For Love of Nature: Exploration and Discovery at Biological Field Stations

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Contemporary natural history, imbued with renewed spirit and emergent on many fronts, is still essentially an outdoor science dependent on field exploration and discovery. An account is given of personal experiences in nature that led to research pursuits in the laboratory. The urge to explore, it is argued, like the ability to discover, can be developed. Biological field stations provide the ideal setting in which to teach students the art of discovery. Courses designed for that purpose could help train field researchers with a strong personal committment to the preservation of nature. Biologists so committed, by virture of their potential activism, are much needed. (*Accepted for publication 9 Septemer 1981*)

"I do not know what I may appear to the world, but to myself I seem to have been only like a boy, playing on the seashore, and diverting myself, in now and then finding a smoother pebble or a prettier shell than ordinary, while the great ocean of truth lay all undiscovered before me." Sir Isaac Newton

RECOLLECTION OF A DISCOVERY

I do not remember the date, but I will never forget the occasion. It was early autumn in 1971, I believe, and I was spending a few days at one of my favorite hideouts, the Huyck Preserve near Albany, New York. I often go there after completion of my summer's experimental program in search of peace and a chance to explore nature at leisure before onset of the formal academic year at Cornell. The region is indescribably beautiful at that time, with the foliage in the midst of its spectral shift and the weather usually crisp and sunny. I was with Robert Silberglied of Harvard on that day, a close friend and fellow nature enthusiast, strolling about in the field with collecting gear and camera, observing colonies of the wooly alder aphid, *Pociphilus tesselatus*. Our fascination was not so much the aphids themselves, but with the attendant ants that stood guard over the aphids, drinking their honeydew and providing them with protection in return. We knew such "shepherding" behavior to be widespread among ants (Way 1963), but neither of us had spent much time watching it. We poked the ants and noted how they held their ground and attempted to bite whatever instrument we used to provoke them. We saw a more interesting phenomenon: Wasps, which were also attracted to the honeydew, were actively prevented by the ants from feeding on the aphids and forced to restrict their drinking to excess honeydew that had dribbled from the aphids to leaves lower down on the alder plant where there were no guarding ants. While attempting to photograph the aphids at close range, I caught sight of something that I knew full well could not be. Aphids, my own experience had told me, are usually sedentary, and when walking are slow at best. Yet here, clearly apparent in the viewing screen of my camera, was a *running aphid!* A careful second look revealed the actual nature of our find. It was the larva of a green lacewing, a so-called chrysopid larva (Neuroptera: Chrysopidae)—not an aphid at all, but an aphid predator—so similar in appearance to the *Prociphilus* with which it was living that it could easily pass as one of them (Figure 1A).

We spent the evening in our makeshift laboratory in a cottage at the preserve, examining the larva and watching its behavior. We saw that it fed on the *Prociphilus* aphids, which it pierced with its sickle-shaped mandibles and sucked dry, as chrysopid larvae typically do with their aphid prey. And we noted again the extraordinary resemblance of the larva to the aphids, rendered all the more striking at the higher magnification of the microscope. The "woolen" investiture of the larva seemed identical to that of its prey. Work done in collaboration with associates at Cornell had shown the aphid wool to consist of tufts of very fine strands of wax, later identified as a long-chain ketoester (Meinwald et al. 1975). The wool of the larva appeared to be made of the same strands, although they were not rooted, as in the aphids, and seemed to be more irregularly arranged. I knew that there were certain chrysopid larvae, called "trash carriers," that cover their backs with debris (Slocum and Lawrey 1976), and it occurred to me that our larva might be of that type and that it obtained its wool by plucking it from the aphids. A simple experiment confirmed this. I removed the wax from the back of the larva with a brush, and when it was thoroughly denuded, released it again among the aphids. Within minutes it began reloading itself. Using its mandibles as a two-pronged fork, it plucked one tuft of wax after another from the aphids and applied the material to its back (Figure 1B). In less than a half hour it had rebuilt its cover. I was fascinated by what I saw and was hooked on the prospects of working with this insect. Some of my Cornell associates, including Karen Hicks and my wife Maria, joined in the project.

There were intriguing questions to be answered. Does the waxy covering protect the larvae against ants? Do the ants actually mistake the larva for an aphid? Via à vis the "shepherding" ants and their aphid "flock," is the larva a true "wolf in sheep's clothing"? We soon learned that the larvae were not at all rare and even relatively easy to collect once we had learned to tell them apart from the aphids. We maintained some in the laboratory, raised them, and had them identified when the lacewings

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emerged. They turned out to be *Chrysopa slossonae,* known from the adult stage only. The larva had never been described. In its near-perfect disguise it had apparently escaped detection.

Experiments with denuded larvae showed that they give high priority to the reloading procedure. They usually began gathering wax soon after being reintroduced among the aphids and continued doing so until their shield was complete. If starved beforehand and therefore driven by the dual need to reload and feed, they divided their time about equally between both activities.

We spent hours observing larvae in the field and found to our delight that the "wolf in sheep's clothing" analogy really held. The ants seemed truly oblivious to the presence of the larvae. As the latter fed on the aphids, impaling one after the other on the mandibles and sucking them out, they induced little overt reaction in their prey. The ants failed to detect the larvae even when they tread on them and continued drinking honeydew from aphids in the immediate vicinity of the larvae.

Without their shields, the larvae are relatively helpless. We denuded 27 larvae, released them into *Prociphilus* colonies, and followed their fate. All except four were discovered by the ants and removed from the colonies. Individual ants grasped them (Figure 1C) and dropped them to the ground or carried them to the ground by descending along the branches of the plant. The four larvae that escaped detection made their way to unguarded sites of the colonies and proceeded to rebuild their shields.

Larvae that were released in the near vicinity of ants with their shields intact, in such fashion that they were bound to be encountered by the ants, were sometimes bitten, but the wax proved an effective deterent. The ants released their hold, and with their mouthparts heavily contaminated with wax, backed away. As the ants then proceeded to cleanse themselves, the larvae made their escape (Eisner et al. 1978a).

The stunning camouflage of the larvae suggested that they might also be protected against other predators, but we did not test for this. Birds, for example, appear not to feed on *Prociphilus* and might therefore also ignore visual mimics of the aphids. And there are other unanswered questions. We know that the female *Chrysopa* lays its eggs in the close vicinity of *Prociphilus* colonies, but do not know how she locates these. We also know little about how the larvae react to one another. Are they, like so many other chrysopid larvae, cannibalistic? Does their resemblance to aphid prey increase their chances of being cannibalized? As is so often the case, discovery leads to followup, and the followup creates its own need for further exploration and discovery.

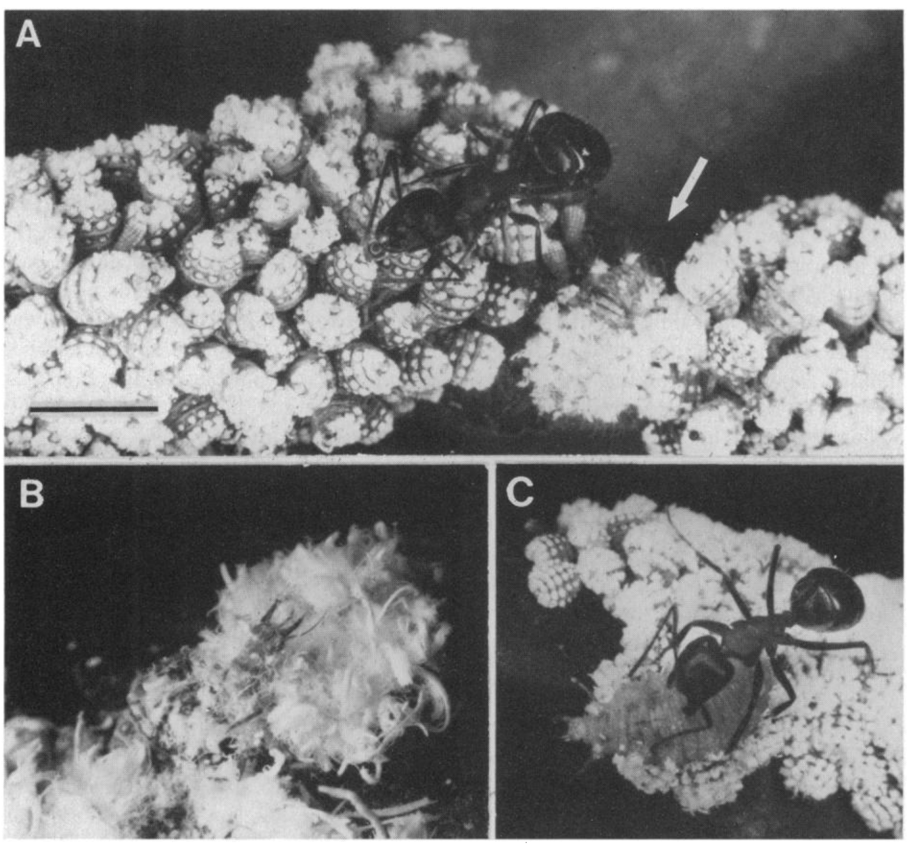

Figure 1. A. Predaceous chrysopid larva (*Chrysopa slossonae,* arrow) among its wooly-aphid prey *(Prociphilus tesselatus).* The shepherding ant *(Camponotus noveboracensis)* is feeding on honeydew from an aphid, seemingly oblivious of the chrysopid larva. **B.** Chrysopid larva in the process of applying "wool" to its back, which it plucked from the aphids. **C.** Artificially denuded chrysopid larva under persistent attack by an ant. Reference bar = 0.5 cm.

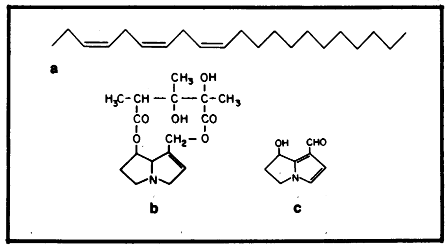

Figure 2. Pheromones and defensive alkaloid from *Utetheisa ornatrix.* **a.** Z,Z,Z-heneicosatriene, the sex attractant produced by the female. **b.** monocrotaline, a pyrrolizidine alkaloid, sequestered by the moth from its larval food plant and stored systemically. **c.** hydroxydanaidone, the sex pheromone of the male, derived from pyrrolizidine alkaloid.

DISCOVERY AND FOLLOWUP

It is often impossible to predict where a given discovery will lead. Another project that is occupying our Cornell group these days and which has proven fruitful in unexpected ways also had its beginning in a casual outdoor observation. I was again doing field work, but this time at the Archbold Biological Station near Lake Placid, Florida, an entirely different, but from a naturalists' point of view, no less fascinating area. My interest at the time was the prey-capture behavior of orb-weaving spiders, and I had just finished filming some of these when I noticed an individual of *Utetheisa ornatrix,* a beautiful brightly colored moth indigenous to the area, fly into one of the webs. Spiders usually attempt to kill captured moths outright, but the *Utetheisa* suffered no such fate. The spider pounced upon the moth and "inspected" it with its legs and palps, but as soon as it did so, it cut the prey loose. Working systematically it severed one after the other the fine threads that were holding the *Utetheisa* until the moth fell free. Before hitting the ground the latter opened its wings and flew away. I observed this behavior with *Nephila clavipes,* but I soon noted, by offering *Utetheisa* to other spiders, that these also reject the moth. I also found *Utetheisa* to be unacceptable to birds. In fact, the tame scrub jays of the Archbold Station, which routinely took other insects that I offered them by hand, refused to peck at *Utetheisa*. These findings were not entirely surprising since there was reason to believe that *Utetheisa* was chemically protected. The moth is aposematic, and its larval foodplants, legumes of the genus *Crotalaria*, contain poisonous pyrrolizidine alkaloids (Figure 2) that the insect might accumulate systemically for protective purposes of its own. However, a defensive role had yet to be demonstrated for such alkaloids. Since the utilization of plant substance by herbivores for defense was a "hot" ecological subject (Gilbert and Raven 1975), I had no difficulty persuading my colleagues to join in a study of the moth.

Our first break came when we succeeded in raising *Utetheisa* on an artificial diet devoid of the alkaloids. We almost felt guilty about what we did with these moths. We offered them to predators and watched what happened. The results were particularly clearcut with the spiders. These attacked and the moths offered no resistence as before, but the spiders killed them and sucked them out, leaving only their undigestible remains (Figure 3A). Additional tests showed the alkaloids themselves to be deterrent. We added these topically to edible morsels that we gave to the spiders and found that the morsels were no longer acceptable. There remained no doubt that the alkaloids were responsible, in part at least, for the invulnerability of *Utetheisa*. What turned out to be unexpected was the finding that the alkaloids also had an indirect pheromonal role. One of my graduate students, William Conner, had turned to a study of the courtship of *Utetheisa*. He first concentrated on the sex attractant pheromone by which the female moth lures the male from downwind—a glandular product, which my chemical associates showed to contain a long-chain unsaturated hydrocarbon (Figure 2a)—and made the interesting incidental discovery that the attractant is emitted in bursts as a pulsed chemical signal (no temporal patterning had ever been demonstrated for an aerial pheromone) (Conner et al. 1980). But he also examined the close-range sexual interaction that takes place when the male locates the female and hovers beside her just before actual copulation. It is then that the male everts a pair of brush-like glandular devices, which he thrusts against the female (Figure 3b), and which upon analysis was found to contain a pheromonal substance derived from the alkaloids (Figure 2c). Males raised on our artificial diet failed to produce the pheromone, and as a consequence, proved much less acceptable to the females. This result led us to suggest that the female might assess the male's defensive fitness on the basis of the pheromone, since the chemical could provide a measure of the male's alkaloid content and of his potentially heritable alkaloid-sequestering ability (Conner et al. 1981, Eisner 1980). In the context of sexual selection, such information could obviously be of value to the female. The finding has also prompted us to look into other behavioral contexts in which prospective mating partners might appraise one another's defensive fitness.

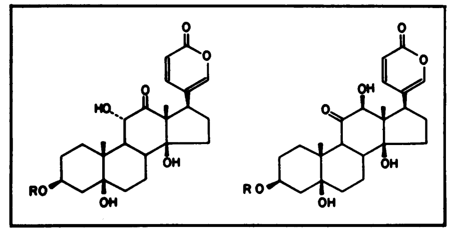

Figure 4. Defensive lucibufagins from fireflies (*Photinus ignitus* and *P. marginellus*); R = H or $COCH_3$.

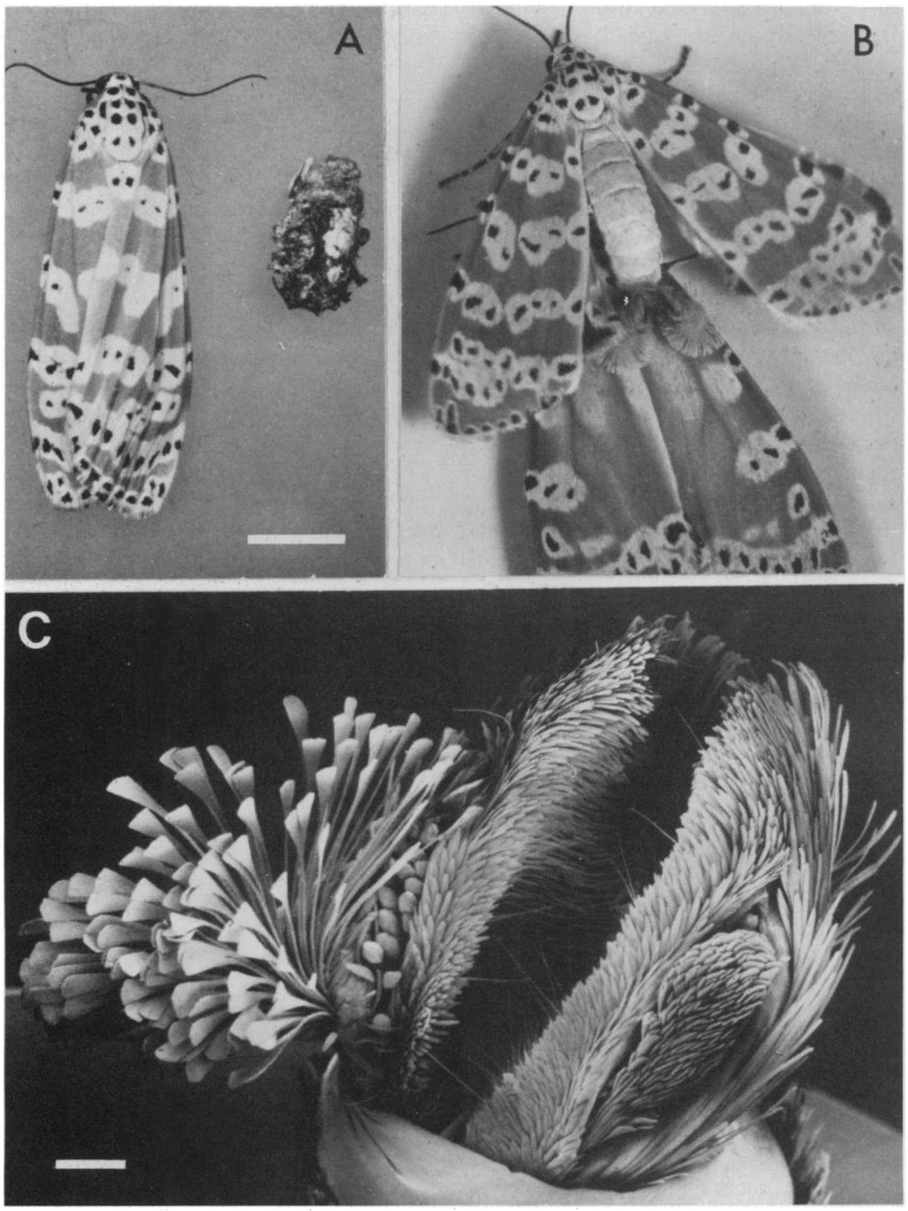

Figure 3. A. Intact *Utetheisa ornatrix* that was raised on its normal pyrrolizidine alkaloid-containing foodplant *(Crotalaria mucronata)* and was rejected by a spider *(Nephila clavipes)* beside remains of another *U. ornatrix* that was raised on an alkaloid-deficient diet and was eaten by *Nephila*. **B.** Male *Utetheisa* courting a female; note the coremata everted from tip of male's abdomen. **C.** Scanning electron micrograph of abdominal tip of male *Utetheisa* (ventral view). The corema on the left is everted, while that on right is in its usual retracted condition. Reference bar: A = 0.5 cm; C = 300 μm.

To someone whose research orientation is unabashedly unapplied (like me), it can be of considerable satisfaction to

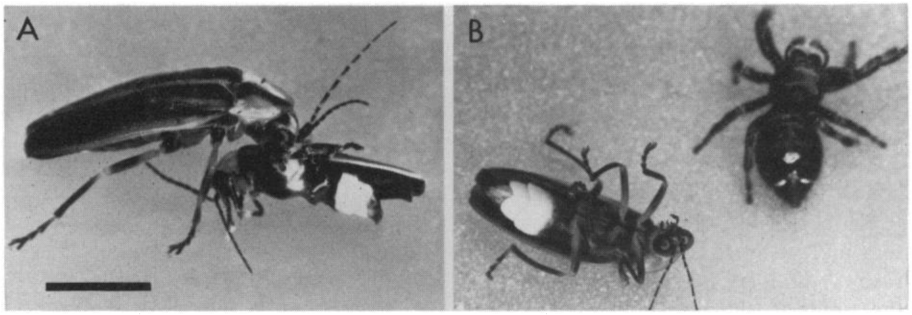

Figure 5. A. *Photuris* "femme fatale" in the process of eating a male *Photinus ignitus.* **B.** Following the meal she is unacceptable to predators by virtue of the lucibufagins that she incorporated from her prey; she is here shown being rejected by a jumping spider *(Phidippus audax).* Reference bar = 0.5 cm.

find that a discovery has unexpected applied implications. We are currently in hopes that certain steroids we discovered in fireflies, and which are apparently cardiotonic to mammals, may turn out to be of biomedical use. We came upon these steroids by following up on an odd observation that I made at the Huyck Preserve. I had a pet thrush named "Phogel" at the time, which I was using in insect palatability tests. Each day I would go out into the field shortly after sunrise to collect about two dozen live insects, which I would then bring back and feed to Phogel at the breakfast table while my wife and I enjoyed our own meal. I presented Phogel with over 500 insects in this fashion, representing over 100 species of 12 orders, and recorded her reaction to each. Among the insects that she liked least were fireflies of the genus *Photinus*. She pecked at these by refused to eat them, and on subsequent occasions, usually ignored them on sight. The logical conclusion was that defensive chemicals were involved, such as had never been identified from fireflies. My long-term collaborator and friend, Jerrold Meinwald, was eager to characterize such compounds. We obtained extracts from fireflies with solvents, tested the extracts for distastefulness in assays with thrushes, and eventually isolated the deterrent steroids, which we called lucibufagins (Figure 4), from active fractions of the extracts (Eisner et al. 1978b, Goetz et al. 1979, Meinwald et al. 1979). There was reason to believe that lucibufagins might be cardiotonic, since they are chemically related to well-known heart drugs such as digitalis. Although such activity was confirmed, we have yet to learn from the drug companies that are testing the lucibufagins whether the compounds are free from side effects and otherwise suitable for therapeutic use.

Not all fireflies produce lucibufagins. Among those that do not are fireflies of the genus *Photuris*. The females of *Photuris* are the so-called firefly "femmes fatales," which are remarkable in one respect. Unlike other female fireflies, which use their light organs to reply to the flash signals of their own males only and lure these for mating, *Photuris* females also answer the "calls" of other males, including *Photinus* males, which they attract and eat. We found that a "femme fatale" derives more than a nutritional benefit from such a meal, for she also sequesters some of the lucibufagins from her prey and incorporates the compounds into her own body. As a result she acquires a level of protectedness that she previously lacked. We found *Photuris* females to feed readily on *Photinus* males in the laboratory (as for that matter on aqueous lucibufagin solution). Whereas prior to such a meal she is acceptable to predators, she is unacceptable thereafter (Figure 5). Female *Photuris* captured in the field have lucibufagin contents ranging from zero to levels commensurate with those in the blood of females that were fed *Photinus* males in the laboratory. At the time of emergence from the pupae, *Photuris* are devoid of lucibufagins.

Passing reference to other fortuitous discoveries could further underscore the extent to which we depend on these in our research. For example, the observation I made during a casual stroll at the Archbold Station that the beetle *Hemisphaerota cyanea* is remarkably difficult to lift from its substate, led to a collaborative study with my engineer friend Daniel Aneshansley of the physics of tarsal adhesion in insects, which is explaining not only how *Hemisphaerota* depends on the mechanism for defense, but also how footholds are generally gained in insect locomotion (Figure 6). Another observation, made at the Mote Marine Laboratory near Sarasota, Florida, where I noted sharks to ignore the large marine "sea hare" *Aplysia brasiliana,* led to the isolation of potent fish antifeedants from this mollusk which, it turns out, the animal derives from its algal food (Dieter et al. 1979, Kinnel et al. 1977, 1979) (Figure 7). Even our current studies on the slime-coagulating mechanism of slugs, which we hope may shed light on the evolution of sclerotiza-

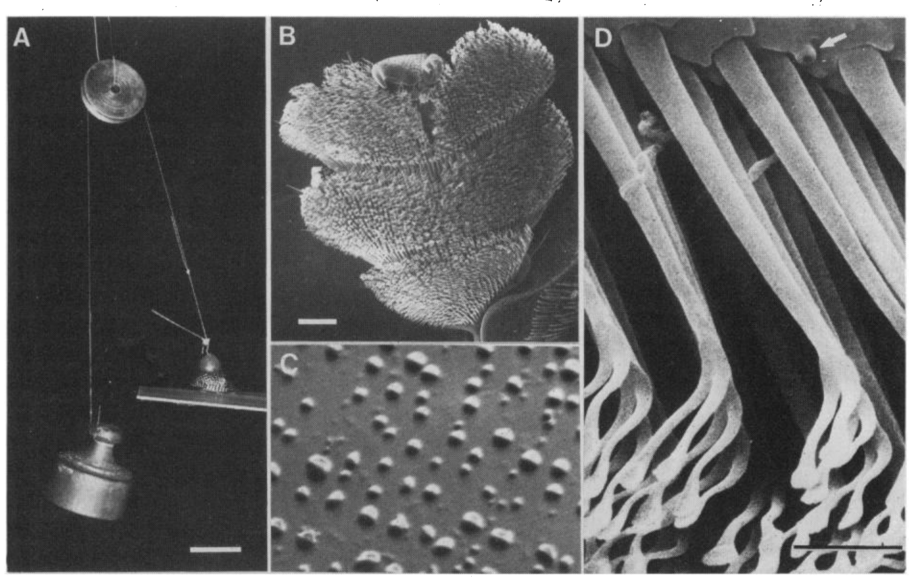

Figure 6. The small southern chrysomelid beetle *Hemisphaerota cyanea* has an uncanny ability to cling to its substrate (palmetto leaves) when disturbed. It is here shown (**A**) withstanding a force of 2 g. The sole of each foot is a mat of thousands of bristles (**B**). Each bristle is distally forked and terminates in a pair of adhesive pads (**D**). The fluid that wets the pads and secures adhesion is an oil, secreted from tiny glandular pores (D, arrow) that open between the bases of the bristles. After the beetle releases its hold and walks away, the former points of contact of the bristles are denoted by tiny oil droplets left behind on the substrate (**C**). The beetle also uses the bristles to secure foot adhesion during ordinary locomotion, but it then commits only a small fraction of the bristles of each foot to contact and as a result "wastes" correspondingly less oil. Reference bars: A = 0.5 cm; B = 100 μm; D = 10 μm.

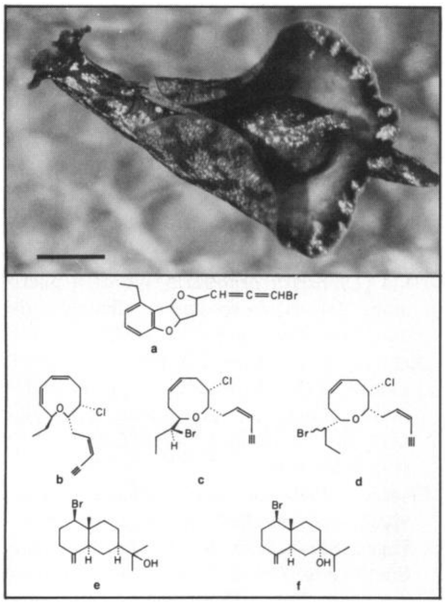

Figure 7. The marine gastropod *Aplysia brasiliana,* one of the so-called sea hares, is a slow and conspicuous swimmer whose potential vulnerability is offset by its distastefulness to fish, including sharks. Several of its chemical antifeedants have been identified and are shown here. They are halogenated isoprene and fatty acid derivatives, apparently sequestered by the animal from its algal diet. **a.** panacene **b.** brasilenyne **c.** *cis*-dihydrorhodophytin **d.** *cis*-isodihydrorhodophytin **e.** brasudol **f.** isobrasudol. Reference bar = 5 cm.

tion mechanisms in invertebrate exoskeletons, had its beginning in an incidental field observation: I saw an ant bite a slug and noted how the bite was instantly "neutralized" by coagulation of the slug's body slime around the mandibles of the ant (Figure 8).

CAN ONE LEARN TO DISCOVER?

Discovery in nature is not purely a matter of chance. An *urge* to discover can increase the frequency of discovery, and the urge, I feel, can be developed. The single prerequisite is a genuine interest in nature, which is almost certainly in all of us unless it has been drummed out of us through our early "education."

From a purely conceptual point of view, students of biology are probably better trained nowadays than ever in the past. Imbued with the fundamentals of the science in their undergraduate years, most have at least some grasp of the major principles by the time they are seniors. There is (as there always has been) some overspecialization—I suppose there will always be zoologists ignorant of botany and molecular biologists who feel that evolution is irrelevant to their discipline—but curricular integration is generally sound today and for those who so wish, there is the chance to acquire a broad overview of biology. But what does the student learn in the laboratory, in that traditional 3-hour session where he is to get a feeling for the actual workings of the living world? Nothing wrong, to be sure, but not enough—and most certainly not enough where the intended teaching is whole-organism related in subjects such as animal behavior, sociobiology, ecology, and evolution, where contemporary advances have been so phenomenal and where the need for the equivalent of a meaningful laboratory experience is so great. The indoor laboratory cannot fulfill this need. Only the actual field experience will do.

Many universities remedy the problem through sponsorship of field courses. These have proved invaluable. Marine and tropical biology courses, summer courses in field ecology, limnology, entomology, and—yes—old fashioned "natural history," have all had a major, if not always tangible effect on the intellectual development of the current crop of biological researchers in the United States. I have no criticsm of these courses, for they are on the whole excellent, but I would like to make the case for an additional dimension in the field experience, which is by necessity not always given its due in the conventional field course. It is an experience that requires a relatively unstructured setting, such as most courses cannot provide. It is what I would like to call the "exploratory experience." It is a sine qua non for the development of the urge, and as a consequence I would argue, of the capacity, to make discoveries in nature.

In our own research group we make it a point to go into the field to try to discover. Much of our day to day activity is tightly structured with experimental programs designed to take existing projects to completion, but we take breaks in the morning, at noon, and at night, when we simply "take off to have a look in nature." One of the reasons we like to do our research at biological field stations is that such walks—which, incidentally, provide the novices among us with the opportunity to gain the "exploratory experience"—can be taken on the spur of the moment into wilderness or semi-wilderness without need to wander far from one's experimental site. It is on such walks that the observational capacity of the individual can be sharpened. We are then all attuned to nature, with our minds focused on the biology we love and with our senses alerted to the occurence of the unexpected or unusual. I have seen the initially "blind" develop a sight for the natural world on such walks, and I have seen improved vision bring forth the urge to discover, and, most memorably, I have been witness to the moment of satisfaction when a student with conceptual notions but no concrete research problem made the discovery that brought his dilemma to an end.

THE ROLE OF THE BIOLOGICAL FIELD STATION

The fundamental reasons for existence of biological field stations are well known. They provide a setting for teaching and research, for short and long-term ecological and behavioral study, and they are often a last enclave of nature preserved in a region of nature "humanized." I would suggest that there is at present underutilization of the potential of such stations for discovery, because too few prospective researchers are brought within their bounds for the spe-

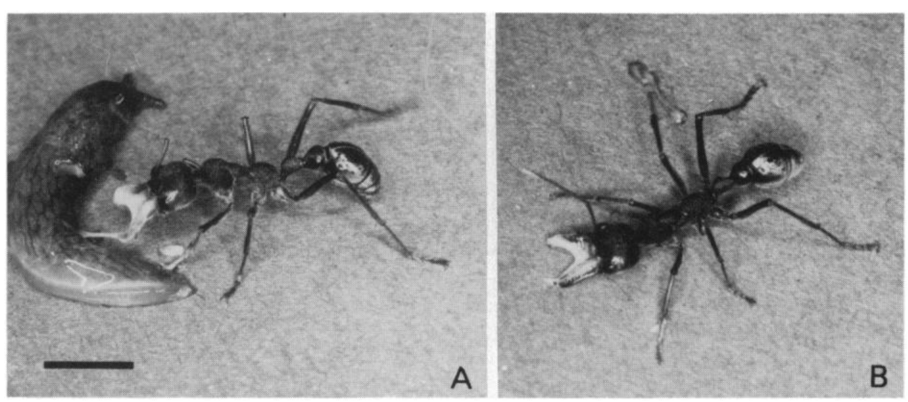

Figure 8. Slugs respond to localized traumatic stimulation by coagulating the body slime at the site affected. An ant is shown here as it backs away from a slug it has just bitten (**A**), and shortly thereafter, as it drags its mouthparts against the substrate (**B**) in an obvious effort to rid itself of the "muzzle" of semi-hardened slime. Photograph of a staged encounter between an Australian bull ant (*Myrmecia* sp.) and an American slug *(Arion subfuscus).* Reference bar = 0.5 cm.

cific purpose of learning the art of discovery. I propose that this art can be learned in field courses designed specifically for the purpose.

Two years ago I was joined by William Connor, Daniel Aneshansley, and another friend, Mel Kreithen, in the teaching of a course at the Archbold Biological Station that we entitled "Exploration, Discovery, and Follow-up." About a dozen graduate students took part, from Cornell, University of Florida, and Wake Forest University, some actually chemists rather than biologists, and Jane Brockman, Marty Crump, Tom Emmel, Pete Feinsinger, and Jim Lloyd came from Gainsville to give guest lectures. The purpose of the course was to expose students to the field, but not so much to aspects already known and previously described by others. The chief intent was to make discoveries, individually or by groups of us as we reconnoitered outdoors, and to gain first hand experience in the evaluation of the research potential of these findings by following up on them with field and laboratory experimentation. To the extent that several studies have already been completed based on that experience and others are in the process of completion by graduate students who have chosen them for their specific research topics, the course was a success. Biological field stations are the perfect setting for such courses, which I would very much like to see taught on an expanded scale.

There is also a subtle additional benefit to be derived from courses of that kind. Students who learn to discover in nature develop a fondness for nature, and almost inevitably in due course, a strong personal commitment to the preservation of nature. In a world increasingly despoiled by man's mindless boosterism and in which the available political alternatives are, in so many ways, no alternatives at all, the potential activism of the biologist so committed is sorely needed.

DEDICATION

This paper is dedicated affectionately to the memory of two close former associates: Robert Silberglied (1946–1982), best of friends and best of naturalists, and Randy Grant (1955–1981), Cornell graduate student of extraordinary potential and participant in "Exploration, Discovery, and Follow-up."

"Everything in nature contains all the powers of nature." Ralph Waldo Emerson

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