PART IV
WHAT A FISH THINKS

Nothing is too wonderful to be true if it is consistent with the laws of nature.

—Michael Faraday

Fins, Scales, and Intelligence

> Every other animal currently considered stupid and boring has its own amazing secrets. It's just that nobody has been able to discover them yet.
>
> —Vladimir Dinets, *Dragon Songs*

Through time, evolution sees to it that animals become highly proficient at what is important to them. We cannot climb as well as a chimpanzee, who has four to five times our upper-body strength. We cannot sprint like a cheetah, or hop like a kangaroo, and a speeding marlin would be at the finish line of a 100-meter race before Michael Phelps came up for his first breath. These animals need to move fast for survival more than we do, and natural selection dictates that faster individuals are more likely to carry their genes for fleetness into the next generation.

The same principle applies to mental abilities. If nature presents a mental problem, and solving it confers a big advantage, then over time creatures may gain the capacity to perform cognitive feats we would otherwise think were beyond their grasp just because they are small, or not closely related to us. The modern scientific field of cognitive ecology recognizes that intelligence is shaped by the survival requirements that an animal must face during its everyday life. Thus, some birds can remember where they buried tens of thousands of nuts and seeds, which allows them to find them during the long winter months; a burrowing rodent can learn a complex underground maze with hundreds of tunnels in just two days; and a crocodile can have the presence of mind to carry sticks on her head and float them just below an area where herons are nesting, then pounce when an unwary bird swoops down to collect nesting material. If you didn't know a reptile could demonstrate planning and tool use, don't feel left out; neither did scientists until this came to public attention in 2015.

What about the mental abilities of fishes? Notwithstanding the liberties taken by filmmakers in popular movies like *The Little Mermaid*, *Finding Nemo*, and its sequel, *Finding Dory*, can fishes really think? Let's have a look at what fishes can do with those brains of theirs.

Here's an example of fish intelligence, courtesy of the frillfin goby, a small fish of intertidal zones of both eastern and western Atlantic shores. When the tide goes out, frillfins like to stay near shore, nestled in warm, isolated tide pools where they may find lots of tasty tidbits. But tide pools are not always safe havens from danger. Predators such as octopuses or herons may come foraging, and it pays to make a hasty exit. But where is a little fish to go? Frillfin gobies deploy an improbable maneuver: they leap to a neighboring pool.

How do they do it without ending up on the rocks, doomed to die in the sun?

With prominent eyes, slightly puffy cheeks looking down on a pouting mouth, a rounded tail, and tan-gray-brown blotchy markings along a three-inch, torpedo-shaped body, the frillfin goby hardly looks like a candidate for the Animal Einstein Olympics. But its brain is an overachiever by any standard. For the little frillfin memorizes the topography of the intertidal zone—fixing in its mind the layout of depressions that will form future pools in the rocks at low tide—while swimming over them at high tide!

This is an example of cognitive mapping. The use of cognitive maps is well known in human navigation and was long thought to be unique to us until discovered in rats in the late 1940s. It has since been documented in many types of animals.

The goby's skill was demonstrated by the biologist Lester Aronson (1911–1996) at the American Museum of Natural History, in New York City. Around the time the rats were wowing us with their cognitive mapping skills, Aronson constructed an artificial reef in his laboratory. He compelled his gobies to jump by poking a predator-mimicking stick into one of his constructed tide pools. Fishes who had had the opportunity to swim over the room at “high tide” were able to leap to safety 97 percent of the time. Naive fishes who’d had no high-tide experience were only successful at about chance level: 15 percent. With just one high-tide learning session the little gobies still remembered their escape route forty days later.

It should be noted that these fishes were almost certainly stressed during these experiments, having been captured from their wild homes and confined in foreign surroundings. Indeed, several died of disease during Aronson’s study, which suggests they were not thriving in their captive setting.

In a recapitulation of patterns we see in other studies, individual performance reflected experience in their wild microhabitats. Fishes collected from beach areas that lacked tide pools at low tide did not perform as well as their seasoned comrades—though they still performed much better than chance. A recent study has found that the brains of rock pool–dwelling goby species are different from those of goby species that hide in the sand and don’t need to jump to safety: the brains of the jumpers have more gray matter devoted to spatial memory, whereas the sand dwellers have a greater neural investment in visual processing.

Frillfin gobies’ ability to make mental maps, allowing them to leap accurately between tide pools, is a textbook example of having a well-honed mental skill wrought of necessity. As the biologist and author Vladimir Dinets, an authority on behavior and cognition in crocodilians, says: “When people use the word ‘intelligence’ what they usually mean is ‘being able to think the same way I do.’” It’s a pretty self-centered way to view being smart. I suspect if a frillfin goby could formulate a definition of intelligence, it would include being able to form and remember mental maps.

Remembering the Escape Route

Forming cognitive maps and recalling them weeks later illustrates more than a frillfin goby’s prodigious talent for avoiding a leap of faith. It also exposes the human prejudice to underestimate creatures that we don’t understand. I do not know what the species did to earn it, but the (gold)fish’s legendary “three-second memory” still lurks in popular culture (just try Googling it). I still see an investment company’s advertisement at airports that uses the goldfish's putative three-second memory to contrast with the importance of our maintaining business connections. (I also wish to declare, with some humility, that my memory sometimes falls shy of three seconds, as when I forget where I absentmindedly placed my mobile phone or my eyeglasses.)

Being able to remember something is as useful to a fish as to a finch or a ferret. Tony Pitcher, a biology professor at the University of British Columbia, recalls a classroom study in an animal behavior course he taught many years ago. The students were exploring color vision in goldfishes. Each fish was assigned a feeding tube painted with subtly differing hues, and the fishes demonstrated their good color vision. After the study, the goldfishes were returned to an aquarium. The following year, some of these same fishes were combined with a new group of novice fishes for the study. When placed in the study habitat, the veterans quickly reestablished themselves in their former tubes, making it immediately evident that each remembered the exact color and/or location of its tube from one year before.

The study of fish memories is not a new thing. In 1908, Jacob Reighard, a professor of zoology at the University of Michigan, published a study in which he fed dead sardines to predatory snapper fishes. Some of the sardines were dyed red, some not. The snappers didn't mind, and gobbled both types. But when Reighard made the red sardines unpalatable by the gruesome method of sewing stinging medusa tentacles into their mouths, the snappers soon stopped eating the red ones. Notably, the snappers still wouldn't touch red sardines twenty days later. This experiment not only demonstrates a snapper's memory, but also his capacities to feel pain and to learn from it.

My favorite study of fish memory comes from Culum Brown, the biologist with a particular interest in fish cognition. Brown is the coeditor of *Fish Cognition and Behavior*, a book that has helped to propel the current revolution in our thinking about fish thinking.

Brown collected adult crimson-spotted rainbowfishes from a creek in Queensland, Australia, and transported them to his lab. They are named for a kaleidoscope of bright colors arranged in bands of scales along their flanks. Adult rainbowfishes are about two inches long, and Brown guessed these ones were between one and three years old. He placed the fishes in three large tanks, about forty to a tank, and allowed them a month to get used to their surroundings.

On testing day, he removed three males and two females at random from their home tanks and put them in an experimental tank, equipped with a pulley system that allowed a vertical net (the trawl) to be pulled along the length of the tank. The mesh size of the trawl was less than half an inch, allowing the fishes a clear view to the other side without being able to squeeze through its holes. A single, slightly bigger hole measuring three-quarters of an inch across was placed at the trawl's center, providing an escape route when it was dragged from one end of the tank to the other.

The fishes were given fifteen minutes to adjust to their new environment, then the trawl was dragged from one end to the other over a period of thirty seconds, stopping just over an inch from the end. The trawl was then removed and placed back at its starting position. This constituted one "run" of the experiment. Four more runs followed, at two-minute intervals. Five groups of five fishes were tested in 1997, then tested again in 1998.

In the 1997 trials the rainbowfishes panicked during the first run, darting about erratically and tending to cling near the tank edges, apparently not knowing what to do to escape the approaching trawl. Most of them ended up trapped between the glass and the net. Thereafter, their performance improved steadily, and by the fifth trial each shoal of five was escaping through the hole.

When the same fishes were retested eleven months later—having not seen the experimental tank or the trawl in the intervening period—they showed much less panic than they had the previous year. And they found and used the escape hole, on the first run, at about the same rate as they had by the end of the 1997 runs. "It was almost as if they had had no break and had ten runs in a row!" Brown told me.

By the way, eleven months is nearly one-third of a rainbowfish's life span. That's a very long time to remember something that has happened to you only on one occasion.

There are many other examples of fishes showing the remembrance of things long past. These include the studies showing hook shyness by carps for over a year, and paradise fishes who for several months avoided an area where they were attacked by a predator. And there are legions of anecdotes, like the story of Bentley, a captive humphead wrasse. When his usual dinner gong was reintroduced after months of disuse, Bentley raced to the spot where his favorite meal of squid and prawns was served.

Living and Learning

Memory is closely intertwined with learning, for to remember something one must first come to know it. "For almost every feat of learning displayed by a mammal or a bird, one can find a similar example in fishes," writes the fish biologist Stéphan Reebs. If you want to impress someone with your knowledge of esoteric fish jargon, try rattling off these types of learning by fishes: non-associative learning, habituation, sensitization, pseudoconditioning, classical conditioning, operant conditioning, avoidance learning, transfer of control, successive reversal learning, and interactive learning.

You can watch YouTube videos of goldfishes being clicker-trained to swim through hoops and push balls into miniature soccer goals. This is achieved through conditioning, or learning by association. On performing the desired behavior, the fish receives a stimulus, such as a flash of light, immediately followed by a food reward. The fish soon learns to associate both swimming through the hoop and the light flash with the reward. In time, the fish will know to swim through the hoop when it sees the light flash alone, and will hopefully perform the task even when no food is given. It's the same approach used to clicker-train dogs, cats, rabbits, rats, and mice.

(With some humility, we may recognize that the fishes are our captives, and we are the ones in control in experiments like these. Many are not given the enrichment and space they need, and instead spend their days in what often amounts to barren confinement, without the companionship of others of their kind, and with few if any places to hide. If the only way for an animal to get food is to push around a ball, he's likely to do it. If we were in a similar situation, we'd probably do it, too. On the other hand, this is still preferable to the common alternative of captive fishes getting no stimulation other than food and whatever activity they can observe going on outside the glass.)

Aquarium fish owners often report how their pets seem to know when it is feeding time. Simple captive experiments bear this out. For example, Culum Brown and his colleagues fed captive *Brachyrhaphis episcopi* fishes (locally known as “bishops”) at one end of their tank in the morning and the other end in the evening. Within about two weeks, the fishes were waiting at the appropriate place and time. Golden shiners and angelfishes take three to four weeks to achieve this so-called *time-place learning*. By comparison, rats take slightly less, about nineteen days, and garden warblers learn slightly more complex tasks involving four locations and four time periods in just eleven days. These numbers are only modestly meaningful, for they assume equal levels of interest in food—the motivator used in learning experiments—over time. In fact, fishes normally eat at much slower rates (about twice a day) than small birds (every few minutes), so it is harder to keep them motivated for learning experiments, and their learning rates may appear artificially slower.

Fishes’ ability to learn quickly is being used to improve the poor survivorship of hatchery-reared fishes after they are released into the wild. Growing up in captive confinement—swimming in circles, receiving food pellets on schedule, and having no exposure to dangerous predators—is a vastly different experience from surviving in the wild. Lacking the worldly survival skills of their wild compatriots, only about five percent of some five billion captive salmons released globally each year to build numbers for angling survive to full adulthood. Research shows that animals bred and reared in captivity for many generations can lose their ability to recognize predators, probably because the ability confers no survival benefit for them.

But when the biologists Flávia Mesquita and Robert Young from Pontificia Catholic University of Minas Gerais, Brazil, exposed very young Nile tilapia to a taxidermied piranha (wrapped in clear plastic to eliminate the release of odors into the water), then immediately caught them at the bottom of the tank with an aquarium net, the tilapia quickly associated the unpleasant netting experience with the sight of the predator. After just three trials tilapia were swimming quickly away in all directions. This “scatter effect” confuses predators. After twelve piranha-netting experiences, the formerly naive youngsters had modified their anti-predator response by rising to the surface and remaining motionless. Control fishes who were not netted initially steered clear of the piranha model—a typical avoidance response by fishes toward a new, unfamiliar object—then soon just ignored it. When the trained fishes were retested seventy-five days after their last training session, more than half of them remembered what they had learned.

Like most studies of fish cognition, these were performed on bony fishes. How do elasmobranchs (the sharks and rays) score in learning tasks? As early as the 1960s, nurse sharks had matched wits with mice on a black-and-white discrimination task, with both species performing at 80 percent success after five days. Demian Chapman with the Institute for Ocean Conservation Science has shown with playback experiments that oceanic whitetip sharks have learned to investigate fishing boats when they shut down their motors, because that signals that a fish has been hooked, and there's an opportunity to get it before the fisherman does. These behaviors suggest a being with a mind.

In a study of problem solving by a cartilaginous fish, a team of biologists from Israel, Austria, and the United States presented hard-to-reach food to vermiculate river stingrays, a freshwater species from South America. In the wild, these rays forage on small animals such as clams and worms buried in the sand by uncovering them and sucking them into their mouths.

During training sessions, the five young stingrays soon learned that an eight-inch piece of plastic PVC pipe contained a piece of food, and they successfully accessed the morsel by creating water suction to draw it toward them. One of the two females was successful in all of her trials, perhaps because she appeared to watch the other rays before her first attempts. Within two days, all five rays had mastered the task. They used different strategies. The two females used undulating fin movements to create a current inside the pipe that moved the food toward them. The three males sometimes used this technique, but more often they used their disk-like body as a suction cup or they combined the suction and undulation methods. (It isn't certain whether these gender differences were coincidental or whether they actually reflect a gender difference in foraging styles in this species.)

Next the experimenters upped the ante. They attached a black and a white connection piece to opposite ends of the pipe. The black connection piece had a mesh barrier inside that would block passage of a piece of food, while the white connection piece had no mesh. Each ray was tested over eight sessions, and by the end all were successfully extracting the food from the pipe by working from the white end. Interestingly, all five rays changed their strategies during this phase of the study. The shift was generally from using undulating fin movements or suction to a combination of both. One male also blew jets of water from his mouth into the pipe to force the food out.

These experiments show that stingrays not only learn, but that they can innovate to solve a problem. And they show tool use by using an agent to manipulate an object, in this case using water to retrieve food. Furthermore, moving away from a strongly attractive cue—the smell of food at one end of the tube—and trying the other side is not a trivial thing; it means they have to work against their natural impulse to follow chemical cues. That involves flexibility, cognition, and a sprinkle of determination.

Malleable Minds

You might be thinking that the 20 percent failure by mice and nurse sharks I mentioned a little earlier is still considerable, and that animals should perform at 100 percent if they want to be considered smart. But like other animals, fishes are not interested in their test scores. They don't succeed by robotically adhering to set patterns of living. They are evolved to be flexible and curious, to try new angles, to think outside the box (or the tube). Even highly trained fishes will always explore alternatives; it's a productive way to behave in the real, dynamic world. With the ever-present threats of storms, earthquakes, floods, and, nowadays, human incursions, it pays to be light on one's fins.

That said, I'm not even remotely suggesting that intelligence is uniformly distributed among the diversity of fishes. Inevitably there are smarter and duller individuals. Then there are differences relating to a species' natural history. More challenging habitats demand more mental sharpness from their residents. As we saw in frillfin gobies living in different shore environments, variations in the sizes of different brain regions and in their associated intelligences can be found within a single species.

Here's an example of how ecological challenges can affect intelligence, from K. K. Sheenaja and K. John Thomas at Sacred Heart College, Kerala, India. In the wild, climbing perches occupy both still and moving water habitats. Individuals were collected from two Indian streams (moving habitat) and compared for their ability to learn a maze with fishes collected from two nearby ponds (still habitat). To navigate the maze, they had to find their way through a small door in each of four walls in their tank to get to a food reward at the other end.

Guess who learned the route faster? It was the stream dwellers. They learned the maze in about four trials, compared to six trials for the average pond dweller. When the research team added visual landmarks by placing a small plant next to each door, the pond perches improved their performance to almost the level of the stream perches, who performed no better than they had before. Apparently, the pond dwellers found the landmarks useful, while the stream dwellers ignored them.

Sheenaja and Thomas have an elegant interpretation for these behavior patterns. Streams are more dynamic habitats than ponds because they are constantly subjected to the flow of water, including periodic floods. Stones, plants, and other landmarks are unreliable for learning a travel route because they are constantly changing as the water flows through. The most reliable constant is oneself. Thus, the better raw maze performance by the stream fishes may be attributed to their relying more on "egocentric cues" than visual ones. By contrast, landmarks are more reliable in a relatively stable habitat like a pond, so it pays to become familiar with them. (Incidentally, studies that find population-level differences within a single species are interesting for another reason: they illustrate evolution in action. One can imagine that if these populations don't interbreed for many generations they might eventually diverge to the extent that they are unable to successfully interbreed. That would qualify them as separate species.)

The malleable mind of a fish can be trained to correct unwanted behaviors, and that can be useful in captive situations. Lisa Davis, a zoological manager of behavioral husbandry for Disney Animal Programs, described to me how they corrected a behavioral problem they were having with their cobias. These large, sleek fishes grow to more than six feet and 172 pounds. With a gourmand's appetite, they are prone to becoming overweight in aquariums. The cobias under Davis's care were having this trouble as well. During feeding hours, they were out-competing the other fishes. So Davis and her team taught them to swim to a particular station in their environment where they would be hand-fed pieces of food. This removed them from the competitive environment where other fishes were being fed “buffet style” twenty feet away. The other fishes in the tank got their fair share, and the cobias returned to more normal weight. Win-win. “Even their previously bulging eyes reduced back to normal positions,” Davis told me.

Similarly, when aquarium residents need medical attention, collaboration is best. Manta rays and groupers at Ocean Park Hong Kong, the Georgia Aquarium in Atlanta, and Epcot Center in Orlando have all learned through positive reinforcement training to swim into stretchers for transport. Using positive reinforcement to train fishes to participate willingly in their care and feeding makes life more interesting and rewarding for captive fishes, and may help dispel former stereotypes about their intelligence.

To this point we’ve seen that fishes are not dunces, that they display features of having a mind and a mental life. But what about some of the more celebrated forms of intellect, such as the ability to plan, and to use tools?