Pure Joy

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Doing the research for this column was pure joy. I keep a folder labeled "Animals," and I sat down with it one day. I ended up spending a wonderful afternoon reading about fascinating adaptations. This column is admittedly a potpourri, but what all the items here have in common is that they are all reminders of why many of us went into biology—it's just the most interesting subject going.

Slow Digestion

I want to start with snakes because this item is strange and wonderful. It includes the kind of statistics that students love, but it also makes a serious point about adaptation as well. Elizabeth Pennisi (1999a) reports on the research of Harvey Lillywhite of the University of Florida who investigated "chronic constipation" in some snake species. But "chronic" is an understatement. In a study of the rate of defecation in a number of large, ground-dwelling snakes, Lillywhite found that the Gabon viper *Bitis gabonica* had the longest "passage time." While it ate a number of times during a year, it only defecated once in 420 days.

While Metamucil® or Ex-Lax® might seem in order for this poor creature, Lillywhite argues that long-term retention of waste is not a matter of real constipation but of bulking up to more effectively land large prey. He found that while *B. gabonica* is an extreme case, a comparison of ground-dwelling with tree-dwelling snakes showed that the average passage time for ground dwellers was 145 days longer than for tree dwellers, with some tree dwellers having passage times that seem positively supersonic next to *B. gabonica*. The slender arboreal snake *Uromacer oxyrhyncus* eliminates waste in less than two days. Lillywhite attributes this difference to the fact that tree dwellers need to be mobile and the extra weight of waste would slow their movements. For ground dwellers, on the other hand, extra weight in the form of waste material can be an advantage especially since it accumulates in the hindgut. Snakes with such extra heft have been found to strike more quickly and to get a firmer grip on prey.

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Shrinking Iguanas

But while some snakes do better with extra weight, some iguanas do better by not just slimming down, but by actually shrinking. Researchers found that some members of a population of Galapagos marine iguanas of the species *Amblyrhynchus cristatus* became shorter over a period of two years during El Niño events when food supplies were low (Wikelski & Thom 2000). Large individuals shrank proportionately more than small ones, and females shrank more than males of the same size. The lizards that shrank more lived longer both because they could move around more easily to forage and because they expended less energy to do so. The extent of shrinkage, up to 20% of body length, indicates that this couldn't just be the result of a decrease in cartilage and connective tissue, but that bone absorption also had to be involved. This is the first report of such shrinkage in an adult vertebrate, and the marine iguanas seem capable of repeating growth and shrinkage cycles several times during their lives, providing the animal with an unusual adaptation to starvation conditions.

Hot Clams & Slow Tubeworms

One of the problems with investigating animals is that it's often difficult to study them where they live. This is particularly true of organisms that reside in the deep ocean, but biologists are finding ways to explore the habits of even these creatures. Japanese researchers used video cameras and temperature sensors to study colonies of the giant white clam, *Calyptogena soyoae*, more than 1,100 meters below the surface of Sagami Bay in Japan (Van Dover 1999). *C. soyoae* belongs to the same genus as clams living near hydrothermal vents in the eastern Pacific, and like these clams, it is a host for endosymbiotic, sulfide-oxidizing microorganisms from which it draws nourishment. But *C. soyoae* lives in a much cooler environment, in sediments into which seep cold waters rich in sulfides.

Observations made with video cameras and temperature sensors over an 18-month period included evidence for 11 cases of spawning by both sexes, and in each case, the spawning was associated with a brief rise in water temperature of only 0.1–0.2° C. The rise lasted less than two hours and was not associated with lunar or seasonal cycles. To test the hypothesis that the water temperature change triggered spawning, researchers placed a plastic dome with a light bulb attached over a group of clams *in situ*. When lit, the light bulb increased the temperature at the surface by 2.2° C, and spawning by several clams began within five minutes of turning on the light. The males spawned first, as is often the case with clams living in shallow waters, and it may be that the release of sperm triggers spawning by females. There was no spawning in the control group.

This piece of research is interesting for two reasons. First, it is amazing what can be learned about animals that live in such inaccessible places. Granted, this was an expensive experiment since the services of a submersible were needed, but it is an indication that deep waters are coming more and more within reach of biologists. Second, this work indicates that the environment at great depths in the ocean is not as unchanging as previously thought. Water temperature does change, perhaps as a result of water circulation patterns. It makes sense that such changes would be used by clams to improve reproductive efficiency. In shallow-water clam species, fertilization rates increase with synchronization of spawning. Also, the large number of larvae generated in these spawning events have a better chance of surviving predation.

In another piece of research on a relative of a hydrothermal vent dweller, biologists from Penn State have investigated a tubeworm of the genus *Lamellibrachia* living in hydrocarbon seeps on the Louisiana continental slope. They found that it requires between 170 to 250 years to grow to a length of two meters (Bergquist, Williams & Fisher 2000). This is very different from the growth rate of its relatives in hydrothermal vents; these are among the fastest growing invertebrates known. It is not just a variance in temperature that explains these rate differences; the availability of nutrients is also a factor. This is a good example of how closely related invertebrates are able to adapt to very different environmental conditions.

Crustaceans on the Move

Before I leave the topic of water-dwelling invertebrates, I want to mention two other items, both related to the movements of crustaceans. First is the crab's walk. Carl Zimmer (2000a) nicely describes how crabs are "engineered" to move efficiently both on dry land and in the water. Such adaptability is difficult because the locomotion demands for the two environments are so different. Walking on land is much the same for crabs and insects and mammals, with some alterations due to the number of legs involved. But walking in the much denser medium of water requires a different approach. The crab's thin body and sideways walk help to reduce drag, and in underwater video movies it's evident that the crab uses its legs more to push off than to maintain balance.

The second item deals with the snapping shrimp, *Alpheus heterochaelis*. It has a large snapper claw that slams shut whenever the shrimp is disturbed. This snap sprays the intruder with a jet of water that usually sends it off in another direction. Biologists had assumed that the crackling noises heard near snapping shrimp colonies were due to the claws banging shut. But now a team of Dutch physicists and biologists reports that the crack is due to a collapsing bubble outside the shrimp's claw.

The shrimp's crackling sound has been studied since World War II, when the Navy became interested because the noise from shrimp colonies could drown out the sonar used to detect submarines. The assumption has always been that the sound came from the snapping, but here again, the video camera became a useful research tool. In each of a number of videos of the shrimp's claw closing, an air bubble can be seen moving out of the claw with the water jet. The bubble enlarges and then breaks up into a mass of tiny bubbles in a process called cavitation, and with this comes the crackling noise. As Kathryn Brown (2000) explains in an article on the research, the shrimp "clamps its claw so rapidly that a water jet gushing from the claw first loses and then gains pressure, causing an air bubble in the jet to swell and collapse with a pronounced 'snap!' The imploding bubble generates shock waves that stun nearby prey and ward off other shrimp" (p. 2020). This is a good example of the fact that it often pays to revisit old problems and old explanations. Often new equipment provides new kinds of information that make revision of old answers necessary.

Wing Restructuring

Neotropical birds called manakins also have an unusual way to make noise (Pennisi 1999b). In about half of the approximately 40 manakin species, the males use their wings to make clicking and rattling sounds to attract mates. What makes this practice unusual is that it has required rather costly reshaping of the manakin's feather and wing structures. These are costly in the sense that they may impair the bird's ability to fly, which brings up the issue of the balance between useful adaptations and characteristics shaped by sexual selection.

The reshaping involves a change in structures such as the ulna which is a thin bone in birds related to the manakins such as flycatchers. In the clicking manakins, the ulna is thicker and has knobs to help support the enlarged muscles attached to the feathers. Among manakins, the species with the most unusual wings are the club-winged manakins. When males of this species display, they lean forward and flip their wings back and then forward. To do this, they have to rotate the elbow joint, a motion that is uncommon in birds. While the muscles attached to the elbow are small in most birds, they are bulky and strong in club-winged manakins. Kim Bostwick of the University of Kansas, Lawrence, who did this study, speculates that all these changes must impede the flying ability of these birds, though she has yet to do the research to confirm this. She is planning to look at both manakins who have secondarily lost their ability to make clicks and at those who make clicks with their tail or vocal cords rather than with their wings.

Birds & the Sense of Smell

While some birds are making sounds in unusual ways, others are making use of a sense that up until recently wasn't considered very important in birds: the sense of smell. The accepted view, based on early work on avian brain anatomy—including the size of the olfactory bulb—is that birds have little or no ability to smell. But research done over the past 30 years indicates that for many species this is hardly the case (Malakoff 1999). Studies on brain anatomy begun in the late 1960s among 151 bird species showed that the olfactory bulb made up as little as 3% of the brain in small songbirds such as the chickadee, but as much as 37% in seabirds like the petrel.

Other research showed that turkey vultures can find food solely on the basis of scent, and that pigeons, those gourmets of city streets, can detect rather subtle scents. Homing pigeons whose sense of smell has been blocked take much longer to find their home base and in some cases never make it. Smell may also help some birds, such as European starlings, locate the plants they use to build their nests and help chickens avoid bad-tasting insects. This is another good example of an area of research that has blossomed as biologists have moved beyond a long-held assumption. Such assumptions are important in the sense that they prevent researchers from exploring areas that are indeed fruitless, but at the same time, the work on birds' sense of smell is a reminder that assumptions need to be revisited from time to time since new techniques and viewpoints can call them into question.

Sexy Bracelets

Though equipment of some kind is necessary for almost all biological work, sometimes the consequences of using a particular device are unexpected. Research on zebra finches provides a case in point. The zebra finch is much studied because it is a small bird that easily adapts to life in the lab. The set of experiments I want to discuss here is on a topic which is of great interest to biologists, that is, the costs and benefits of sexual selection. Researchers found that females who mated with more attractive males deposited more testosterone in their eggs (Vogel 1999). Studies on canaries suggest that chicks exposed to more testosterone during development thrived because they begged more for food and grew faster; the same may be true for zebra finches. Here is a case where healthier chicks resulting from mating with a desirable male may not be the result of the male's having better genes, but of the female being induced to make a larger investment in her offspring.

What makes this study particularly interesting is that the basis upon which zebra finch females were choosing males as more desirable was definitely not hereditary—it was the color of the male's identification bands. Previous studies had shown that zebra finch males with red bracelets around their feet were more sought after as mates than males with green bracelets. It has been hypothesized that attractive ornamentation might signal the presence of good genes and so by selecting mates with such adornment, members of the opposite sex are increasing the chance that their offspring will have a desirable genetic makeup. In this case, however, genes just can't be involved. As this study shows, offspring may in fact be more robust for reasons that have absolutely nothing to do with genes. Still, this investigation is very preliminary. The relationship between testosterone and healthier chicks has yet to be established for zebra finches since the researchers destroyed the eggs in the process of measuring hormone levels. There is also the question of how females control testosterone levels in the eggs. It may be that mating with attractive males increases arousal; there is a study showing that—in canaries again—there is a relationship between hormone levels in the females' blood and in the eggs. In any case, the bracelet study is a nice example of a "natural" experiment which teases apart genetic and nongenetic factors that usually go hand-in-hand.

Constructing a Family Tree

Teasing out the genetic relationships among members of another group of birds has proven particularly difficult for ornithologists. There are 240 species of ovenbirds that inhabit parts of Central and South America, and until now, it has been impossible to construct a convincing ovenbird family tree. Now researchers at the University of Kansas have accomplished this task by focusing on the types of nests these birds create to incubate eggs away from harsh weather and predators (Holden 1999). The ovenbirds are known for their nests which come in a great variety of shapes and sizes; in fact, they are named for the fact that *Furnarius* creates nests of clay that resemble earthen ovens. The nests of ovenbird species were analyzed on the basis of 24 different characteristics including shape, material, and construction techniques such as macerating plants, stripping leaves, and hollowing out trees. The assumption was that species with similarly constructed nests might have had a recent common ancestor. This approach seems to have yielded results that bring reasonable order to this group of birds' family tree. For example, *Furnarius* in the past had been thought to be only distantly related to other genera that nest in earthen burrows. But the fact that all these birds have nests with linings that are cup-shaped and made of grass and strips of bark, indicates that they are probably closely related.

Smoke Detector

I am interested in the metaphors biologists use to explain their work, for example, to describe adaptations in organisms. So when I saw an article with the title, "Insect Antenna as a Smoke Detector," I read on (Schütz et al. 1999). It seems that larvae of the jewel beetle *Melanophila acuminata* can only develop in the wood of trees that have just died in a fire. This level of choosiness means that the beetle has to be able to detect a fire from some distance. *M. acuminata* does have paired thoracic pit organs that are extremely sensitive infrared receptors, but heat can only be detected when the beetle is relatively close to the fire. Is there a way for it to find more distant conflagrations? Researchers in Germany have looked for such a capacity in the beetle's antennae. They removed antennae from live beetles and immediately connected each antenna to a gas chromatograph designed to detect volatile substances in burning wood. The antennae were sensitive to several of the chemicals released by smoldering *Pinus sylvestris* wood, particularly methoxylated phenols that are produced during the incomplete combustion of lignin. So it looks as if this jewel beetle does indeed have a smoke detector—and a detector tuned to the residues of burning woods. This is of interest not only to beetle-lovers; a biosensor based on this system might be useful as a new type of smoke detector with many applications.

Putting Noise to Good Use

Still another kind of sensory ability has now been investigated in the paddlefish, which seems to make use of noise to sharpen its electroreceptors (Collins 1999). In the 1980s, physicists developed the idea of stochastic resonance which means that a certain level of noise can actually enhance the ability of some nonlinear systems to detect and transmit weak signals. Since then such phenomena have been found in crayfish mechanoreceptors, in the cricket cercal sensory system that detects air disturbances, and even in human muscle spindles that sense stretch. But in none of these cases has it been demonstrated that stochastic resonance is beneficial to the organism.

This situation has changed with the publication of a study on the paddlefish *Polyodon spathula* which has passive electroreceptors to detect electrical signals from its prey, the zooplankton *Daphnia*. Researchers found that when they applied an intermediate level of noise the paddlefish were able to detect zooplankton over a wider range and with increased accuracy. But this research was done in a tank; what would be the noise source in the natural environment? It may be the plankton themselves. Swarms of plankton emit randomly fluctuating electrical signals. This background noise could make paddlefish more sensitive to signals produced by individual plankton.

Gecko Toes

Several years ago while on a trip to Hawaii, I met my first gecko. It was sitting on top of the toaster when I turned the lights on in the kitchen one night. Being from New York, I was used to roaches, but not geckos. When we visited a friend's apartment in Honolulu the next day, there was another gecko climbing the wall. That's how I was introduced to this ubiquitous tropical apartment dweller. So last summer, when several publications ran articles on gecko toes, I was particularly interested (Downs 2000; Gee 2000; Karow 2000; Pennisi 2000; Zimmer 2000b). It seems that for years, researchers have tried to explain how geckos manage to scale walls and even climb across ceilings so easily. Obviously, it had something to do with the animal's feet, but the search for suction cups or the presence of an adhesive turned up nothing. Recently, a team of biologists and engineers has come up with a more plausible explanation, and it has to do with van der Waals forces, one of those things that we all learned about in chemistry class. They are the momentary forces exerted by atoms when there is uneven distribution of charge within the atom.

The gecko's toes are covered with rows of keratinous hairs called setae, with about half a million on each toe. Each of the setae splits into hundreds of rounded ends called spatulae, which are what actually make contact with a surface. Engineers built a device to measure the force of attraction between a single seta and a surface. At first they had difficulty getting any measurements, until they dragged the seta across the surface. The force of attraction increased dramatically when the hair was parallel to the surface. The force detected was 10 times greater than expected, and strong enough that a gecko could hang from the ceiling by one toe. This result was particularly convincing because the dragging motion used was much like that normally found in the movement of the gecko's feet. I think this item got so much publicity not only because walking across the ceiling is a notable accomplishment, but because the reports were accompanied by photographs of the setae and spatulae. Here was a case where microscope photographs made sense to the general reader since they were related to a phenomenon visible with the naked eye. Also, the pictures, especially of the spatulae, were quite attractive because they are graceful structures, structures that adorn the feet of a particularly graceful animal.

Malformed Whales

Not all images in biology are so attractive. A recent article on sperm whales was accompanied by a photo of a grossly malformed jaw (Pennisi 1999c). But even though the congenitally twisted bone was very abnormal, it came from an adult whale, one who had obviously managed to survive despite this disability. And this is hardly a unique case. A number of such jawbones have been found, as well as normal ones that have been broken into several pieces. These findings are somewhat surprising because it would seem that the whale would need its jaw to grasp food in order to survive. But Alexander Werth of Hampden-Sydney College in Virginia argues that sperm whales don't grasp their food, but suck it in, and his anatomical studies of the sperm whale's tongue support this view. The muscles in the tongue that are used by most animals to manipulate food so it can be swallowed are very reduced in the whale's tongue. But the tongue does have well-developed muscles connecting it to the jaw and skull, so that it can move easily back and forth over the throat, thus creating suction.

Conclusion

Whales with broken jaws, beetles with smoke detectors, birds with bracelets—is it any wonder that we chose biology as a career and still find it fascinating? When we get up in the morning we have another day of wonders to look forward to, thanks to the thousands of biologists who continue to spread joy by providing fascinating new research to keep us and our students on our setae-less toes.

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