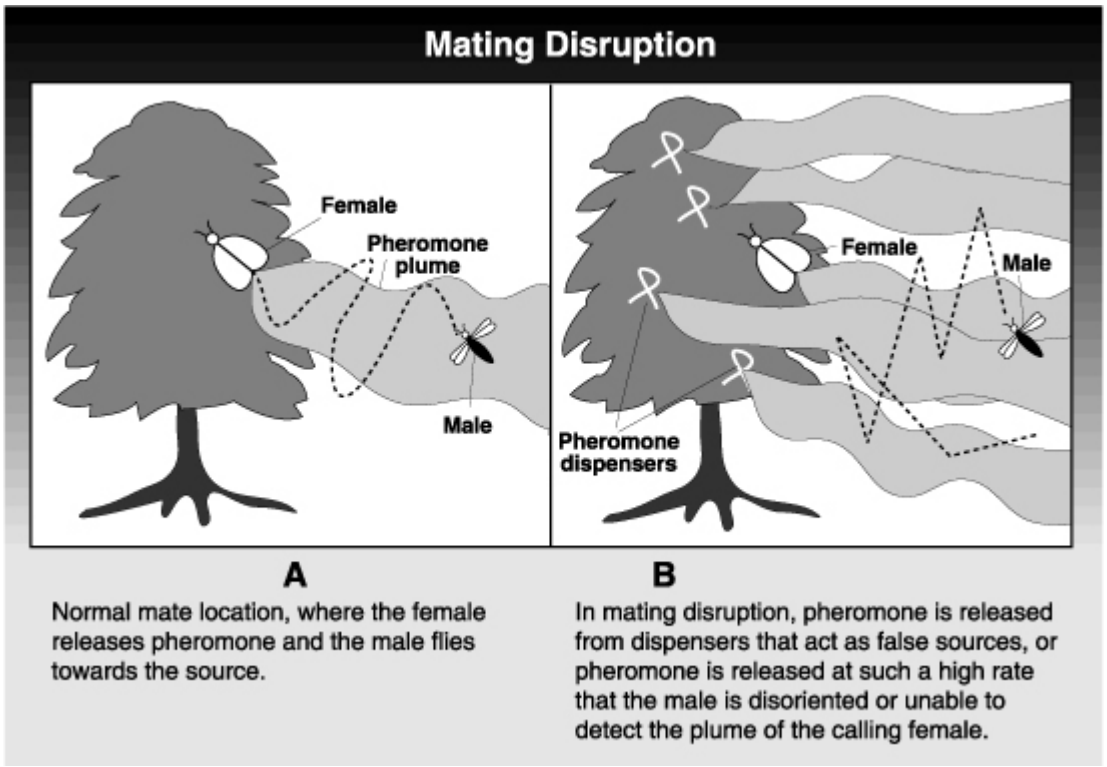
Mating Disruption

by Jay F. Brunner and Alan Knight, originally published 1993

Mating disruption involves the use of sex pheromones to prevent male insects finding females and mating. Pheromones are chemicals produced by an insect to communicate in some way with others of the same species.

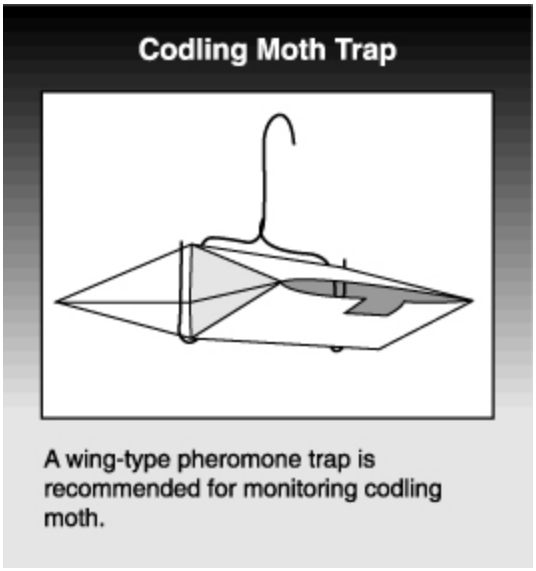
There are several types of pheromones. For example, ants lay a trail pheromone to direct other ants to a food source. Aphids release an alarm pheromone that warns other aphids of potential danger, usually the presence of a predator or parasite. Sex pheromones are chemicals released by female insects to attract males from long distances to mate. A female releasing a pheromone is said to be ”calling” the male. The male flies upwind, crisscrossing the pheromone plume, following the increasing concentration until it finds the source. After mating, the female stops calling.



Pheromones of many different insects have been identified and synthesized. When a small amount of a species’ pheromone is put into a rubber or plastic dispenser and placed in a trap, males of that species are attracted to the trap as they would be to a calling female.

These pheromone traps are used to monitor the activity or even estimate the density of some Lepidoptera that are pests of fruit crops.

The pheromone of most moths has from 2 to 6 components. Different components or different ratios of the same components make them specific attractants for a species. For example, several leafroller species have pheromones with the same components. Specificity results from components being present in different ratios in different species.



A wing-type pheromone trap is recommended for monitoring codling moth.

Other insects, such as campylomma, scales and mealybug, also produce pheromones and may be candidates for mating disruption. After mating, the female stops calling.

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How mating disruption works

There are several ways mating disruption may work. Dispensers in the orchard might mimic a calling female, attracting the male to many false sources, or dispensers might release so much pheromone that the background concentration masks normal communication.

It is important to understand how mating disruption works because different mechanisms can influence how pheromones should be used in the orchard. Four different mechanisms have been proposed to explain how mating disruption works. It is possible that for a pest species more than one of these mechanisms could be operating at the same time to achieve control. The mechanisms are:

Adaptation or habituation

Long-term exposure to a stimulus can affect the sensory organs or nervous system of an insect so it does not function properly. Moths detect pheromones through olfactory receptors on their antennae.

- **Adaptation** occurs when sensory organs are exposed constantly to high and uniform levels of pheromone in the orchard, inhibiting their ability to detect the pheromone. Adapted sensory organs recover rapidly, in 2 to 3 seconds, when they are no longer exposed to the pheromone.
- **Habituation** occurs when high concentrations of a pheromone inhibit the insect's ability to respond for several minutes or even a few hours. The effect is apparently on the nerve that fires in response to high concentrations but does not recover normally. Then, when exposed to a normal amount of pheromone, the nerve does not send the proper signal. Habituation could play an important role in mating disruption by making males less responsive for long periods after exposure to high concentrations of pheromone.

False trails

Unlike habituation or adaptation, this mechanism assumes the male moth can still sense and respond to the pheromone. If numerous sources of pheromone are placed in the orchard, male moths would spend time and energy following pheromone trails to false sources. If there were enough false sources, the chances of a male finding a calling female would be very low. Ideally, the false pheromone sources would be distributed evenly and would all emit about the same amount of pheromone as a calling female.

Most dispensers used in mating disruption release much more pheromone than a calling female. While male moths are no longer attracted to a pheromone source when the concentration gets too high, false-trail following might still be the mechanism at work. The male moths may follow false pheromone trails until they reach concentrations that are too high and no longer attractive.

Masking

This mechanism also assumes the moth's sensory system is working normally. In this case, the background level of the pheromone is high and uniform enough to mask the odor trail from a calling female. The male's normal navigation system for finding a mate is useless in the pheromone fog.

Imbalanced sensory input

The pheromone of most moths has more than one component. Even where the pheromones of different species have the same components, different ratios make them distinctive. If a single component of the pheromone, or an altered ratio of components, is released, males might not be able to detect or find the blend of pheromone released by females. If they continually receive signals that are out of balance with the one their

sensory system is designed to pick up, their mate-seeking behavior might be inhibited. Antipheromones are chemicals that resemble the true pheromone or may have completely different chemical structures. It is possible that some antipheromones compete with the true pheromone for the same receptor sites on the moths' sensory organs. However, some antipheromones that do not chemically resemble the true pheromones may also block mate location.

Pheromone dispensers

The dispensers used to release a pheromone in mating disruption are just as important as using the right chemicals. If the right pheromone is used, but is released too slowly, then the concentration in the atmosphere might be too low to block mate finding. If, on the other hand, the dispenser releases pheromone too fast, control might not last as long as needed.

Isomate CTT dispenser (MIke Doerr)

Several types of dispensers have been used in mating disruption tests. Pheromones have been impregnated in rubber tubing, incorporated in plastic wafers, placed inside hollow fibers and even formulated into sprays.

The most common dispenser systems used in mating disruption on fruit crops incorporate pheromones in plastic tubes, ampules or packets designed to release the product slowly over several weeks. The dispensers are usually placed in the orchard by hand, at a rate of 150 to 400 per acre. Different dispenser systems containing the same pheromone may not provide the same level of pest control. It will take careful research on each type of dispenser system to find out how well they disrupt mating.

Benefits of mating disruption

Improved biological control

The use of mating disruption to control a key pest, such as codling moth, would reduce the use of broad-spectrum insecticides in Pacific Northwest orchards and improve biological control of many other pests.

In 1989, more than a third of all insecticides applied in Washington orchards were aimed at codling moth. Secondary pests, such as aphids, leafhoppers and leafminers, have developed resistance to insecticides used against codling moth so orchardists have also had to apply other insecticides to control those insects. Eliminating the broad-spectrum organophosphates used to control codling moth would allow better survival of natural

enemies of aphids, leafhoppers and leafminers. In many orchards, these secondary pests could eventually be controlled by their natural enemies.

Use of mating disruption over several years could suppress pest populations to very low levels or even lead to local eradication. Under these conditions, controls may be suspended until pest populations increase again. The recovery of the pest population could be monitored with pheromone traps or by inspecting fruit at harvest.

Slower development of pesticide resistance

Pesticide resistance is all too common in agriculture. Mating disruption is an alternative control tactic that could help slow the development of resistance to insecticides. It is important to conserve the usefulness of insecticides at a time when many are being lost in the re-registration process.

Less exposure to pesticides

Exposure of farm workers to insecticide residues during fruit thinning and harvest is another important issue. Pheromones are not toxic to mammals at the levels released in mating disruption programs. Because the chemicals are enclosed in the dispenser packet, workers are not directly exposed to them.

No residues

Because pheromones are not applied directly to the fruit, there are no residues on the crop. The use of mating disruption to control key pests could help reduce the already low levels of insecticide residues on fruit. Consumers who have difficulty understanding the complex issues of food safety would welcome technology that reduces chemical residues on their food.

Factors influencing mating disruption

Size and location of orchard

Mating disruption may not work for every insect that communicates by pheromones nor will it work equally well in every location. The success of mating disruption can be influenced by orchard size and isolation. In small orchards (less than 10 acres) or in larger ones near a source of the pest, mating disruption may not provide reliable control. The pheromone does not kill the pest; thus, mated females can fly into the treated area and lay eggs, producing larvae that will cause damage. For an insect like codling moth, isolation of between 50 and 100 meters (55 to 110 yards) should be adequate. Border sprays may be needed as part of a mating disruption program if a source of the pest is nearby.

Pest levels

Mating disruption alone will normally not be adequate to reduce high pest populations to nondamaging levels. It is primarily intended as a tactic to keep pest populations low. The

first year in which mating disruption is used, insecticidal control may be required to reduce pest populations to levels that can then be maintained by pheromones alone.

Nontarget pests

The highly selective nature of mating disruption has a negative side. Pests that were kept at nondamaging levels by insecticides aimed at the target pest of mating disruption will be released from control. Predators and parasites will keep some of these pests below damaging levels, but others may have to be controlled with insecticides. Thus, the switch to mating disruption as a control for codling moth does not mean that insecticides will not be needed to control other pests.

Monitoring

More intensive monitoring will be needed in a mating disruption program. Because the target of mating disruption is not killed by the treatment, its activity and density in the orchard must be followed to ensure adequate control. Although monitoring has been encouraged in the past, the reliance on insecticides for control meant little was actually done. To take full advantage of mating disruption and the increased potential for biological control of other pests, it will be necessary to monitor populations of pests and their natural enemies.

Cost

The cost of mating disruption will be higher than conventional chemical control, at least in the short term. In 1991, the cost of a mating disruption program for codling moth in apple averaged about 50% more than an average chemical control program. Cost differences between mating disruption and conventional programs could lessen if sprays for secondary pests, such as aphids and leafminers, are eliminated because of better controls. However, if pests that had been controlled by codling moth sprays increase, additional sprays might be needed.

Other factors

Other factors might influence the success of mating disruption, and these need further research. The uniformity of the orchard canopy can affect distribution of the pheromone, leaving areas where control could fail. In orchards on windy sites or steep slopes, the pheromone might not be evenly distributed throughout the orchard or might not be in high enough concentrations to provide control. Weather patterns could also influence the success of mating disruption. Mating disruption in regions with high summer temperatures might require dispensers with different release rates than those in cooler regions.

Mating disruption in the Pacific Northwest

Several characteristics of fruit production in the Northwest make mating disruption appealing and may contribute to its success.

Pest complex

The insect pest complex attacking fruit crops in the Pacific Northwest is smaller than in the eastern United States. The absence of pests such as the apple maggot and plum curculio should make mating disruption for codling moth and leafrollers more feasible because if these pests were present 3 to 5 additional insecticide treatments would be needed. Also, populations of most pests, especially codling moth, are already low in most commercial orchards because of broad-spectrum insecticide use. This means that mating disruption could be implemented immediately without having to reduce pest levels first.

Contiguous plantings

Most orchards in the Pacific Northwest are not isolated units, but contiguous plantings, often of several hundred acres. That, plus the tradition of controlling pests on a regional basis, could work to increase the chances of success of mating disruption.

Lack of alternate hosts

The habitat surrounding most Northwest orchards does not contain alternate host plants for the targets of mating disruption. The chance of pests immigrating from native habitats is thus much lower than in regions where orchards are surrounded by hosts for target pests.

Natural enemies

Without the disruption caused by broad-spectrum insecticides, natural enemies can provide biological control of some pests. This is especially true for the western tentiform leafminer and possibly the apple aphid, white apple leafhopper and grape mealybug. Although more research is needed, there is evidence that orchardists would be able to rely more on biological control where mating disruption is used for codling moth control.

Regulation and registration

The U.S. Environmental Protection Agency (EPA) regulates only certain uses of pheromones. The use of pheromones in traps to monitor insects is not regulated. However, if the intent is to prevent, destroy, repel or otherwise mitigate a pest population, the EPA considers pheromone a pesticide and regulates its use through registration.

The EPA has recognized that pheromones are inherently different from conventional pesticides and supports the concept of mating disruption as an environmentally safe pest control tactic. Pheromones have a unique, nontoxic mode of action, are highly specific, occur naturally, and are used in very low volumes.

The EPA has developed a tiered testing scheme to ensure that the minimum amount of data is needed to register them. Pheromones do not need to undergo further testing if they pass all the first tier data requirements. The EPA has waived the requirement for a tolerance on food crops, as the chances of residues are nil. The EPA has registered pheromone products to control oriental fruit moth, peachtree borer and codling moth, as well as pests on some nonfood crops. It has taken much less time to register these products than to register conventional pesticides.

Mating disruption successes

One of the most successful examples of mating disruption has been on oriental fruit moth. Control of oriental fruit moth with a pheromone has been reported to be as good as or better than with conventional insecticidal control in several orchards in California. The pheromone was registered in 1986 and in 1990 was used on 10,000 acres of peach orchards in Washington and California.

A pheromone product to control codling moth was registered in 1991. Research has produced mixed results, although under the right conditions the product has given good control.