NATURAL HISTORY

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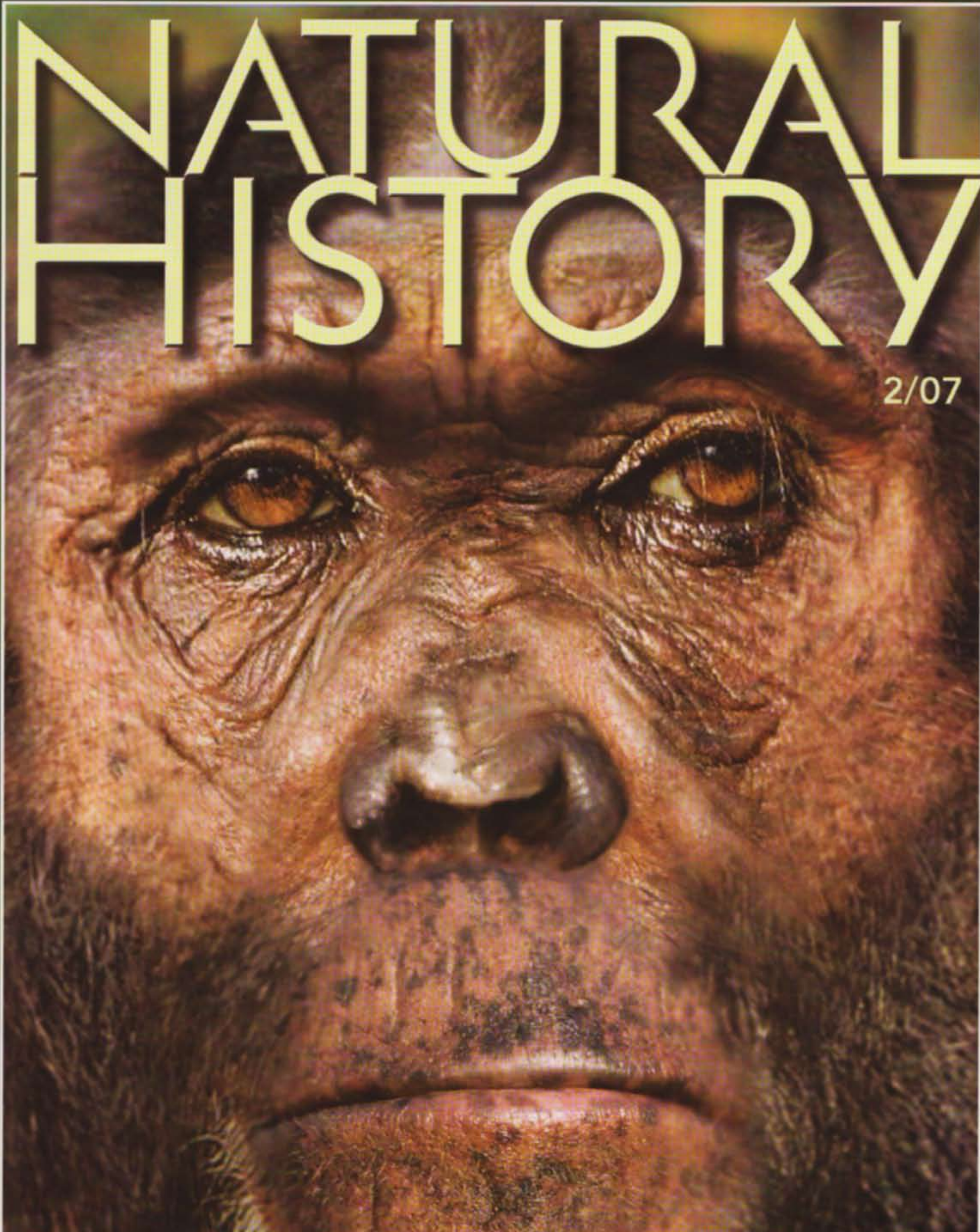

NEW FACES OF THE HUMAN PAST

NATURAL HISTORY

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FEATURES

ON THE COVER: The hominid species *Homo rudolfensis* lived in East Africa between 1.8 and 1.9 million years ago. Illustration by Viktor Deak

Eight Arms, With Attitude

Octopuses count playfulness, personality, and practical intelligence among their leading character traits.

By Jennifer A. Mather

Twenty-five years ago, when I started my fieldwork on the behavior of juvenile common octopuses in the azure waters of Bermuda, I expected all my subjects to be much the same. I assumed their activities would be fairly limited; individuals would hunt, rest, and avoid predators, all in roughly the same way. In fact, I learned, their behavior is quite complex and variable. I watched as they carefully chose rocky crevices for their dens and blockaded the entrances with piles of rocks. I observed them navigate complicated routes across the sea bottom to and from their hunting grounds. But I was most intrigued to discover that individual octopuses are very different from one another.

I could swear, for instance, that octopus number 45 never left its crevice—except that the discarded shells of clams, crabs, and snails kept appearing in front of the crevice. It must have been making secret hunting forays when my back was turned. By contrast, octopus number 26 was anything but shy. One afternoon I watched it as I floated in the shallow Bermuda water, hanging on to a rocky outcrop. The little octopus peered back at me from inside its den for some time, then suddenly jetted three or four feet directly toward me and landed on my dive glove. After about a minute of exploring, it must have decided the glove didn't taste good, and slowly jetted back home. I was hooked.

Around the same time, Roland C. Anderson, a marine biologist at the Seattle Aquarium who has since become my frequent collaborator, noticed that aquarium workers gave names to only three kinds of animals in their care: seals, sea otters, and giant Pacific octopuses. The workers named the octopuses for their distinctive behaviors. Leisure Suit Larry, for instance, was all arms. He touched and groped his keepers so often that had he been a person, he would have been cited for inappropriate behavior. Emily Dickinson, by contrast, hid permanently behind the artificial backdrop of her display tank, so retiring that eventually she had to be replaced by a more active octopus for aquarium visitors to watch. Then there was Lucretia McEvil, whose caretakers were afraid to approach her, and who ripped up the interior of her tank. All those "characters" set me to thinking about whether octopuses might just have something like human personality.

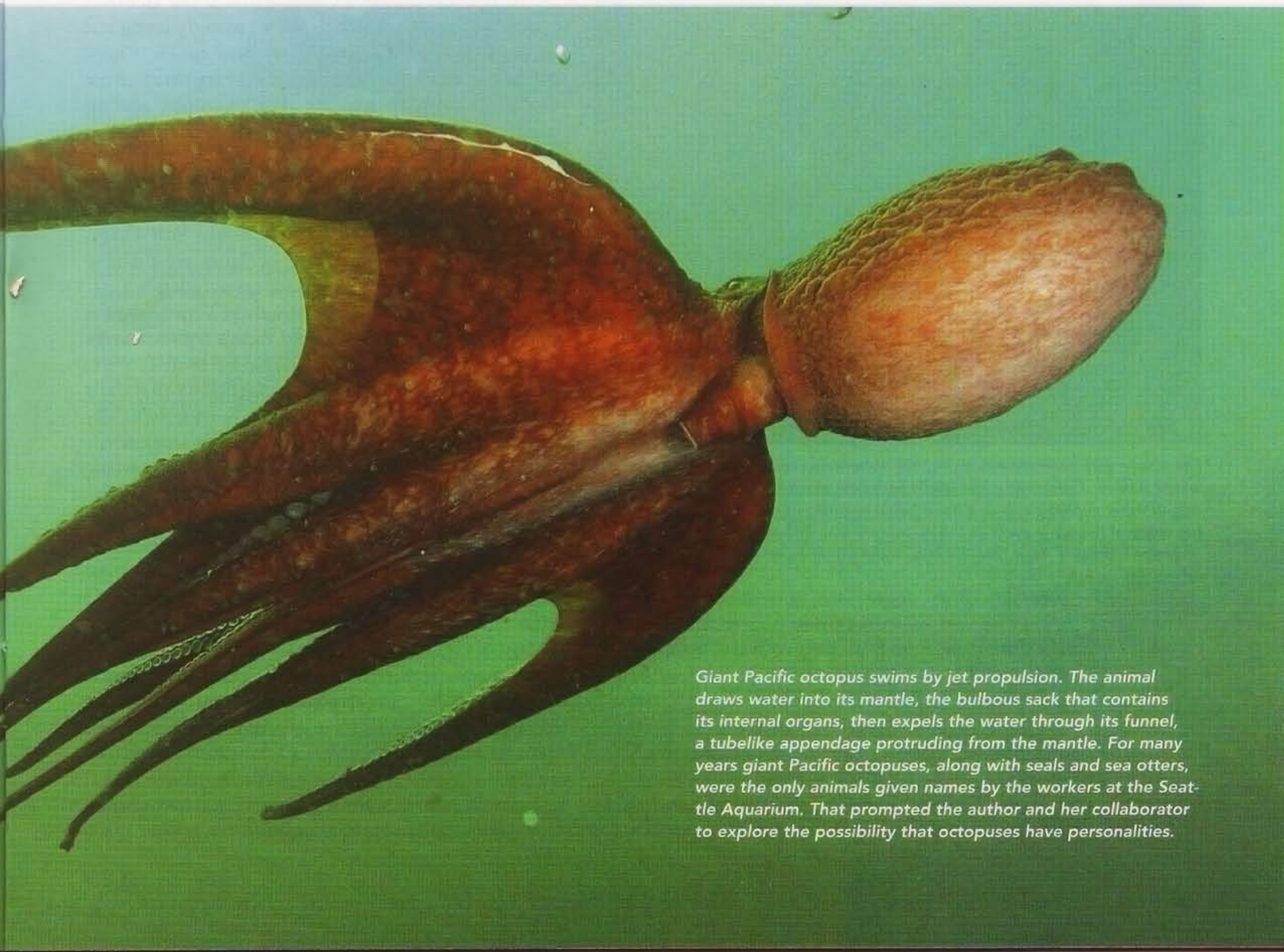
Twenty-five years ago it was hard to know what

to expect of octopus behavior: the creatures had seldom been studied, and when they had, it was mostly in captivity. Furthermore, they are invertebrate mollusks, and so they are evolutionarily distant from vertebrates; it would have been hard to justify extrapolating the significance of their activities from the well-studied behaviors of mammals and birds.

Most mollusks are clams or snails that hide within hard shells and have little brainpower. But cuttlefish, octopuses, and squid (which along with nautiluses make up the cephalopod mollusks) are nothing like their shell-bound relatives. Evolution led them to lose their protective shells, but what they gained was far more interesting: dexterous, sucker-lined arms; ever-changing camouflage skin; complex eyes; and remarkably well-developed brains and nervous systems. The 289 known species of octopus range in size from the one-ounce Atlantic pygmy octopus, *Octopus joubini*, to the giant Pacific octopus, *Enteroctopus dofleini*, which can weigh more than a hundred pounds. They are all ocean-dwellers, and, though the group is distributed from the poles to the tropics, octopuses are reclusive beasts; individuals are hard to find, let alone study.

The intelligence of octopuses has long been noted, and to some extent studied. But in recent years, research by myself and others into their personalities, play, and problem-solving skills has both added to and elaborated the list of their remarkable attributes. They turn out to be uncannily familiar creatures, not nearly as unlike you and me as one might expect—given their startlingly different physiques and the 1.2 billion years of evolution that separate us from these eight-armed marvels of the sea.

Personality is hard to define, but one can begin to describe it as a unique pattern of individual behavior that remains consistent over time and in a variety of circumstances. I've adopted the model that developmental psychologists have applied to study the behavior of children. Psychologists begin with the idea of "temperament," or behavioral tendencies genetically pro-



Giant Pacific octopus swims by jet propulsion. The animal draws water into its mantle, the bulbous sack that contains its internal organs, then expels the water through its funnel, a tubelike appendage protruding from the mantle. For many years giant Pacific octopuses, along with seals and sea otters, were the only animals given names by the workers at the Seattle Aquarium. That prompted the author and her collaborator to explore the possibility that octopuses have personalities.

grammed before birth. After birth the environment shapes an individual's temperament to give rise to an adult personality.

Many people assume that only human beings have personalities. Yet in the past fifteen years or so a number of investigators have reported evidence of personality in animals as diverse as guppies, hyenas, and rhesus monkeys. To pin down what can be a notoriously slippery concept, they have identified a number of personality traits, or "dimensions,"

Eye-to-eye with a common octopus, the camera records a view that few fish would survive. The octopus eye (circle with dark slit at top of the image), like that of other cephalopods, is a remarkable example of convergent evolution; it has many of the same parts as the vertebrate eye, including a cornea, iris, lens, and retina, despite more than 1.2 billion years of independent evolution.

such as activity, aggression, curiosity, and sociability. Many animals, including people, can be rated along each of those dimensions, and an individual's rating along one dimension can vary more or less independently of its ratings along the others.

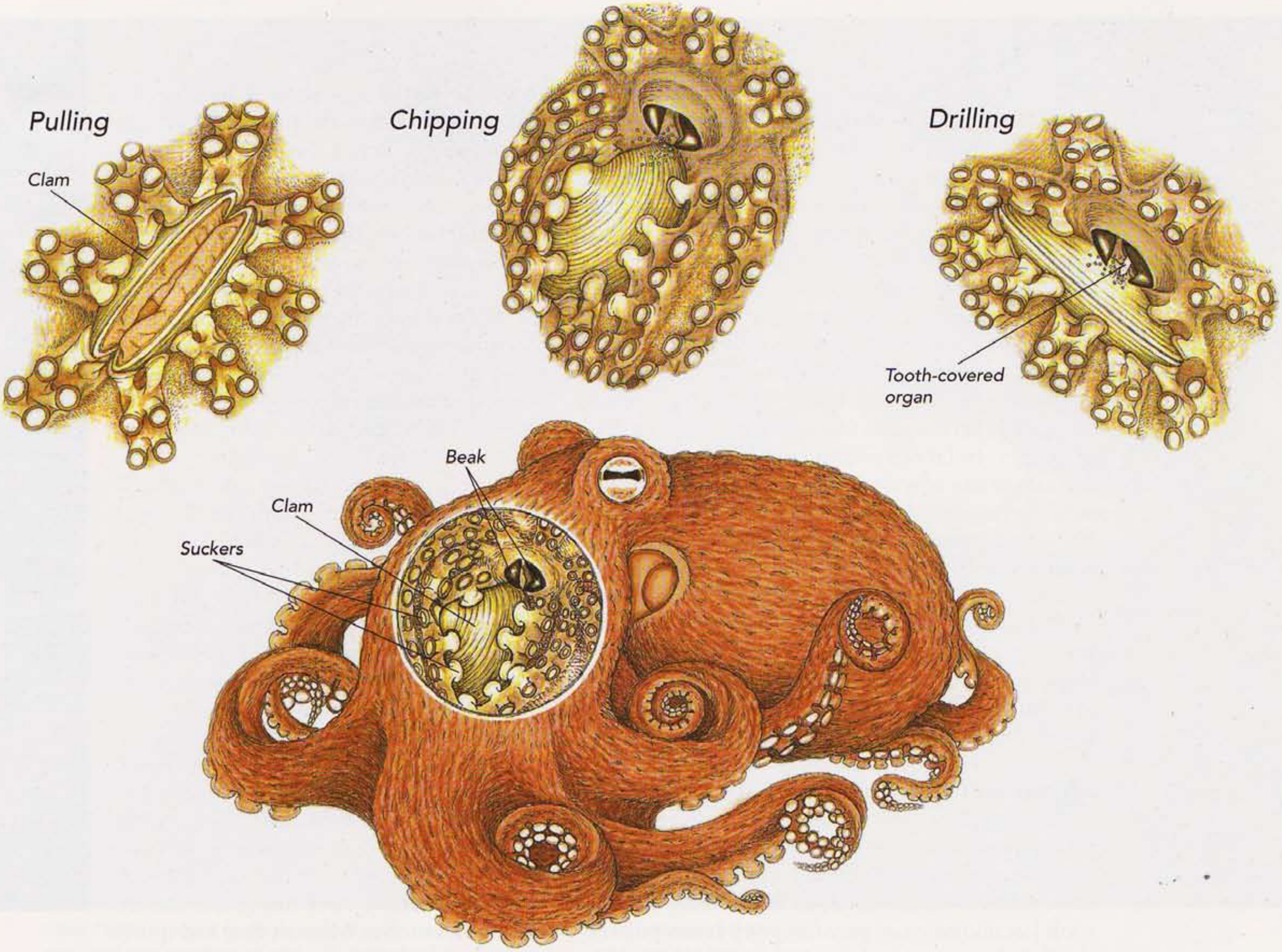
Could a combination of differences in genes and life experience—personality—have made individual octopuses behave so differently from one another? Our experiences led Anderson and me to think so. We didn't expect to discover a sociability dimension because octopuses lead solitary lives, but we thought we might find differences along such dimensions as activity or aggression.

We gave "personality tests" to forty-four red octopuses *(Octopus rubescens)*, natives of the West Coast of North America that weigh as much as a pound. We exposed each animal to three test conditions, seven times each, during a two-week period. We measured and recorded their responses when we opened the tank lid, when we touched them with a brush, and when we fed them a crab. The brush prompted the greatest variety of responses. Some octopuses grabbed it, stood their ground, and inflated their mantle to look bigger. Others jetted to the opposite end of the tank, leaving a cloud of obscuring dark ink in their wake. Individuals gave the same responses to the tests even after being exposed to them several times.

In all, the forty-four octopuses responded to the three tests with nineteen distinct behaviors. Statistical analysis enabled us to group the nineteen behaviors and place them along three personality dimensions: activity (how much the octopus moved around), reactivity (how strongly it reacted to the stimuli), and avoidance (how much it kept out of our way). An octopus could vary on all three dimensions independently. For example, among highly avoidant octopuses, which tended to remain in their dens during testing, some were extremely reactive, shrinking at the first sign of the brush. Others were not reactive at all, practically ignoring the brush. (By extension, Leisure Suit Larry, the touchy-feely giant Pacific octopus, would have rated high on activity and low on avoidance.)

So do octopuses have personality? Our answer is a qualified "yes." Because we didn't try to change their personalities by manipulating their experiences, we couldn't rule out the possibility that their behavioral variations might have been genetically preprogrammed. But given the octopus's legendary intelligence, behavioral flexibility, and learning ability, such preprogramming seems unlikely.

How much of the behavioral differences among individual octopuses is inherited, and how much is learned? For his master's thesis, David L. Sinn, now a zoologist at the University of Tasmania in Hobart, raised laboratory-born California two-spot octopuses *(Octopus bimaculoides)* in small isolation chambers and gave juveniles the same three tests Anderson and I gave our red octopuses. The genetic effects were clear. Octopuses that shared at least a mother (female octopuses mate several times with any available male, so paternity was all but impossible to determine) reacted to the three



Cutaway view of a giant Pacific octopus (above) shows how it manipulates a clam it is about to eat. Octopuses have several techniques for breaking into clam shells. They can pull the shell halves apart with their arms and suckers (top left). They can chip with their beaks (top middle). Or they can drill a hole by alternately secreting acid and scraping with a tooth-covered organ in the mouth (top right). If an octopus drills or chips, it secretes a paralytic toxin into the shell to weaken the muscles holding the shell halves together. Octopuses are excellent problem-solvers: which technique an octopus chooses depends on the species of clam, the thickness of the shell, and the strength of the clam's muscles.

tests more similarly than octopuses from different broods. Intriguingly, Sinn also discovered that as the animals matured, their responses to the tests changed in a predictable way.

Sinn did not raise his subjects to maturity, so no one knows whether youthful experiences might have added a layer to the octopuses' temperaments to yield true adult personalities. It's too bad—it would be fascinating to know whether octopuses' differing experiences when young would result in differing adult personalities. Was Lucretia McEvil's destructiveness, for instance, the result of a "bad childhood"?

Another question about octopus personality is whether it has evolutionary benefits or drawbacks. The only scientific clue comes from Sinn's doctoral work, which showed that squid, too, vary along the personality dimensions of avoidance, activity, and reactivity. Shy female southern bobtail squid, Sinn found, mate with males that are shy, bold, or anything in between along the avoidance dimension. But bold females tend to reject shy males. Score one for the survival of the boldest. Sinn also found, however, that shy females are more successful than bold females at hatching their broods of eggs. No obvious pattern emerges, but personality clearly does affect survival and reproductive fitness.

Evidence for the octopus's intelligence begins with its anatomy. Intelligent animals typically have large brains, and octopuses' brains are large for their body size compared to those of other animals—larger than fishes' brains and, proportionally, as large as those of some birds and perhaps some mammals. Moreover, three-fifths of an octopus's neurons aren't even in its brain. Instead, they are divided among its eight arms to coordinate the arms' remarkable flexibility. The big brain itself is mostly dedicated to learning, planning, and coordinating actions with stimuli.

Broadly defined, intelligence is the measure of an animal's ability to acquire information from its environment and to change its behavior in response—in short, to learn. The octopus's behavioral repertoire has few fixed, preprogrammed responses, and it can respond to a given stimulus in a great variety of ways; those are both hallmarks of intelligence and learning. The sea slug, by contrast, has only a limited palette of reflexive responses, no matter what the stimulus. In one particularly vivid demonstration, published in 1970, the biologist William R.A. Muntz showed that octopuses could learn to tell complex visual figures apart by forming a new rule for each for each new set of figures. He concluded that octopuses aren't merely able to learn; they can also learn what to learn.

Anderson and I became interested in how octopuses apply their intelligence to predation. After capturing a clam, an octopus must break through the hard shell to get to the meat inside. To do so, it can deploy a veritable built-in Swiss Army knife of tools [*see illustration on preceding page*]. It can pull the shell's halves apart with its arms and suckers, chip at the shell's edge with its beak, or drill a tiny hole in the shell by alternately secreting acid to dissolve it and scraping at it with one of two tooth-covered organs in its mouth. (Which of the two organs it uses remains subject to debate.) If the octopus breaches the shell by chipping or drilling, it secretes a paralytic toxin into the clam's muscles so that it can more easily pull the shell halves apart—and then it's dinnertime.

We discovered that giant Pacific octopuses apply differing techniques to various clam species: they break fragile mussel shells, probably while pulling on them; they pull apart the stronger Manila clams; and they drill or chip at the strongest clams, the littlenecks. We placed individuals of each species on a device of our own design (which we darkly called the "clam rack"), and measured how much force it took to overcome the clam's muscles and pull the shell halves apart. Intriguingly, octopuses ate plenty of weak-muscled mussels when they had to open dinner by themselves, but they gobbled up littleneck clams—all but ignoring the mussels—when we offered all three species on the half shell. Maybe the mussels were less tasty but easier to get at than the littlenecks.

Octopuses conduct the business of breaking into clams with the clams near their mouths, which are under their arms and so out of sight. There they dexterously manipulate the clams into position by touch. To pull clam shells apart, an octopus holds it with the umbo (the bump near the shell's hinge) toward its mouth. But if it chooses to chip at the shells' edge, it moves the clam's "sides," where the muscle insertions are, toward its mouth. And when it drills, it turns the broad side of the shell toward its mouth.

Giant pacific octopuses usually drill through the center of a clam's shell into its heart. But they must learn where to drill the holes. Anderson found that juveniles drill their first few holes randomly on the shell, but they soon master the art of drilling near the heart or the muscles that hold the shell halves together. Either place is a good target for injecting paralytic toxin.

We were curious about what octopuses would do with artificially strong Manila clams, whose shells they usually just pull apart. We gave each octopus Manila clams held together with strong wire. The octopuses simply switched tactics to drilling or chipping, thereby confirming the numerous studies such as Muntz's that had shown they are good problem-solvers. They can weigh effort against food reward, flexibly switch penetration tactics, and orient the clam to penetrate its shell most effectively—all good uses of intelligence, indeed.

After investigating a few octopus problem-solving skills, Anderson and I turned our attention to two less-studied categories of behavior that are also linked to intelligence: exploration and play. Philosophers and psychologists have debated for centuries about the nature of play, where it comes from, and what purpose it serves. When animals play with objects, their explorations move from "What does this object do?" to "What can I do with this object?"

Gordon M. Burghardt, a biologist at the University of Tennessee in Knoxville, recently offered a clear and useful definition of play in healthy animals. Play, he writes, is made up of voluntary, incomplete, repeated fragments of activity that have no obvious purpose, and which are often exaggerated and out of normal context. Some scholars still maintain that people are the only animals that truly

Giant Pacific octopus feeds on a dead spiny dogfish. Octopuses can instantaneously change color and texture, often to camouflage themselves. Giant Pacific octopuses can change from a "relaxed" rusty red to gray, pale beige, coral, orange, red, or any mottled variation in between. Certain colors may indicate an octopus's internal state: the scarlet color of the octopus shown here could indicate stress, possibly triggered by the camera's flash. Or it could be a simple, automatic reaction to the burst of light.

play. But dog owners know that when their companion lowers its front end and raises its hind end, tail wagging, it has no purpose but to communicate that the next set of interactions should be just for fun. Crows slip down a playground slide over and over, or grasp a clothesline in their claws and spin round and round like a pinwheel, calling "Wheee" the whole time. Those behaviors clearly conform to Burghardt's definition, and other examples are documented in many animals, including dolphins, lab rats, and river otters.

Would an octopus play if given the chance? We decided to find out. Animals are more likely to play when they are satiated and secure, without any threat from predators. An aquarium tank is such an environment. There we presented eight well-fed giant Pacific octopuses with plastic pill bottles containing enough water that they floated at the surface of the tank. The octopuses followed a fairly predictable behavioral sequence. First, they grasped a pill bottle with one or more of their arms and explored it with their suckers. Then they pulled it to their mouths, and sometimes bit it with their parrotlike beaks. Gradually, both within each trial, and by the end of all ten trials, most of them lost interest in the bottle.

But two of the octopuses independently did something very different in the later trials. Like most aquariums, their tanks had water-circulation systems; water entered the tank at one end and exited at the other. While sitting near the outflow, each animal released the bottle it had been holding and jetted water through its funnel, sending the bottle against the gentle current to the inflow end of its tank. (A funnel is a tubelike appendage that an octopus uses for breathing and for jetting through the water [*see photograph on pages 30–31*].) When the bottles returned on the current, the octopuses jetted them upstream again, repeating the process more than twenty times. Anderson, who had been skeptical that octopuses play, phoned me excitedly after watching the first playful octopus and said, "It's like she's bouncing a ball!"

In vertebrates, some kinds of play have benefits as well as simply being fun. They strengthen and define social relationships, as in the roughhousing of canines. Or they give young animals the chance to hone fragmentary actions into polished sequences, as when a kitten plays with a mouse to "practice" capturing prey in the future. Skeptics often dismiss play by nonhuman animals as functional, and thus in violation of Burghardt's definition that it have no obvious purpose.

Play in octopuses has been documented experimentally, but remains controversial. After investigating and habituating to blocks for several days, common octopuses engaged in play or playlike behavior, passing the blocks from arm to arm, towing the blocks, or repeatedly pushing and pulling them back and forth. The octopus pictured here exploring a block with her mouth was among the most playful in the experiment. In another experiment, giant Pacific octopuses sent buoyant pill bottles circling repeatedly around their tanks.

But octopuses don't have social relationships—they're solitary creatures, except when they mate. And as for the argument that only the young play because only they need to practice their skills, Michael J. Kuba, a former graduate student of mine now at Hebrew University in Jerusalem, recently showed that adult common octopuses also engage in playlike behavior. They passed a plastic block from arm to arm or pulled it along when they swam just as often as the young did. Still, in our view, octopus play is neither as extensive as it is in mammals, nor as potentially adaptive. It may simply be a sign of an active mind at work.

Octopuses have personalities. They learn. They solve problems. They play. Does all that add up to a simple form of consciousness? The suggestion is even more contentious than the ideas that octopuse s play or have personalities. Just defining consciousness is tricky; one general definition is that an animal with primary consciousness—a dog, for instance—is aware of the complexity of a given circumstance as well as its role there and its decision-making options. Higher-order consciousness has more stringent criteria: using language, being able to report on the content of one's thoughts, being able to think about thinking. Only people and perhaps chimpanzees exhibit that exalted form of consciousness.

But how could one tell whether octopuses have some form of primary consciousness? Some theorists say it is enough to show complex and flexible behavior, such as the octopus's clam-opening tactics. Others say an animal must be able to shift its attention from one set of stimuli to another, making decisions in rapidly changing conditions. Octopuses meet that criterion in their varied responses to a predator: they can flash unpredictable changes in pattern and color, jet off in an unexpected direction to escape, or squirt out ink to form a smoke screen.

Still other theorists argue that conscious animals build a complex, multidimensional set of internal impressions about the world on the basis of their sensory perceptions. For example, the human mind constructs a three-dimensional image of objects from the two-dimensional array of stimuli that arrive at the retina. Additional study of how octopuses analyze visual shapes might show whether they meet that criterion, too. Or perhaps a conscious animal must have a concept of self. What do octopuses see when they look in a mirror? Answering that question will be our next research project.

It will be hard to say for sure whether octopuses possess consciousness in some simple form. But from what biologists already know about them, there's no denying they are some smart suckers. □

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