Biology Today

The Riches of Biology

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My husband and I are buying a house, a process that has made us acutely aware that we are not rich. But, in preparing for our move, I've been cleaning out my files, and I've come across a wealth of fascinating articles I'd clipped and saved for future use. They involve many aspects of the magnificent world of living things. In this column and the next, I would like to share this wealth, and describe some of the recent findings that have fascinated me. This month I'll focus on plants and animals and next month on human biology.

Sharp Teeth

One thing that makes biology such a rich science is that it includes the study not only of present-day organisms, but those of the past as well. Our contacts with the latter are obviously sketchier and are often confined to a few fossil remnants. Yet biologists make the most of the resources available to them, sometimes using the behavior of extant organisms to provide clues to the behavior of fossil species. For example, while great white sharks and sabre-toothed cats are hardly closely related species, there seem to be similarities in their attack methods (Diamond 1986). Scars on seals that survived attack indicate that great white sharks try to make a single massive bite on the underside of the body, a view corroborated by underwater observations. After the single bite, the shark waits for its prey to go into shock or hemorrhage before closing in for the kill. In this way, it avoids attack by the prey, a distinct possibility when the victim is of another shark species. Sabre-tooth cats seemed to have used a similar strategy. Muscle scars on fossil skulls of this species indicate that when the cat's massive canine teeth had sunk into the skin of its prey, it could rotate its head until the jaws closed. It could then pull out a large fold of flesh, producing a deep wound. It is possible that the cat could pull down a baby mammoth and take a chunk out of its abdomen. This wouldn't kill the mammoth instantly, but the cat could hide from the baby's avenging mother who would abandon her offspring when it died.

Footprints in the Sand

In the case just cited above scientists are trying to discover something about the habits of an extinct species, but they also can use an extinct organism's behavior to understand the terrain of the past. Dinosaur footprints can be used not only to identify the track makers, but to reveal something about the terrain in which the tracks were made (Benton 1986). Some geologists suggest that many dinosaur tracks were made along the margins of bodies of water, and that the tracts can be used to reconstruct the exact position of a shoreline. Footprints within a single track can vary in depth—the shallow prints made on dry land and the deeper ones formed when the dinosaur moved through shallow water. Dinosaur prints formed on dry land can also indicate the slope of the land because "on walking up a sand dune, heaps of sand are pushed back by the heels, and on walking downhill, the toes dig in deeper than normal." Such studies reveal the way scientists mine the traces left by extinct species. They put the riches of the past to good use, often yielding great dividends from the available information.

Trees on the Move

Records of the past also can help to answer such questions as how fast does a forest move? This question doesn't imply that trees are tiptoeing around when no one is looking, but rather that climactic fluctuations over the past two million years have caused dramatic migrations of forests. Pollen residues indicate movement of tree species. Peter Moore (1987b) notes that "studies of the polewards movements of trees since the end of the last glaciation about 10,000 years ago demonstrate that migration rates were surprisingly rapid, often in excess of 300 m per years." Even species with very different modes of dispersal had similar movement rates. Trees that produce heavy fruits, such as oaks, seemed to migrate as fast as pines with their wind-dispersed seeds. Heavy seeds can travel fast when eaten by mobile animals. Migratory species are particularly good vectors. There is some evidence that in North America the now-extinct passenger pigeon was an important vector. "Because the crop of a passenger pigeon could hold up to 30 acorns the possibility of bird death, regurgitation or viable passage was considerable, especially taking into account the vast flocks of these birds which once foraged and migrated over wide areas of North America."

Clean-up Beetles

The passenger pigeon is just one of a host of species that humans have brought to extinction, thus depleting the earth of its biological richness and causing deterioration of the environment. Sometimes this destruction is inadvertent, as is the case with the anti-parasitic drug invermectin which is fed to livestock (Coe 1987). The drug causes changes in the animals' feces, making the dung inhospitable to dung beetles. These may not appear to be very pleasant creatures, but they are important in recycling wastes. There are 14,000 species of dung beetle, with the larvae of most species completing their development in dung. These insects are particularly active in tropical areas. Researchers in Tsavo National Park in Kenya have recorded up to 48,000 beetles visiting a six-and-a-half-pound pile of elephant dung. In two hours, all the soft edible material had been eaten at the site, buried beneath it or rolled up to 220 meters away.

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Such efficient cleanup helps to eliminate breeding sites for flies, while the burrowing activity aids soil aeration. It is thus unfortunate that such valuable organisms are being harmed by a drug which itself is valuable in keeping livestock healthy.

Big Bites

Livestock have been the focus of another study, also done in Kenya. Researchers recorded the food intake pattern of the species in the mixed flocks kept by nomads. In reporting on this work, Peter Moore (1987a) reviews the ways to determine the dietary habits of such herbivores. Analyzing the gut contents of dead animals is one option, but a wasteful one. Another way is through surgery to create a fistula to make it possible to examine the gut contents of live animals, but this is usually impractical in the field. Fecal analysis is often inaccurate since some plants are more thoroughly digested and therefore less recognizable than others. Another alternative which requires time and patience is direct observation, logging the number of bites a particular animal takes from each plant species in a given time. This is hard to do both because the plants must be identified at a distance, and because many grazing animals are fast eaters; sheep, cattle and deer all eat at a rate of about 50 bites per minute, while reindeer can eat at four times that speed.

Though tedious, this last method of diet analysis has yielded information on the grazing behavior of mixed herds in semi-arid areas. The nomadic people who use the grasslands of Nairobi National Park keep several different domesticated grazers to exploit the poor productivity of the area. The cattle consume grass almost exclusively, while camels browse mainly on trees and shrubs. Sheep, goats and donkeys have more mixed diets. Another study showed that there is little overlap between the growing activities of sheep and goats. Even though they both graze on shrubs, they concentrate on different species. There is also temporal diet specialization—sheep and goats switch from herbs to shrubs when the herbs become either scarce or less nutritious. Overall, this specialization of domesticated animals is well adapted to maximize resource use. It is similar to the specialization seen in the natural grazers found in these areas of Africa, which indicates the adaptiveness of such traditional pastoral systems.

Making Waves

A quite different environment that recently has yielded rather surprising information is the intertidal zone (Lewin 1987). Many intertidal communities which are constantly battered by waves are much more productive biologically than rain forests, which are usually considered the lushest of habitats. The key to this productivity is that organisms in intertidal zones exploit the energy of ocean waves. Those kelp communities with the highest standing crops are found in the most wave-beaten areas. Intertidal mussels are also very prolific in these areas.

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There seem to be four mechanisms at work in the harnessing of wave energy by intertidal communities. First, the waves provide protection against predation. Starfish, which feed on mussels, and sea urchins, which eat kelp, cannot function in rough sea conditions. The waves also aid nutrient flow; the moving water increases exchange of nutrients at the surface of sea palm fronds. Wave action keeps the fronds in motion too. This optimizes their use of sunlight. The fronds repeatedly move into and out of the shade thrown by other fronds, and photosynthesis is most efficient under such conditions of rapidly alternating light-dark exposure. Finally, organisms are often dislodged by crashing waves, and this allows other species to colonize the space. Mussels, for example, often move into areas where sea palms have been ripped away. Because of all these factors, the harsh environment created by wave action encourages rather than discourages growth of organisms.

Wet Wanderers

While some organisms use the ocean as a source of energy, others use it as a means of travel. As Jared Diamond (1987) remarks, "Several recent studies make the surprising discovery that overwater dispersal of flightless mammals occurs sufficiently often to measure." He lists the "least implausible" methods by which mammals could cross water: swimming; rafting on floating vegetation; and, at high latitudes, rafting on ice floes or crossing frozen straits in winter. Several kinds of evidence have accumulated to prove that such travel does occur. In a study of 2,175 voles on coastal islands in Finland, 98 were recaptured on other islands, and four had made two interisland trips.

In another study, 60 shrews were captured on islands that had no breeding populations, so these individuals could only have reached these islands by crossing water. One of the females was pregnant, probably having moved to the island after mating elsewhere. Such a case illustrates how a single migrant could found a population. An indication of how often shrews take to the waters between islands is that the stomachs of 2,486 trout yielded 270 shrews. A study of Maine coastal islands revealed that 13 mammal species founded new populations within recent decades. Direct observations were made of deer, moose and otter swimming across straits up to seven miles wide. These studies point up a relationship between the animals' size and distance traveled—larger animals can store more energy, and can thus swim longer distances. But, where very long distances are involved, rafting is a more likely method of dispersal, and here smaller colonists are favored.

Fat Bears

Weight is also a factor in how well bears survive hibernation, or more precisely, their stores of body fat are the key. A black bear can hibernate for up to seven months. It does not eat or drink during this time, but since its body temperature is near normal, it burns 4,000 calories a day. No protein is destroyed, nor are any feces or urine produced. All the energy comes from fat metabolism which produces no nitrogen waste. To prepare for this intensive fat metabolism, black bears feed for up to 20 hours a day in the fall and increase their calorie intake from 5,000 to 8,000 calories up to 20,000 calories. All this chowing down results in a 25 percent increase in body weight.

How bears prevent the production of nitrogen waste might provide clues to how to slow this process in people suffering from kidney failure who cannot remove such wastes from their blood (McDonald 1985). Bears selectively burn only fat. This process produces water as a by-product, but any water that accumulates in the bladder is reabsorbed to help prevent dehy-

dration. The bears also recycle any nitrogen waste and use it to synthesize amino acids. There is some evidence that bears can make the amino acids themselves that other animals must get from their diet. Research is continuing, but it is made difficult by the fact that bears are easily roused during hibernation since their body temperature is close to normal. Also, the research can be done only during the hibernation period. That's why new studies are beginning on polar bears, which can have a protein-sparing metabolism throughout the year. It may seem odd that researchers would travel to the arctic to help kidney patients, but that's one of the joys of biology—all living things are related. The unique adaptations of one species can help us to understand processes in other species.

Whale Sonar

In fact, much of the richness of biology comes from studies of the relationships between organisms, such as that of predator and prey. From a human point of view, this is a rather ugly association. But besides being necessary to the balance of nature, it can also be a quite exquisite and complex form of affiliation, with each species adapting to the behavior of the other. In some situations, however, the degree of adaptation can be overinterpreted. This seems to be the case with whales and squid. Toothed whales can locate their prey, which includes squid, cuttlefish and octopuses, by echolocation. They can also use their sound production apparatus to produce intense bursts of sound to stun their prey. Some have suggested that the deafness of the squid, cuttlefish and octopus, all coleoid cephalopods, may be an adaptation to resist these attacks. But, in fact, deafness might actually be a handicap against these attacks because the animals cannot detect the sound waves that were used to locate them preparatory to the stunning sound. Also, since all modern coleoids are deaf, it is probable that their common ancestor was deaf. This ancestor probably evolved about 100 million years before the first whale-like animals, so deafness can hardly be considered an adaptation to whale predation (Taylor 1986).

Squid elude the whale's echolocation system because they do not reflect sound well. Early cephalopods had air-filled buoyancy chambers that reflect sound strongly, but in squid these have been replaced by a hydrodynamic lift system. But again, this cannot be an adaptation to whale predation; squid existed in their present form long before whales came on the scene. Hydrodynamic control of buoyancy produces less drag than do air-filled chambers, and thus makes it possible for squid to move faster and with less energy expenditure. So, though the hydrodynamic system works to protect squid from wales, it did not evolve for this purpose. Whales, in turn, may have tried to outsmart their prey by lying still at great depths, listening for swimming giant squid. This quietness might also have another purpose—to avoid alerting other whales that might want to share the feast. All this points up the difficulty of determining cause and effect in the relationships between organisms.

"Mity" Lizards

Another example of this problem involves a different type of relationship—between host and parasite. As Michael Benton (1987) notes, "Many lizards are infested by chiggers, the larvae of trombiculid mites, which feed on tissue fluid and cell debris. Surprisingly, lizards seem to go out of their way to attract chiggers—they have special mite pockets that provide a protected, warm and humid site." These structures are usually localized on one part of the body, though the location varies with the species—they may be on the side of the neck, in the armpit or groin area or at the side of the base of the tail. In many cases, the skin lining the pocket has smaller scales than normal and a good blood supply, which allows the parasites to feed more easily. Such pockets are found in more than 150 species, and in five families of lizards. This suggests that the structure have evolved independently many times. But why would so many lizard species create structures that apparently attract chiggers? The answer may be that the pockets are a way for the lizards to localize and limit chigger infestation. Since the skin in the pockets is especially resilient, it recovers rapidly after the chiggers drop out to metamorphose into the adult form.

Wounded Plants

Biology is rich with examples of complex interactions not only involving animals, but plants and microorganisms as well. Some strains of *Agrobacterium* can induce tumors on plants, specifically on dicots. Tumor formation results from the inheritance of DNA (T-DNA) transferred from the bacterium to the plant. This process depends on the function of virulence (*vir*) genes. Tumors only form at the site of a wound, raising the question of how the *vir* genes are regulated so *Agrobacterium* can recognize wounds as being T-DNA transfer. Researchers have recently found that the *vir* genes are induced by specific signal molecules that are produced by wounded plant cells, but not by intact cells. Thus, tumor formation depends on interactions between the two organisms. The authors of this report foresee "a surge of activity in the identification of plant molecules that act as specific inducers of genes in symbiotic and pathogenic microorganisms."

There is always something new to discover about the living world around us. Sometimes this aspect of biology seems daunting—there is so much to learn. But that is also what makes this science so exciting.

Avoiding Incest

Sometimes organisms must avoid relationships that are too close, for example, matings between parents and their offspring or between siblings. A review of field studies of birds and mammals reveals that less than 2 percent of matings are incestuous (Harvey & Ralls 1986). A variety of mechanisms are used to prevent incest. In many species, males and females move different distances from their birthplace before breeding, thus making matings between siblings unlikely. In one bird species, the great tit, the young learn song types typical of those sung at their birthsite, and those with similar songs avoid mating with each other. Female black-tailed prairie dogs, when in groups where the dominant breeding males were relatives, avoided mating with them by mating with unrelated males, by leaving the group to mate elsewhere, by failing to copulate while in estrus, or even by failing to come into estrus. In just this one situation, the richness of responses is amazing!

These examples I have cited of the richness of biology are a miniscule sampling of the treasure trove of research being done today. Like the best of fairy-tale treasure chests, this one is

bottomless; there is always something new to discover about the living world around us. Sometimes this aspect of biology seems daunting—there is so much to learn. But that is also what makes this science so exciting. No matter how bogged down I might get with mortgage applications and paint cans, it's nice to know that there'll always be new biological treasures waiting for me and my students.

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Letters

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visection the opportunity to continue their work in the biological disciplines, and clarify what steps should be taken in the event that instructor and student cannot agree on a satisfactory alternative? Such policies would not guarantee that the values of the student will always prevail; but it would ensure that those values will at least be taken into account.

What is to be gained by denying students who might otherwise be attracted to the study of biology alternative means of satisfying those academic expectations currently associated with laboratory dissection and/or vivisection?

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Research Reviews

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The diversity of animals is illustrated by the diversity of their methods of obtaining food. This month's column reviews papers dealing with some unusual aspects of animal feeding.

Cannibalism

Meefe, G.K. & Crump, M.L. (1987) Possible growth and reproductive benefits of cannibalism in mosquitofish. *The American Naturalist, 129,* 203-212.

Cannibalism has been reported in many groups of animals. Starvation, overcrowding, behavior stress and availability of victims have all been suggested as factors that might lead to cannibalistic behavior in various animals. Meefe and Crump provide evidence that mosquitofish derive nutritional benefits from cannibalism, and thus nutrition is an additional factor in the evolution of cannibalism.

Meefe and Crump fed mosquitofish (*Gambusia affinis*) a diet of commercial fish food supplemented with meal prepared from a crustacean, an unrelated fish, or mosquitofish. Fish fed unsupplemented food served as a control group. The cannibalistic mosquitofish had a significantly higher reproductive index (a measure of both number of embryos produced and rate of embryo development) than controls and fish fed with other supplements. In a second experiment, cannibalistic fish had the highest dry weight. Thus mosquitofish, which are known to be cannibalistic in nature, derive nutritional benefits from cannibalism. It is presumed that the nutritional benefits are at least partly due to the fact that nutrients required by mosquitofish would be present in exactly the right proportions in other mosquitofish.

Plants Benefit from Being Eaten

Paige, K.N. & Whitham, T.G. (1987) Overcompensation in response to mammalian herbivory: The advantage of being eaten. *The American Naturalist, 129,* 407-416.

It is logical to assume that plants are harmed by the activities of herbivores. They lose energy and photosynthetic tissues, or their reproductive structures may be destroyed. And they may become more susceptible to pathogens. We tell our students about the many defenses plants have against herbivores . . . anatomical ones like thorns and chemical ones like poisons. But strange as it may seem, there appear to be benefits that plants derive from being eaten.

Paige and Whitham report on experiments with biennial scarlet gilia (*Ipomopsis aggregata*), a plant that grows in the mountains of the Western United States. The inflorescence of scarlet gilia is frequently browsed by mule deer and elk; in many cases, 95 percent of the aboveground biomass is consumed. Browsed plants are somehow stimulated and produce an average of four new inflorescences. Thus browsed plants are able to produce 2.4 times as many viable seeds as unbrowsed plants. Such an increase in fitness as a result of browsing is entirely unexpected. The mechanism for this overcompensation is not known, but will be an important topic for future studies. Perhaps this ability to overcompensate can be incorporated into crop plants.

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