Tools, Plans, and Monkey Minds

Knowledge comes, but wisdom lingers.

—Alfred, Lord Tennyson

On July 12, 2009, while diving off the Pacific islands of Palau, Giacomo Bernardi witnessed something unusual, and was lucky enough to capture it on film. An orange-dotted tuskfish uncovered a clam buried in the sand by blowing water at it, picked up the mollusk in his mouth, and carried it to a large rock thirty yards away. Then, using several rapid head-flicks and well-timed releases, the fish eventually smashed open the clam against the rock. In the ensuing twenty minutes, the tuskfish ate three clams, using the same sequence of behaviors to open them.

Bernardi, a professor of evolutionary biology at the University of California, Santa Cruz, is thought to be the first scientist to film a fish demonstrating tool use. By any measure it is remarkable behavior from a fish. Tool use was long believed unique to humans, and it is only in the last decade that scientists have begun to appreciate the behavior beyond mammals and birds.

Bernardi's video unveils new gems every time I watch it. I initially failed to notice that the enterprising tuskfish doesn't uncover the clam in a manner we might expect—by blowing jets of water from his mouth. He actually turns away from the target and snaps his gill cover shut, generating a pulse of water the same way that a book creates a puff of air when you close it fast. And it’s more than tool use. By using a logical series of flexible behaviors separated in time and space, the tuskfish is a planner. This behavior brings to mind chimpanzees’ use of twigs or grass stems to draw termites from their nests. Or Brazilian capuchin monkeys who use heavy stones to smash hard nuts against flat boulders that serve as anvils. Or crows who drop nuts onto busy intersections and then swoop down during a red light to retrieve the fragments that the car wheels have cracked open for them.

Like a seaborne celebrity, the tuskfish draws an aquatic audience. Fishes of several types swim up to watch the sand blowing in action, and others briefly join our hero during his swim to the rock, like reporters hoping for a good quote.

Halfway to his destination, our tuskfish stops to try out a smaller rock lying on the sand. He makes a couple of halfhearted whacks, then heads on his way again, as if he’s decided this one’s not worth his time. Who can’t relate to his misguided attempts and how they reflect the fallibility of a mortal life?

These are impressive cognitive feats for any animal. That they are performed by a fish clearly upsets the still commonly held assumption that fishes are at the dim end of the animal intelligence spectrum. Even if this particular tuskfish were a rare Stephen Hawking among fishes, his behavior would be remarkable.

But what Bernardi saw that day was not exceptional. Scientists have noticed similar behavior in green wrasses, also called blackspot tuskfishes, on Australia’s Great Barrier Reef; in yellowhead wrasses off the coast of Florida; and in a sixbar wrasse in an aquarium setting. In the case of the sixbar wrasse, the captive fish was given pellets that were too large to swallow and too hard to break into pieces using only his jaws. The fish carried one of the pellets to a rock in the aquarium tank and smashed it, much as the tuskfish did the clam. The zoologist who observed this, Łukasz Paśko from the University of Wroclaw in Poland, saw the wrasse perform the pellet-smashing behavior on fifteen occasions, and it was only following many weeks of captivity that he had first noticed it. He described the behavior as “remarkably consistent” and “nearly always successful.”

Hard-nosed skeptics might point out that this sort of thing isn’t *real* tool use because the fishes aren’t wielding one object to manipulate another, as we do with an axe splitting a log for firewood, or a chimpanzee does by using a stick to get to the tastiest termites. Paśko himself refers to the wrasses' actions as "tool-like." But this is not to demean the behavior, for as he points out, smashing a clam or a pellet with a separate tool is simply not an option for a fish. For one thing, a fish isn't equipped with grasping limbs. In addition, the viscosity and density of water makes it difficult to generate sufficient momentum with an isolated tool (try smashing a walnut shell underwater by throwing it against a rock). And clasping a tool in his mouth, the fish's only other practical option, is inefficient because fragments of food would float away, only to be snatched up by other hungry swimmers.

Just as the tuskfish uses water as a force for moving sand, the archerfish also uses water as a force—only this time as a hunting projectile. These four-inch-long tropical marksmen—sporting a row of handsome black patches down their silvery sides—mostly inhabit brackish waters of estuaries, mangroves, and streams from India to the Philippines, Australia, and Polynesia. Their eyes are sufficiently wide, large, and mobile to allow binocular vision. They also have an impressive underbite, which they use to create a gun barrel of sorts. By pressing their tongue against a groove in the upper jaw and suddenly compressing the throat and mouth, archerfishes can squirt a sharp jet of water up to ten feet through the air. With an accuracy in some individuals of nearly 100 percent at a distance of three feet, woe betide a beetle or a grasshopper perched on a leaf above the backwaters where these fishes lurk.

The behavior is notably flexible. An archerfish can squirt water in a single shot, or in a machine gun–like fusillade. Targets have included insects, spiders, an infant lizard, bits of raw meat, scientific models of typical prey, and even observers' eyes—along with their lit cigarettes. Archerfishes also load their weapons according to the size of their prey, using more water for larger, heavier targets. Experienced archers may aim just below their prey on a vertical surface to knock it straight down into the water instead of farther away on land.

Using water as a projectile is only one of many foraging options for these fishes. Most of the time they forage underwater as ordinary fishes do. And if a meal is within just a foot of the surface of the water, they may take the more direct route, leaping to snatch it in their mouths.

Archerfishes live in groups, and they have fantastic observational learning skill. Their hunting prowess doesn't come preinstalled, so novices can only make successful shots at speedy targets after a prolonged training period. Researchers studying captive archerfishes at the University of Erlangen-Nuremberg, Germany, found that inexperienced individuals were not able to successfully hit a target even if it was moving as slowly as a half inch per second. But after watching a thousand attempts (successful and unsuccessful) by another archerfish to hit a moving target, the novices were able to make successful shots at rapidly moving targets. The scientists concluded that archerfishes can assume the viewpoint of another archerfish to learn a difficult skill from a distance. Biologists call this *perspective taking*. What an archerfish does might not require the same level of cognition as that shown by a captive chimp who carried a disabled starling up a tree to help launch it back to the air, but it is nevertheless a form of grasping something from the perspective of another.

High-speed video recordings reveal that these fishes use different shooting strategies depending on the speed and location of flying prey. When using what the researchers call the "predictive leading strategy," archerfishes adjust the trajectory of their sharp jets of water to account for the speed of a flying insect—they aim farther ahead of the target if it is moving faster. If the target is flying low (usually less than seven inches above the water), archerfishes often use a different strategy, which the researchers term "turn and shoot." This involves the fish firing while simultaneously rotating his body horizontally to match the lateral movement of the target, causing the jet of water to "track" the target on its airborne path. These fishes would do any quarterback proud.

Archerfishes compensate for the optical distortion produced by the water-to-air transition, and they do this by learning the physical laws governing apparent target size and the fish's relative position to the target. Having a generalizable rule of fin like this enables an archerfish to gauge the absolute sizes of objects from unfamiliar angles and distances. I wonder if archerfishes also practice entomology, visually identifying insects in order to know whether they are tasty, whether they're too big to eat or too small to bother with, or whether they sting.

Most likely, archerfishes have been squirting water jets for at least as long as humans have been throwing stones, and I suspect that wrasses were using rocks to crack clams open long before our ancestors started bashing hot metal against anvils in the Iron Age. But can fishes spontaneously invent tool use, as we can when unexpected conditions require us to improvise? In May 2014, a study highlighted an example of innovative tool use by Atlantic cods being held in captivity for aquaculture research. Each fish wore a colored plastic tag affixed to the back near the dorsal fin, which allowed the researchers to identify them individually. The holding tank had a self-feeder activated by a string with a loop at the end, and the fishes soon learned that they could release a morsel of food by swimming up to the loop, grabbing it in their mouth, and pulling on it.

Apparently by accident, some of the cods discovered that they could activate the feeder by hooking the loop onto their tag and then swimming a short distance away. These clever cods honed their technique through hundreds of "tests"—and it became a finely tuned series of goal-directed, coordinated movements. It also demonstrated true refinement, because the innovators were able to grab the pellet a fraction of a second faster than by using their mouth to get the food. That fishes are routinely expected to interact with a foreign device to feed themselves is impressive enough, but that some devised a new way of using their tags shows a fish's capacity for flexibility and originality.

Tool use by fishes, so far as we know, seems confined to a limited number of fish groups. Culum Brown suggests that wrasses in particular may be the fishes' answer to the primates among mammals and the corvids (crows, ravens, magpies, and jays) among birds in having a greater-than-expected number of examples of tool use. It could just be that living underwater offers fewer opportunities for tool use than living on land. But we do know that the tuskfishes (a member of the wrasse family) and archerfishes are prime examples of evolution's boundless capacity for creative problem solving, and they might turn out to have plenty of company among other fishes.

Might we count tigerfishes among them?

Turning the Tables

For millennia, birds have been diving into the water to catch fishes. Pelicans, ospreys, gannets, terns, and kingfishers are among the more spectacular examples of an army of feathered fish foes. Gannets, who measure over three feet long and can weigh eight pounds, launch themselves downward from a height of 50 to 100 feet and can be going sixty miles per hour when they fold back their wings just before impact and torpedo to depths of 60 feet to grab an unsuspecting fish with their pointed beaks.

Sometimes the tables are turned.

In January 2014 at Schroda Dam, a man-made lake in Limpopo Province, South Africa, scientists documented on film something that locals had reported seeing before. As a trio of barn swallows skimmed just above the water, a tigerfish leaped up and snatched one of the birds out of midair.

Tigerfishes are oval-shaped, silver-scaled predatory fishes of African freshwaters. There are several species, the largest of which can reach 150 pounds. They are named for horizontal stripes along their sides, and for the rows of large, sharp teeth that line their mouths. They are prized by fishermen as a game species.

The swallow capture wasn't an isolated incident. The research team that published it reported about twenty separate swallow-snatching incidents per day, which represents as many as 300 barn swallows meeting their maker during the fifteen-day survey.

Think about that for a moment. Swallows are known for their speed and agility as they maneuver after insects on the wing. These birds are probably going at least twenty miles per hour when they suddenly become fish food. I have a hard time imagining a fish without any presence of mind having any success at catching a swallow in flight. Without planning, I think a million hopeful random fish leaps and snaps at the air wouldn't yield a feather. Even if the tigerfish waited just below the surface for an approaching bird, then launched straight up from the depths—as great white sharks do to catch seals porpoising across the surface—I am guessing said fish would be doing an air-snap at a swallow long gone. But the grainy footage of a successful catch didn't reveal a vertical leap by the fish. Instead, the bird was ambushed from the rear. In the video of the fish catching the swallow, the fish leaps at great speed from directly behind the bird, and overtakes it in midair before splashing back into the water.

The four ecologists describe two distinct methods of attack being used by the tigerfishes. One involves skimming along the surface immediately behind the swallow, then launching to catch it. The other is a direct upward attack initiated from at least 1.5 feet below the surface. The advantage of the first approach is that the fish need make no adjustment for the surface-image shift due to light refraction at the water surface, which from underwater makes the swallow appear to be behind where it actually is. One disadvantage of this method is that it may compromise the element of surprise. Obviously, at least some of these fishes have learned to compensate for the distortion angle of the water surface, or else they would have no success with the second method.

This behavior raises a host of questions. How long have tigerfishes been doing this? How did it originate? How was it transmitted through the tigerfish population? And why aren't swallows taking evasive action to avoid being caught, such as flying farther above the water?

I decided to ask the lead author of the tigerfish bird predation studies, Gordon O'Brien, a freshwater ecologist from the University of KwaZulu-Natal's School of Life Sciences, in Pietermaritzburg, South Africa: "The tigerfish population in Schroda Dam was only established very recently from the lower reaches of the Limpopo River, in around the late 1990s. So the population there is very 'young,'" replied O'Brien. "Although tigerfish are faring well within most of their range, in South Africa they are declining due to numerous human impacts. As a result, tigerfish have been placed on the South African protected species list, and introductions to man-made habitats are ongoing."

I asked O'Brien how the bird-hunting behavior originated. He explained that from a tigerfish's perspective the dam is very small, and that he believes the population has been forced to adapt or perish. He and his colleagues saw many larger individuals in very poor condition around the period when this behavior was first recorded in 2009.

O'Brien also had quite a bit to say about the ways in which bird hunting is transmitted through tigerfish populations: "This seems to be a learned behavior. Smaller individuals are not as successful and prefer a 'surface chase' approach to ambushing and striking from deeper below the surface, where the individual has to compensate for the light refraction.… We know that tigerfish are very opportunistic and are attracted to heightened activity of other individuals—they get into some sort of a feeding frenzy. When the swallows return on their migrations the sight is quite spectacular and I think that it is during this period that the younger [tigerfishes] learn the behavior."

Avivory (the technical term for eating birds) is not unique to tigerfishes. Largemouth basses, pikes, and other predatory fishes have been witnessed on rare occasions leaping up to grab small birds perched on reeds near the surface. Large catfishes were recently filmed catching pigeons who come to drink from the shallows of the River Tarn in southern France; they use the same ambush technique used by orcas to catch sea lions, lunging and beaching themselves temporarily as they try to grab the prey with their mouths.

It isn't likely that these fishes are showing off. They may actually be hunting birds out of desperation. Schroda Dam is a man-made habitat built in 1993, and the tigerfishes were introduced there to help boost their populations, which were dwindling elsewhere in South Africa. Earlier study had shown that the Schroda Dam tigerfishes are spending considerably more time foraging (up to three times more) than other local tigerfishes, possibly due to food scarcity in the lake. The behavior may even put the tigerfishes themselves at risk of predation from African fish eagles, who are common in the area. The pigeon-catching catfishes at the River Tarn might share a parallel plight. Introduced in 1983, they have survived, but pigeons are not normally on a catfish's grocery list, and the fishes may be pursuing the birds due to a documented shortage of their usual prey: smaller fishes and crayfish. If necessity really is the mother of invention, then it applies to fishes, too.

The authors of the discovery at Schroda Dam cite published notes from 1945 and again in 1960, from other locations in South Africa, by biologists who suspected that tigerfishes were catching birds in flight. Maybe one enterprising tigerfish made a lucky strike at an unsuspecting swallow, then honed his or her skill through practice. The behavior could have spread through the population by observational learning, which fishes can be very good at, as archerfishes demonstrate.

However it started, it has the hallmarks of flexible, cognitive behavior: it is opportunistic, since it is unusual behavior for the species; it requires practice to develop, and skill (and no doubt many failed attempts) to execute; it is almost certainly transmitted through observational learning; and different methods are used.

As for why the swallows have not learned to avoid tigerfishes by flying higher above the water, there are several possibilities: (a) the swallows simply aren't aware they're being caught by fishes; (b) the birds benefit energetically by flying just above the surface; and/or (c) that's where most of the insects are. It seems doubtful that the birds haven't detected the danger, for it would be hard not to notice a sizable fish bursting from the water to grab a colleague flying nearby. Maybe capture by a fish is too rare an event, and the benefits of foraging near the surface too great, for the swallows to abandon surface flying.

Fishes Versus Primates

If fishes can innovate and learn to perform exacting, risky maneuvers to catch food, can they also reason their way through a space-time puzzle designed by humans? Imagine you are hungry and I offer you two identical pieces of pizza. I also tell you that the one on the left will be removed in two minutes, while the other one will not be taken away. Which piece will you eat first? Assuming you're hungry enough to eat both pieces, you will almost certainly start with the piece on the left.

Now imagine you are a fish—a cleaner wrasse, in this instance—and you are offered a similar situation: two plates of identical food that differ only in their color. If you start eating from the blue plate, then the red plate is removed; if you choose red first, the blue plate is left where it is and you can have both. Since we can't simply tell a fish that the red plate will be removed first, the fish has to learn it by experience. Elsewhere, similar experiments have been done with three species of brainy primates: eight capuchin monkeys, four orangutans, and four chimpanzees.

Who do you think did better? If you guessed it was one of the apes, no pizza for you. The fishes solved the problem better than any of the primates. Of the six adult cleaner wrasses tested, all six learned to eat from the red plate first. It took them an average of forty-five trials to figure it out. In contrast, only two of the chimpanzees solved the problem in less than one hundred trials (sixty and seventy, respectively). The remaining two chimps, and all of the orangutans and monkeys, failed the test. The test was then revised to help the primates learn, and all of the capuchins and three of the orangs got it within 100 trials. The other two chimps never did.

The researchers—ten scientists in Germany, Switzerland, and the United States—then presented the successful subjects with reversal tests, in which the plates suddenly took on the opposite roles. No one took well to this bit of deviousness. And only the adult cleaner wrasses and the capuchin monkeys switched preferences within the first hundred trials.

Several juvenile cleaner wrasses were also tested, and they performed markedly worse than the adult fishes, indicating that this is a mental skill that must be learned. One of the study authors, Redouan Bshary, even tried the test on his four-year-old daughter. He set up an equivalent "foraging" trial, placing chocolate M&M's on distinctive permanent and temporary plates. After one hundred trials she had not learned to eat from the temporary plate first.

The authors draw a key conclusion: "The sophisticated foraging decisions which cleaner wrasses demonstrate … are not easily achieved by other species with larger and more complexly organized brains." But these skills did not come out of the blue (so to speak). The wrasses' shrewd choice of which plate to eat from first resembles decisions these cleanerfishes have to make in the wild during interactions with client reef fish. And the logic of the experiment was deliberately designed to mimic that situation. Brain size be damned, if it's critical to a species' survival then that species will most likely be good at it.

Because cleanerfishes make their living by gleaning tidbits from the bodies of other fishes who have their own agendas, they need to be more attentive to the possibility that that food source might swim away at any moment. Bananas don't do this; transient client fishes do. And cleaners get a lot of practice. Even on a slow day at the office, cleaner wrasses service hundreds of clients. When business is booming, they can have more than 2,000 interactions per day with a great variety of clients—some of them "regulars" who are residents of the reef, others (perhaps other species) "visitors" who are just passing through. Cleaners are able to discriminate between the two, and they start by servicing visiting clients who will swim off and visit another cleaner at another station if not inspected immediately. Regulars will still be around later on. Red plate, blue plate.

If you're like me, you're rather disappointed in the performance of the primates in what to us seems like a fairly straightforward mental challenge. "The apes' unexpected lack of success appeared to be due to frustration with the task," write the authors. It certainly isn't because they are stupid. Great apes are renowned for solving puzzles, some of which they do better than humans can. For instance, chimpanzees far outperform humans in a spatial memory task with numbers randomly scattered on a computer screen. They also have the wits to use Archimedes' principle—which exploits an object's buoyancy—when confronted with a peanut sitting at the bottom of a clear narrow tube. Unable to dislodge the peanut or to reach into the tube, they will retrieve water from a nearby source, carry it in their mouths, and squirt it into the tube until the peanut floats within reach. Some inventive chimps will even urinate into the tube. Orangutans make mental maps of the locations of hundreds of fruiting trees in their forests, as well as the schedules on which they produce fruit. They are also renowned for their escape artistry, being able to pick locks, and they have even tricked keepers into giving up their keys.

But those are different types of skills. It also probably didn't help the primates that they were all born in captivity, where food was routinely provided several times per day and was not taken away. By contrast, the wrasses were wild-caught and had to fend for themselves during their lives.

* * *

When fishes outperform primates on a mental task, it is another reminder of how brain size, body size, presence of fur or scales, and evolutionary proximity to humans are wobbly criteria for gauging intelligence. They also illustrate the plurality and contextuality of intelligence, the fact that it is not one general property but rather a suite of abilities that may be expressed along different axes. One of the reasons that the concept of multiple intelligences is so appealing is that it helps explain how one person can be an excellent artist or an accomplished athlete yet do rather poorly at, say, mathematical or logical tasks. It diminishes the importance we have historically placed on "intelligence" as defined by a selection of human abilities that's too narrow even for our own species.

To this point, most of what we have explored has involved fishes acting as individuals. But few fishes live alone; most are social creatures, and their societies reveal new facets of their lives.