

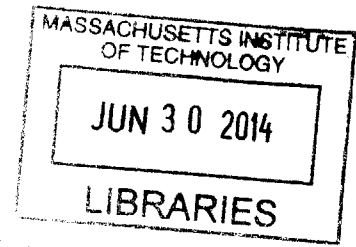
One Fish, Two Fish, Lungfish, Youfish:
Embracing Traditional Taxonomy in a Molecular World

ARCHIVES

By

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SUBMITTED TO THE PROGRAM IN COMPARATIVE MEDIA STUDIES/WRITING
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ABSTRACT

In today's increasingly digitized, data-driven world, the "old ways" of doing things, especially science, are quickly abandoned in favor of newer, ostensibly better methods. One such discipline is the ancient study of taxonomy, the discovery and organization of life on Earth. New techniques like DNA sequencing are allowing taxonomists to gain insight into the tangled web of relationships between species (among the Acanthomorph fish, for example). But is the newest, shiniest toy always the best? Are we in danger of losing vital information about the world if we abandon the thousands of years of cumulative human knowledge to gather dust in basements? This thesis explores the current crossroads at which taxonomy finds itself, and offers a solution to preserve the past while diving headlong into the future.

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In the basement of Harvard University's Museum of Natural History, over one million dead fish lie gathering dust. Some are preserved in glass jars of formaldehyde or alcohol, others are dried and mummified, and a few are stuffed and mounted like trophies. Among a jumble of several ivory-colored skeletons is one particular specimen of blue parrotfish, *Scarus coeruleus*, that's older than the museum itself. It arrived at Harvard in 1869 from Cuba wrapped in newspaper, was filed away in a drawer and sat there unopened for 144 years. I happened to be exploring the collection, indulging my lifelong fascination with fish, when I found the parrotfish still sealed in its paper cocoon. Intrigued, and with the somewhat bemused consent of the collection's curator, I carefully began to unwrap it.

The newspaper had turned tobacco-brown with time and crumbled in my fingers like dead leaves. *Diario de la Marina* was printed across the top in bold, black letters, and below that "El periódico oficial del apostadero de la Habana" - "the official newspaper of the colony of Havana," Cuba. This issue was dated Tuesday, the 31st of August 1869. The news briefs on the front page included a London Evening Post report that Spain had firmly refused the United States' most recent propositions regarding Cuba's independence. The fragment of another article detailed the most recent military offenses against the Spanish forces. All had clearly not been quiet on this fish's home front.

Along with the parrotfish's skeleton, I discovered a packet of its scales, contained in what looked like a folded letter. I opened that, too. Beautiful cursive writing stretched across the crinkled, time-stained page, dated July 13th. "My dear father," it

began in Spanish, "The other day I sent you a barrel; inside were fifteen and a half yards of cloth for wrapping fish..." It was signed "Your daughter, Amelia." The other million fish around me were immediately forgotten. Who was this father was whose hands had so lovingly wrapped his daughter's words around this fish, preserving a slice of history and his own life along with its bones? That question would launch me on a months-long quest deep into the heart of taxonomy - the science of organizing life.

The man was Felipe Poey, Cuba's most celebrated naturalist and one of the most prolific zoologists of the nineteenth century. Over the course of his long career he catalogued thousands of species and supplied hundreds of samples to Louis Agassiz, who founded Harvard's museum in 1859. He employed Poey as a kind of freelance naturalist to help achieve his grand ambition: to acquire a sample of every animal on Earth and classify them according to their divinely prescribed order. Poey certainly delivered; some of his shipments contained over fifty specimens of Cuban fish, and several species bear his name today.

While Poey and Agassiz kept up a cordial, professional exchange chronicled by letters, meticulous receipts and species lists, the field of taxonomy around them was in an uproar. Darwin's *On the Origin of Species* had just been published, adding more fuel the raging debate over how classifying and naming creatures should be done. While Poey carried on as he always had, carefully cataloging the genus and species names of his samples, those categories were being jostled around, the relationships between them coming under scrutiny. Despite his prominence at the time, Poey

flew under the radar of history because he remained committed to the old ways, never fully engaging with the evolutionary theory that eventually became the basis for the new taxonomy.

Today, taxonomy is embroiled in another debate. The standoff now is not between evolutionists and creationists, but between those who use DNA to classify organisms and those who stick to the traditional method of using physical traits. The straight, black lines between species that we see on evolutionary trees in textbooks seem to promise that this, finally, is the truth about how those species came to be and are related. But taxonomists are far from agreeing on what arrangement is actually correct. Even the species that we thought we'd known for generations are being called up for questioning.

Most of us, like Poey, would be content to ignore the debate and continue on with life as usual. After all, it's not often that someone comes up to us on the street and demands to know whether we think the blue parrotfish belongs in the family Scaridae or Labridae. But we use taxonomy all the time, often without realizing it. We classify animals as tame or wild; people as friends, family or acquaintances; clothes as formal or casual. When our inherent taxonomic system is turned on its head, the outcome often seems ridiculous, even if it's scientifically true (like saying that birds are descended from dinosaurs).

But that's just what modern taxonomy is doing. It's calling into question our innate organizational system that has evolved over the millennia, beginning with our ancestors' earliest attempts to understand the world around them and subsequently being woven throughout art, religion, philosophy, literature and science. Poey

was devoted to uncovering what he thought was the natural order of the world, and he wasn't the first. Scientists today continue to tackle that age-old pursuit, but the way they go about it is quite different from shipping fish in barrels.

Dr. Tom Near would fit right in at a startup or tech company like Google. Large, twin Mac computer monitors on his desk dominate his gleaming white office at Yale University. Every minute or so a new word scrolls across the glowing blue screens with its definition below, exciting my inner trivia nerd: Hydrophobia. Tumid. Apothegm. A long table against one wall of the office is covered in neatly arranged stacks of clipped papers on top of manila folders. Near himself enters from his department's lounge where he has just set a pot of coffee brewing. With his square, dark-framed glasses, brush-cut dark hair and beard flecked with gray, and purple checked Oxford shirt, he matches the stereotype of "tech junkie."

Near is one of the leading experts in using computer-based methods to analyze DNA sequences. The only thing that gives away exactly what kind of DNA he studies is a large drainage map of the United States hanging on the wall, which shows how all of the country's major rivers flow into one another and ultimately empty into the oceans. But Near isn't interested in the rivers so much as what they contain: fish.

"The group of fish I work on is called darters. They're a really charismatic group of North American freshwater fish. I'll show you a picture," he says excitedly, taking down a book from the packed floor-to-ceiling bookcase. It's called *The Fishes of*

Tennessee, an immense, 600+ page hardcover tome that would put a serious dent in an undergraduate's bank account.

"There's about 250 species, they're found only in eastern North America. They're beautiful," he says as he flips through the well-worn book. He stops on a page showing drawings of small fish with rounded, feathery fins and bright, jewel-like colors. He points to one that has a horizontal line of black blotches running the length its pale body and swaths of bright red painted along its belly and on its fins. It's called a cherry darter. "They do weird stuff, these guys. The males defend their nest territories under rocks, and they have knobs on their fins that look like eggs. They're thought to mimic eggs to draw females in; the idea is 'Oh, he knows what he's doing.'

"The red banded darter is one of my favorites," he says, indicating another fish that sports pale green and orange stripes with a streak of red at the base of the dorsal fin on its back. He talks about these fish with the passion of a true outdoorsman who has spent a good deal of time with them, confounding my first impression of him as a computer guy. The truth is, he's both.

Near, a native Chicagoan, grew up fishing in Lake Michigan with his father, and at a young age became curious about the different non-game fish that they sometimes reeled in on the ends of their poles. That interest in diversity led him to enroll in Northern Illinois University, thinking he wanted to be a microbiologist and study different kinds of bacteria. But the labs he worked in mostly focused on biochemistry, analyzing individual proteins and enzymes rather than the bacteria

themselves. It was a discipline he found "very reductive and just not my thing."

Then during his sophomore year he took a course that would change his life: Microbial Systematics and Diversity. It was the late 1990s and DNA sequencing, the process of reading the letters that make up the genetic code, was just starting to become easier. Now that scientists could look at complete genes, they could compare those genetic sequences in different organisms and determine how closely related the samples were. "And I realized, 'Wow, you can apply this to fish!' And maybe one can make a living doing this," he says.

Since then Near's work has been largely focused on the family trees of different groups of fish, mostly the darters, and trying to figure out how their evolutionary pasts led to the current landscape of species. When he got to Yale, he started to become interested in what he calls the "big picture stuff." He wanted to make his work with darters more broadly applicable and beneficial to the wider scientific community. To do so, he decided to undertake an ambitious project: figuring out the genetic family tree for a much, much larger kettle of fish - on the order of 10,000 species.

One of the best places to see some examples of those thousands of fish is the Giant Ocean Tank, the crown jewel of Boston's New England Aquarium. The Tank's 67 windows glow in the center of the dim aquarium like Near's computer screens. But instead of words, creatures of all shapes and sizes drift across them, ranging from the majestic to the beautiful to the bizarre. Huge manta rays flap slowly through the clear water at the top, above the 20-foot tower of multicolored coral that

descends to the bottom of the tank. A twelve-foot long, kelly green moray eel slides past at regular intervals, mouth gaping open. Schools of shimmering, silvery permit fish the size of dinner plates dart by, competing for food with massive tarpon - torpedo-shaped, muscular fish with huge underbites. I giggle as a pufferfish motors slowly through the water, its fins moving comically fast at the sides of its tilt-prone, boxy body. A flounder appears swimming sideways, its body flat as a pancake, both bulbous eyes perched on the top side of its head, its pectoral fin sticking straight up like a flag.

Arranged around the Giant Ocean Tank are other exhibits representing different aquatic habitats and the species one is likely to find there. One tank hosts leafy sea dragons, their sine-curve bodies covered in thin leaf-like projections that help them blend in with the aquatic plants behind them. A thick-lipped grouper drifts forward out of the darkness of another tank and swims along the glass, the same size as the toddlers who stare at it in wonder. The Pacific Reef Community tank houses a motley of nearly 70 different kinds of fish in endlessly varied colors and shapes: long-snouted butterflyfish striped vivid black, white and yellow; three different kinds of angelfish; almond-shaped triggerfish with pointed snouts; blue and yellow tangs and beaked parrotfish in fuchsia and azure - they all swirl around each other in a glorious mess of hues and fins.

Their graceful, dizzying aquatic dance is hypnotic; I could park myself in front of one of the tank windows for hours, just watching them wheel through the water. Compared to them I feel drab and gangly, which is also what draws me to them. They're alien and familiar at the

same time, and take on more forms than I could possibly imagine. It's no wonder that Tom Near got hooked.

The vast majority of these "endless forms most beautiful and most wonderful,"¹ to borrow an often-used phrase from Darwin, belong to a class of fish called Acanthomorpha. Numbering 14,000-16,000 species, they comprise one-third of all living vertebrates on earth; there are more of this type of fish than all the amphibians and reptiles combined. The largest order of fish within Acanthomorpha is one called Perciformes, which contains Felipe Poey's blue parrotfish and Tom Near's darters and is the largest single order of vertebrates in the world.

Although it means "perch-like," Perciformes has traditionally been a kind of "waste bucket" category for the fish that don't quite fit into any other groups in the fish family tree; familiar ones like tunas, barracudas and snappers, and flat-out weird ones like seahorses, cusk-eels, lumpfish, and morwongs. This is the snarl of relationships that has longest withstood detangling: the "bush at the top" of the evolutionary tree. Trying to catalog and organize this hodgepodge of finned creatures has plagued ichthyologists and taxonomists over the centuries, and Tom Near is now undertaking the daunting task of resolving it once and for all.

For most of history, fish were classified according to their physical traits; if it looked like a trout, swam like a trout, and gulped air like a trout, it was probably a trout. Scientists like Poey painstakingly recorded even the most minute variations in their specimens,

¹ John van Wyhe, editor. 2002. The Complete Work of Charles Darwin Online (<http://darwin-online.org.uk/>).

sometimes down to the number of folds in their intestine, because differences in those “characters” were used to draw the line between species and group them into families. The ordering of life was and still is considered essential to understanding the world around us, because it allows for quick identification of later specimens and helps scientists understand how life on Earth developed. But what do you do when confronted with a leafy sea dragon, which almost looks more like a plant than an animal? If you have a shiny silver fish, a mottled brown fish and a smooth, rainbow-colored fish that are all shaped like a trout, are they variations within one species of trout, or three different species?

Many of those longstanding questions are now being answered, thanks to faster DNA sequencing and a resulting shift in the way taxonomy is done. Traditionally when scientists discover a new species, they describe its morphology, or its collection of physical traits, along with any behavior they’ve been able to observe, and then place it into the group of organisms with which it shares the most traits; for example, a fish that swims along the bottom of rivers and streams and has long whisker-like projections called barbels would be classified as a catfish. Other scientists who are experts on a given group of organisms will then evaluate the new species and either confirm the new discovery or propose a different grouping if they feel it has been identified incorrectly, which takes time and a bit of politicking. Now, “more and more people are actually saying ‘I’m going to sequence a piece of DNA from this thing that looks like a catfish, and compare it to these samples I’ve got for all these other catfishes,’” and

immediately get a sense of where it fits in the fish tree of life, says Near.

Once DNA is extracted from a tissue sample, molecular scientists isolate specific, well-known genes that are present across many species, such as *tbr1*, which is necessary for proper brain development. After a gene has been sequenced, scientists perform a “sequence alignment,” which is simply looking at the different samples’ genes and comparing the order of their molecules. If the two samples differ, it means there has been a mutation. DNA mutations happen occasionally when cells make errors in copying their DNA before they divide into new cells. The mistakes are usually automatically detected and fixed by the cell’s own machinery, and never affect the organism. But sometimes they escape the cell’s notice and get passed down to later generations.

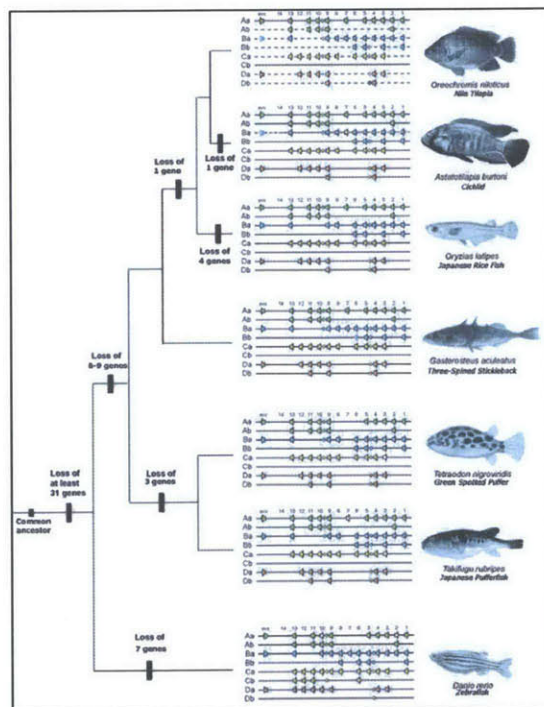


Figure 1: By comparing the same genetic sequences across different species, molecular taxonomists can determine when mutations most likely occurred in the past, and by extension, when those species diverged from each other.

Given enough time, mutations in certain individuals can accumulate to the point where they cause physical changes that give rise to new traits and, eventually, new species.

Just as a traditional taxonomist would use physical characters like the number of spines or shape of the dorsal fin to classify fish, molecular taxonomists examine genetic characters across species. By looking at how much two species' genes differ from the genes of their most recent common ancestor, it's possible to tell how closely they're related; the more genetic disparity, the longer ago a given species probably separated from the ancestor and thus the less closely related it is to the other species.

Near and his team performed sequence alignments for ten genes across 579 different species of Acanthomorph fish, mostly within Perciformes, and then used computer models to arrange all of the resulting families based on genetic relationships. Some of the results were a bit surprising. The genes tell us, for example, that flatfish are closely related to billfish. That means that a flounder (that odd, sideways-swimming fish from the New England Aquarium with both eyes on one side of its head) is essentially first cousin to a swordfish (an impressive sport fish renowned worldwide for its grace and power). And both of them are genetic second cousins to the swamp eel, a long, brown, snakelike fish that slithers through shallow freshwater habitats and has rudimentary lungs that allow it to breathe air. Another unlikely grouping puts anglerfish (scary-looking, deep-sea fish with long teeth and a glowing lure dangling from the tops of their heads) into the same family as pufferfish (those cube-shaped, poisonous fish which can

inflate to several times their size by filling their stomachs with water or air).

If these new families were to hold reunions, I expect things would be a little awkward.

These and other results completely go against our previous understanding of how fish are related. Saying that an anglerfish and a pufferfish are close relatives is like saying that opossums are more closely related to primates than they are to other marsupials. That sounds absurd, because it's clear from just looking at an opossum and a gorilla that they're very different. Opossums have pouches and long tails, pointy snouts and big ears, while gorillas lack all of those things. Yet this is the scale of disruption that genetics is causing in fish. Anglerfish and pufferfish look almost nothing alike and yet their genes say they are indeed kissing cousins.

There may be a method to all this taxonomic madness. Anglerfish, pufferfish and flatfish are all certainly strange in their own, very distinctive ways. "But isn't it kind of odd that those are the ones that are involved with the most dramatic taxonomic rebooting?" asks Near excitedly. The very fact that these strange-looking fish turn out to be close relatives might be telling us something about how extreme physical forms evolve. It may be that there was some tweak in those fishes' common ancestor long ago that enabled it to change its body shape more dramatically over the generations, giving rise to such diverse descendents. That would mean that the common sense of "similar-looking things are more closely related" might not always be true. Near thinks this is one of the most important insights from his work. "We're going to have a new revolution in how people interpret

phenotype,” the collection of an organism’s physical traits, he says.

More than any other animal, fish have the greatest disparity between the old groupings based on physical traits and the new ones that genetics is revealing. Rather than being concerned by the mismatch, Near is excited by the enormous possibility that molecular taxonomy has to resolve longstanding problems that have resisted traditional methods for centuries. “That’s really interesting and super neat,” he says, the coffee he made earlier completely forgotten.

It seems like knowing an organism is no longer necessary to classify it - all you need is a chunk of its DNA. All this focus on genes and computer sequencing makes me wonder what will happen to large collections of specimens like the one sitting in Harvard’s basement. Will they eventually be closed and shuttered forever, a mass tomb that would gradually be forgotten? Will their contents, along with hidden treasures like Felipe Poey’s letter from his daughter, be thrown out and erased from history? To answer those questions, Near directs me to “somebody who thinks all this [molecular stuff] is going the wrong way:” G. David Johnson, curator of the fish collection at the Smithsonian Institution. Within a month I find myself in his office in Washington, D.C. which is, appropriately, in the basement of the National Museum of Natural History.

If Tom Near’s office is a minimalist, 21st-century workspace centered around technology, Johnson’s looks like it was incongruously plucked from an antiques store. A carved wooden

Native American bust stares at me grimly from atop his Lexmark printer. Four bookshelves are packed with colorful series of books that look like old encyclopedias: *Oceanic Ichthyology*, dated 1895; *Resultats Campagnes Scientifiques*, published in 1920. A stuffed armadillo perches on the windowsill. Old advertising signs of painted wood and hammered tin cover almost all the available wall space, promoting things like Black Bass Plug chewing tobacco, a cure for typhus and a garage for rent. A silver boom box softly plays 1940s music.

Now in his mid-60s, Johnson has been at the Smithsonian for over 30 years. His grizzled gray hair and beard are streaked with white and his booming, gravelly voice still retains some of its native Texas twang. Wearing a white and red checkered shirt and jeans, he even looks like he could be sitting a Lone Star saloon; all he needs is a cowboy hat and some spurs.

“I’m that asshole at the fish market busting people who are trying to sell *Rhomboplites* as red snapper,” he says, giving a characteristically enthusiastic guffaw.

If anyone has spent a majority of their life thinking about and looking at fish, it’s Johnson. He entered graduate school at the Scripps Institution of Oceanography in 1970 with “this romantic notion that I wanted to work on whales and porpoises.” That goal abruptly changed when he and a group of other students decided to dig up a whale carcass from beneath the sand near San Diego. One of his professors had convinced the U.S. Navy to help bury the beast ten years earlier so that its skeleton would be preserved while the flesh was stripped away by microbes. Johnson shows me a picture of himself

holding the whale's tongue, the only soft tissue that was left. The stench of decomposing whale was so overpowering, says Johnson, "I still can't get it out of my mind to this day." That same year he took his first class in fish diversity, and decided to be an ichthyologist. His research has mostly focused on identifying fish in their juvenile, larval stage and he's discovered his fair share of new species. He's a morphologist through and through - molecular taxonomy didn't exist when he started classifying fish.

The first thing Johnson does is take me down the hall to meet some of his colleagues at the Department of Fishes' "Friday Fish Coffee Hour." We're greeted in the lunch room by seven scientists sitting around a large table drinking coffee out of paper cups and nibbling on prepackaged cookies from colorful, fish-shaped plates. The meeting mostly consists of the heckling and joking typical of groups of people who have known each other for a long time. Many of them have; all but two of them are certainly over 60 years old, and several have been in the department as long as Johnson has. They could have easily collected their Social Security years ago, but all of them truly love their work and simply can't stay away. One of the most senior, Vic Springer, proudly proclaims himself a "ROMEO" (Retired Old Man Eating Out), but keeps active in the department "because it's fun."

This is the morphology world these days - a passionate but aging population whose ranks aren't being replenished with young scientists. Museum curators' jobs are being eliminated after they retire, leaving collections without any caretakers. Smaller museums sometimes sell or jettison their collections to larger ones

(the National Park Service's natural history collections were transferred to the Smithsonian for curation in 2012), but others are simply left to languish. The main problem is money; there simply isn't investment in morphological taxonomy anymore. These days, it's all about molecules and DNA.

As we walk back to his office I remark on a low, rumbling sound that permeates the hallway. Johnson wryly tells me that it's the ventilation system "for the chemicals or whatever it is they've got up there" in the molecular biology labs upstairs, which took the place of the Museum's fish collection (it's now at an offsite location about 30 minutes away). Part of the reason genetics is so appealing is, ironically, its cost. If a molecular scientist is awarded a grant that includes a \$10,000 piece of machinery needed to sequence DNA, then their lab can say that it brought in a larger amount of money and is therefore more valuable to their institution or school. The Smithsonian is currently submitting grants totaling about \$100 million to do molecular "next gen" research, while having reduced its staff of curators from 135 to 85 over the last few decades. Morphologists can write grants for funding too, but their required materials are much more basic: usually a salary for a graduate student assistant or two and some collecting supplies. A single genetics machine can sometimes cost more than a multi-year morphology project.

The result of this shift in investment is that fewer students are interested in studying morphology, which exacerbates the problem. "Students do not get deeply trained in the morphology like they used to. It's hard to sell yourself as a pure morphologist. And the danger in that is

that you have fewer people who are giving the courses that relate to it and give them the expertise,” Johnson says.

That expertise represents the culmination of hundreds of years of human inquiry into the nature of our world; our desire to order and classify the things around us. Our whole understanding of fish (and other organisms) so far has been based on that careful attention to detail and cataloging of subtle variations. Morphologists use a number of traits to classify fish: the shape of the tail fin, the number of spines along its back, the shape of its scales, whether it has an overbite or an underbite, etc. A yellow perch and a smallmouth bass are both yellowish, oval-shaped fish that have a dorsal fin that’s split into two, but the bass’ fin has shorter spines on the front half and the perch has distinctive black bands on its body, which help tell the species apart.

Morphology itself is a fascinating subject with seemingly endless questions: Why do male seahorses incubate their mates’ eggs and hatch their young? Why are tube-eyes’ eyes shaped like tubes? How does one species of trout evolve three different-colored varieties that are still trout?

“The molecular stuff is inherently, completely uninteresting without the morphological stuff. What is our perspective on organisms, or biology, or whatever? It’s morphological. You don’t have any questions to ask unless you know the morphology. And the more you know about the morphology, the more interesting these questions about the discrepancies or the congruences become,” Johnson says.

In the famously nebulous world of fish relationships, those discrepancies can be huge. Take, for example, Near’s research and the new fish family

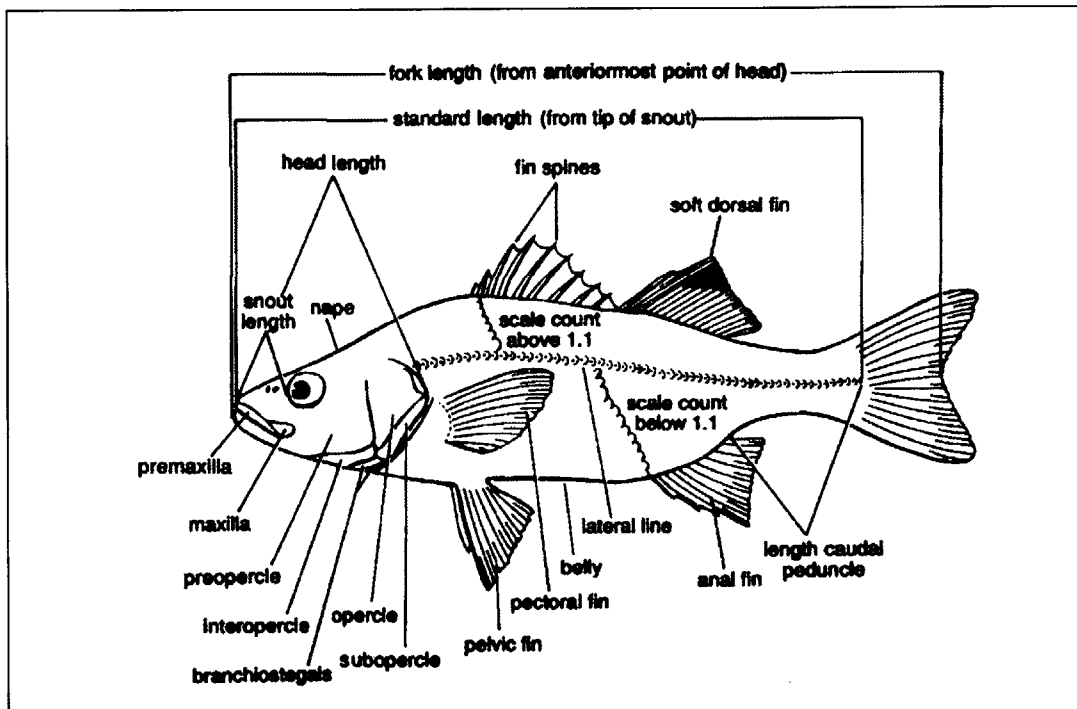


Figure 2: Some of the common characters morphologists use to identify fish species.

relationships it's suggesting. "That's just absolute bullshit," says Bruce Collette, one of Johnson's more brusque colleagues at the Smithsonian. "They're setting up a hypothesis based on genetics that is so dissimilar that we can't disprove it morphologically, because there are no common characters. I don't believe any of that. The only way you can make seahorses the sister group of tunas is if you believe in creation science and that God made them that way."

Johnson agrees, saying that many scientists write off morphological knowledge as an imperfect, outdated interpretation of the world that needs to be shelved in favor of molecular data. "People who don't know morphology propose groups and look for evidence to suggest those groups go together. And sometimes these people say 'We've got the real answer, this is what God said, now it's up to the morphologists to find the characters that support this.' I know my animals well enough that there's nothing to suggest that these fish are closely related."

Johnson and his colleagues aren't just trouncing molecular data because it's the latest, new-fangled thing, however. They're fully aware and appreciative of the insights it can provide. In 2009, Johnson published a paper which determined that three fish that were assigned to three different families actually all belonged in the whalefish family. His collaborator Masaki Miya at Chiba University in Japan sequenced DNA from a whalefish and from the three other specimens, and found the DNA from the fishes' mitochondria to be nearly identical. Johnson originally thought Miya's data were completely wrong, because it had been accepted for years that those three fish were physically too different to be

in the same family. But just in case, he went back over the morphological information in greater detail. He discovered that the three samples in question actually were all whalefish; they were examples of the male, female, and larva, respectively. The three forms are so dramatically different that Johnson believes the whalefish are the most extreme example of physical variation from juvenile to adulthood and between the sexes among all vertebrates. Such a scientific breakthrough would have been impossible without the input of both morphological and molecular approaches.

Problems can arise, however, when the results of both methods are completely antithetical, because neither is completely infallible. If the same physical trait exists in two different families, it's hard to tell without looking at DNA whether they inherited it from a common ancestor or developed it independently. On the other hand, genetic analyses are only as good as the data they're using, and those data are often incomplete given how new DNA studies are. There simply hasn't been enough time to sequence all of the genes from all 10,000 Acanthomorph species, so molecular taxonomists rely on computer models to fill in the gaps and predict results.

Tom Near's lab is unique in that they sequence all of the samples they use rather than using others' data, and their sequences are 85% complete, which is nearly double the field's standards. That means that other scientists are making claims about molecular taxonomy despite significant knowledge gaps, which is Johnson's primary complaint. It's often hard to know whether radical genetic results indicate a previously hidden truth or an error caused by a lack

of good information. Traditional taxonomy has had hundreds of years to develop and self-correct, and generally produces results that can be validated by the collective community.

Not all molecular scientists think morphology is irrelevant. Tom Near makes a point of connecting the sequences of DNA on the computer screen with the finned creatures from which they came. “With my students I really emphasize developing some field perspective. Even to those who are lab eggheads, I say ‘Look, you have to get to know your critters and have those experiences, sociological as well as biological, of being out in the field.’” That’s morphology.

Near acknowledged that the molecular data aren’t infallible, because the very nature of genetic analysis involves models and assumptions that are subject to change as information and methods improve. “I think the work we’ve produced [on Acanthomorph families] shows that we have something. Now, is that the right tree? I don’t know. I’ll never know, because guess what? It’s an inference,” he said. No matter how complete DNA sequences studying them is still an attempt to look deep into the past by studying the present. There’s no way to do an experiment to see when a certain fish family broke off from the main trunk of the evolutionary tree. Morphologists face exactly the same problem, they just look for answers using evidence from physical traits rather than genetic ones. “We’re very analogous to historians who are diving through archives trying to find out what happened in the past,” said Near, whether those archives are genetic sequences or jars of fish soaking in formaldehyde.

One of the advantages molecules have over eyes and hands is the speed at which analyses can be done. With today’s increased competition for funding, producing meaningful research quickly can make or break entire disciplines. “There’s a lot of chatter about museums closing down and firing their research staff, but if you look at those people who are getting laid off, it’s a lot of fairly low-productivity, esoteric stuff like cataloguing ten new species of catfishes from South America,” said Near. “As much as it would be wonderful for us to fund all of this work of all these specialists, it’s an old model that just isn’t sustainable.” As the new, molecular generation is shaking things up, the perspectives and practices of traditional taxonomy, and those who have devoted their lives to it, are being challenged.

Over the course of my visit with Johnson and his colleagues at the Smithsonian, I realize that they’re not just worried about their job security. They truly feel a deep connection to the work they do, and they fear that the abandonment of a morphological approach to ordering life is a serious detriment to humanity at large.

“The molecular people always talk about how morphology is important, but they don’t do anything about it,” says Johnson. Despite the insights that morphological information continues to provide, it’s falling by the wayside in the current scientific ecosystem. “Some people think this is outdated, arcane, sort of like stamp collecting. You can’t get a Nobel prize for taxonomy, and almost no taxonomists ever get elected to the National Academy of Sciences. It’s the low end of the totem pole,” adds Bruce Collette. “It’s discouraging to be in a

field that you see crumbling when you think it's valuable and can't persuade people with money and power that it's really a fundamental science."

I start to wonder if there's something more to taxonomy than just rearranging the branches of the family tree. Why do people feel so strongly about a discipline that seems rather mundane compared to fields like biochemical engineering and computer science? Why are scientists still trying to resolve the minute distinctions between thousands of fish species? Fortunately, the answers to those questions happened to be just down the street from my home in Cambridge, Massachusetts.

Dr. Harriet Ritvo is nursing a Venti Starbucks coffee in her office at the Massachusetts Institute of Technology. "They've been doing studies for years trying to prove that it's bad for you, but there has been absolutely no conclusive evidence that caffeine has any negative effects," she says, the laugh lines at the corners of her eyes crinkling. Given the trend I've noticed with taxonomists and their coffee, and the extra strong mug of chai tea I drank earlier to make it to our morning interview, I'm somewhat relieved. The sky outside is gray-white, matching her short hair, and snowflakes are just beginning to swirl down into the Charles River; a sign that winter has finally arrived in New England.

Ritvo doesn't exactly look like your stereotypical MIT faculty member. Rather than a lab coat and latex gloves, she's wearing a dark blue flannel shirt over a black turtleneck, a delicate silver chain link necklace and navy blue sneakers. The paperback books stacked

eight high on her desk are copies of *The American Historical Review*, not a scientific journal like *Nature* or *Science*. She's a professor of history; specifically, the history of natural history, focusing on how humans and animals relate to each other. It just so happens that she's also a leading authority on the history of taxonomy, having written the book *The Animal Estate* on the topic in 1987, and several others since.

Taxonomy, she says, arose from one of the most fundamental aspects of being human: communication. "The early taxonomy largely had to do with retrieval - simply, we need the words so we know what we're talking about." Our ancient hunter-gatherer ancestors had to be able to identify plants as "poisonous" or "tasty," and decide what types of animals were prey as opposed to predators. The transition from a nomadic lifestyle to agriculture around 11,000 years ago caused a shift in how early humans understood the world around them. They now needed to know not only what things were, but how they were related to each other and their environment: what kinds of plants grew best together, which animals were domesticable, etc.

As civilization advanced, humans probed further into the mysteries of the natural world through disciplines like astronomy, medicine, and philosophy, which were often steeped in magic and legend; the gods caused bad weather because they were displeased by us, and strange creatures like centaurs inhabited distant, mythical lands. Around 600 BCE, ancient Greek and Roman philosophers began studying the forces of nature in earnest, some attempting to describe natural phenomena through logic that wrote the gods and other

mystical forces out of the equation altogether.

That scientific spirit was abandoned when the Roman Empire crumbled in the sixth century and Christianity became the primary Western worldview. Religious scholars thought the creatures of the world were arranged in a divine *scala naturae*, or “great chain of being;” a fixed, hierarchical order that formed a continuous linkage from the “lowest,” inanimate objects up through the plants, animals, man, angels and finally to God at the apex. Attempts to organize animals according to that order were recorded in bestiaries, an early form of encyclopedia that included all the animals known to mankind, accompanied by Christian moral teachings. Early bestiaries didn’t discriminate between real and mythical creatures. “You have one article about lions, and another about unicorns, and those entries were often based on similar authority - someone who wrote it down in the past,” says Ritvo. Far from the rationalism of the ancients, the medieval Christian worldview held that if humans could imagine creatures like unicorns, surely the superior mind of God had already thought of them and created them somewhere on Earth. Not to include one of God’s creations just because it hadn’t yet been seen would be disrespectful and perhaps even blasphemous.

The Renaissance movement gained traction across Europe in the fourteenth century and brought about a renewed interest in observing nature empirically. As exploration and colonialism opened new frontiers worldwide, the range for human imagination became smaller and smaller, as there were fewer uncharted places for fantastical creatures to hide, says Ritvo.

Explorers saw many new and wonderful things in their travels, but noticeably absent were unicorns, leviathans and the like.

At the same time, new species of plants and animals were being described at an alarmingly fast rate. Whereas a medieval bestiary might describe between 50 and 150 animals, expeditions were returning from afar loaded with several times that number of exotic samples. It became increasingly clear that a formal system of naming and classification was needed, now that the world was vastly larger and its inhabitants more wondrous than previously thought. Encyclopedias and other reference books published in the seventeenth and eighteenth centuries organized plants and animals in various ways: by name, by geographical location, by usefulness to humans, etc. But none of those systems achieved what scholars were really after: a complete and easily referenced catalog of all the species.

That all changed with the arrival of the superstar of taxonomy, eighteenth-century Swedish botanist and medical doctor Carl Linnaeus. Far from the plodding, systematic scientist, Linnaeus seemed to revel in flying by the seat of his pants from one wealthy “sponsor” to the next, shirking his academic duties and relying on his charisma and impressive knowledge of plants to eke out a living. He published the first edition of his landmark *Systema Naturae* in 1735, which catalogued 6,000 species of plants and 4,200 species of animals. Rather than trying to evaluate and group plants by using several different physical features, which had caused widespread confusion among his predecessors and colleagues, he organized them according to their sexual structures alone. He also

grouped the animals into kingdoms based on clearly defined traits: fish live in the water, are covered with scales, have gills and swim bladders. The result was a consistent, straightforward system that allowed anyone, not just a trained naturalist, to look at something and identify its place in the order of life.

Unlike the natural philosophers who attempted to structure the world according to what they perceived as God's natural order, Linnaeus' classification scheme was blatantly artificial, because he determined what features were important in evaluating a plant or an animal's identity. It earned him many scholarly enemies and initiated taxonomy's long history of heated internal debate. Johann Dillenius, a contemporary at Oxford University, referred to Linnaeus as "the man who confounds all Botany."² Linnaeus seems to have been immune to the criticism, once saying famously, "God created, Linnaeus organized." It may not have been the *scala naturae* toward which most naturalists still strove, but his system was the most practical and useful option to date. Linnaeus helped elevate taxonomy to the level of a "true" science, one that was based on systematic logic and adhered to its principles.

Naturalists in the later eighteenth and nineteenth centuries continued to classify plants and animals according to Linnaean taxonomy. They believed in its ability to accurately and comprehensively describe and order the world; they just had to carry it to completion by cataloguing all the species. But as time went on, a problem

developed. "The greater the number of traits attributed to a given group of animals, the more of those traits it was likely to share with similar groups, and the more difficult it became to decide which of them were truly significant for classification," says Ritvo. One of the most famous conundrums was the platypus. Taxonomists simply had no idea what to do with it. Did it belong with the mammals, because of its fur? Or with the birds, because it had a bill and webbed feet and laid eggs? Which of those traits were more important?

Just as the confusion and tension were threatening to collapse the field back into pre-Linnaean turmoil, Charles Darwin came along and swept the quarreling taxonomists' feet right out from under them. His theory of evolution finally revealed the natural order of species, but it was completely different from what anyone had anticipated. Rather than a *scala naturae*, the "natural" groupings of organisms that had been observed for centuries turned out to be a reflection of evolutionary history, as one species morphed into another through the generations. "There wasn't a time that someone said 'I am a *Homo sapiens* and my parents were something else,'" says Ritvo. The species weren't fixed, they were fluid; and not only that, the process of evolution was happening all the time. As the very last line of Darwin's *Origin* so eloquently puts it, the species "have been, and are being, evolved."³ That idea was disturbing to many people, especially the taxonomists. Now they not only had to place organisms in the right niche on the tree of life, they had to understand how they had evolved into

² Knapp, Sandra. What's In a Name? A History of Taxonomy. <http://www.nhm.ac.uk/nature-online/science-of-natural-history/taxonomy-systematics/history-taxonomy/index.html>.

³ John van Wyhe, editor. 2002. The Complete Work of Charles Darwin Online (<http://darwin-online.org.uk/>).

their present form from their ancestors. The collective goal of cataloging a finite list of unique species was not just challenging, it seemed nearly impossible.

And yet they doggedly kept at it. Zoologists like Felipe Poey continued to identify new species and creationist scientists like Louis Agassiz continued to believe in a divine natural order. Over the course of the early twentieth century a new movement within the naturalist community arose, as technology advanced and scientific standards became stricter and more analytical. These scientists called themselves biologists, because they were strictly focused on the study of life, rather than the broad subject of the natural world that was typical of naturalists up to that point (in addition to being a zoologist, Agassiz was the first to scientifically propose the idea of an ice age).

Biologists didn't simply observe life and draw conclusions from it, they poked, prodded it, and examined it under microscopes. They designed experiments that could produce definite answers to questions that naturalists had only speculated about. How do certain physical traits get passed from one generation to the next, for example? We can thank Gregor Mendel for the countless hours he spent manually transferring pollen between pea plants in the mid-1800s, from which he concluded the theory of genetic inheritance.

As the standards of scientific inquiry became stricter and more analytical, biologists saw the traditional taxonomists as woefully behind the times. Taxonomy's main stumbling block was that it still largely relied on individual scientists' opinions when classifying species, and lacked the objective rigor of other scientific

disciplines. One taxonomist might separate groups of fish based on the number of dorsal spines, while another might prefer to use the shape of its jaw. It seemed to be going the way of other defunct disciplines like phrenology (measuring the lumps and bumps on someone's skull to determine their mental strengths) and iridology (looking at the iris of the eye to evaluate someone's health).

That was just the beginning. Over the last 60 years a number of revolutions have attempted to bring taxonomy up to speed with the rest of biology. First in the 1950s was numerical taxonomy, which assigned numbers to organisms' physical traits and then used computers to calculate how similar any given samples were and construct an evolutionary tree based on those results. Taxonomists faced with the possibility that their careful observations and how well they "knew" their critters would be thrown out in favor of stark, bare numbers. Then in the 1960s came molecular taxonomy, in which scientists didn't even need to know what an animal looked like to classify it; they simply sequenced a piece of its DNA and compared the same pieces from different samples to determine how related they were.

A third revolution arose at almost exactly the same time: cladistics. Taking its name from the Greek word "klados," which means "branch," cladistics finally solved the age-old problem of which traits should be used to determine relatedness: only the ones that were unique to the descendants of one particular ancestor. Organisms were sorted into groups called "clades" that consisted of one ancestor and all of its evolutionary offspring. More than any other method, cladistics caused radical

changes to the traditional taxonomic groupings.

One of the worst insults was the cladists' claim that the category of "fish" as we know it - all the smooth, scaly things that swim in water - doesn't exist. To be a valid clade, "fish" would have to include all of the things that evolved from the very first fish, like amphibians, birds, and even humans. By that logic, we are all technically highly evolved lungfish. It may sound absurd, but evidence from both morphology and genetics supports the cladistics approach. A lungfish may look more like a salmon than a human at first glance, but because humans and lungfish share characteristics that no other related fish have (like a windpipe, the ability to breathe air, and similarities in the way their hearts are formed) cladistics declares that we are the lungfish's closer kin.

Despite all of the upheavals that have threatened its relevance, morphologically-based taxonomy has persisted to this day (though largely relegated to museum basements). "Current scientists say 'everything is new and completely different'" in today's debate between molecular methods, says Ritvo, but it's actually very similar to what's happened before. "When anatomy became more sophisticated and physiology emerged in the 19th century, lots of things got reshuffled, just like DNA analysis has produced new reshufflings. When you come right down to it, cladistics in taxonomy resembles what it replaces in many ways," she says. Traditional taxonomy has faced a series of opponents over the centuries, and though it appears to be on a losing streak, it's not going down without a fight.

As a historian, Ritvo sees value in the morphological perspective because it reflects humans' innate fascination with the natural world and our desire to define our place in it. While each iteration of new technologies and methods has revealed insights that traditional taxonomists hadn't observed before, "it didn't obviate the connections they had seen," she says emphatically. Molecular information doesn't necessarily make our knowledge of morphology obsolete, just as learning that the baldness gene is on the X chromosome doesn't negate the ages-old observation that it's passed from mother to son.

But there's no denying that the newest thing always overshadows the old. Ritvo says the majority of people in the academic community view traditional taxonomy much like they view new editions of existing books. "They're necessary and it's good that someone does them, but it's not the most exciting thing," she says. While it may benefit humanity to chase down, name and correctly classify every last organism on the planet, there isn't a significant community of amateur naturalists who find that effort relevant and interesting anymore. "Most people couldn't care less about taxonomy," says Ritvo, spreading her hands in resigned demonstration of an obvious truth.

It's true that spending research dollars trying to untangle the complicated "bush" of Acanthomorpha seems a bit backward when there are so many other fields with more tangible results, like cancer treatment and alternative energy. But perhaps it only seems less valuable because we've lost touch with our innate human connection to the natural world. As scientific pursuit has become more technical and esoteric,

the average person understands less and less of it. Far fewer people are likely to learn how to use a computer program that analyzes DNA than how to identify a smallmouth bass.

But just because one way of understanding the world is more accurate doesn't mean it's the most useful, as Linnaeus knew when he created his taxonomic system for plants. Knowing that a flounder and a swordfish are closely related doesn't reveal the best way to fish for one vs. the other. The fact that one of our distant ancestor was a lungfish won't tell us how to identify one in the wild. That's information that only taxonomy rooted in the tradition of observing live species can provide, and that's what's at stake in today's scientific world. There must be some value in that knowledge; despite hundreds of years of innovations that have repeatedly threatened to make it obsolete, we just can't seem to shake morphological taxonomy.

Much as a morphologist has a deep sense of "knowing" their animals and understanding them at a fundamental level, we as humans inherently "know" nature. Ask virtually anyone to imagine a fish, and they will think of something scaly with fins of some sort that lives in the water - something that any other person would also identify as "fish." Our common experiences with the natural world give us a common sense for it; very few people would consider an antelope or their neighbor a fish, even though cladistics has confirmed that both are indeed fish in an evolutionary sense. This brings up an interesting question: is the way that we interpret the world through science more correct or real than the way that we know it through our own senses, simply by being human?

Through talking with these experts, I realized that we need to embrace our inner lungfish. What I mean by that is recognizing and promoting both molecular and morphological taxonomy as valid and valuable. Accepting the fact that we are indeed descendants of lungfish would affirm the truths that science is revealing (as illogical as they may sometimes seem) and also help reconnect us to other creatures. The more we understand our relationship to every other living thing, the more we can learn about ourselves; past, present and future.

Hard-nosed scientists might say that such an approach is silly and promotes a blind, willful belief in things that just aren't real. Even though evolution and our own genes tell us that there is no overall divine plan, no preordained order, no *scala naturae*, we still see the world as being governed by some kind of absolute truth, regardless of its plausibility. Ritvo sees that kind of knee-jerk reaction as part of our response to the increasingly secular interpretation of the modern world, "or the disappearance of magic or something like it." When confronted with the overwhelming evidence that there is no El Dorado, no Lady of the Lake, no method to the madness of living things, we cling to any last scrap of the mysterious and wonderful that we so strongly crave. In the case of taxonomy, we have a hard time letting go of things that just seem right because they are woven into the fabric of our interpretation of the world. A lungfish looks like it should be more closely related to the salmon than to us, even though the opposite is true. We should acknowledge that our preferred and personal classifications might not be

entirely accurate, but we shouldn't jettison them completely.

"It's pretty clear that evolution did happen," says Ritvo, as the snow starts to fall in thicker and thicker clumps outside and I feel my chai buzz starting to settle down. "There's no scientific argument about it. And yet many people don't feel that that's something that should decide their own attitude toward it." Science might claim to hold the keys to the empirical truth about the world, but we as a species are not quick to accept them. We are all humans before we are scientists. Morphology celebrates our collective experience and understanding of the world and the organisms with whom we share it. To sever that link completely would be a tragedy for our species; the loss of a fundamental aspect of being human.



Figure 3: Acanthomorph diversity.

Some scientists, like Tom Near, already advocate a hybrid approach to the study of life. We talked until I had seen the word *Tumid* flash across the computer screensaver more times than I could count, and the world outside his window had gone dark. But Near was still as alert as ever. From the way his eyes lit up when he talked about his darters, I could tell that he isn't, in Bruce Collette's words, a biologist who "can't tell one fish from another."

Near acknowledged that there has been resistance to molecular approaches, and he's trying to change that. "An ambition I have in the next few years is to sample all 18,000 species of Acanthomorphs and figure out some way of getting data for all of that and try to make it work. I realized this is what I'm really interested in doing for the next 20 years of my life. And I can do it, meaning it hasn't been done yet." The more genetic information his lab can analyze, the more they will be able to refine their Acanthomorph tree of life. Perhaps it will turn out that flounders and swordfish aren't closely related after all, and the current results are a fluke based on incomplete data. Or maybe there are even stranger relationships hiding in the as-yet unsequenced DNA of the spotted cowfish. Only time and many more studies will tell.

Before I left, I asked Dr. Near whether he agreed with something that Bruce Collette from the Smithsonian had told me over the phone: "the field of taxonomy is being driven to extinction." Near leaned back in his chair and looked thoughtfully toward the small collection of plastic fish and dinosaurs on his side table. One of them was a coelacanth, the oldest lineage of living fish in the world. After a minute he sat up straight. "I find it troubling that we're losing this expertise," he said, "and we're losing it in other taxonomic groups other than vertebrates too, like diatoms and algae. That's why I'm of two minds about this. I feel that you want to say 'Come on, get with it' to those [morphological] people, but on the other hand, you have to respect the process for the way that that information is gathered and these discoveries are made."

Near also thought that while the structure of the field might be changing,

the science of taxonomy itself isn't going anywhere. "We really learn a lot about how evolution works and what is possible, in even our part of the tree of life, by understanding the evolutionary history of fish," he said. Immunologists are interested in studying anglerfish because the tiny male fish permanently attaches to the female's body, becoming a kind of parasite in order to mate with her. If we can learn what genes make the female's body accept the male rather than attacking him, we might be able to "fix" those faulty genes in people who have autoimmune disorders, in which their bodies overreact to their own cells.

There could be thousands, if not hundreds of thousands of species that still haven't been described and sampled. The more we learn about what's in our world, the better we can learn to manage and preserve it. Taxonomy is not just done for taxonomy's sake. "It's the foundational step before you can do ecology, biology, environmental science, or management of fisheries," Bruce Collette had told me earlier. "Step one in doing anything is to identify what organism you have. If you can't tell one thing from another, you can't do anything else." Near agreed, saying it's "really important to have an understanding of the biodiversity of fish in some kind of historical perspective," so we can create a picture not just of how our world's species look today, but how they got there.

Near is starting to see inklings of our connection to our inner lungfish in his own life. "When I teach the ichthyology course here at Yale, it's getting about fifty percent non-science majors now. There's just something about this one half of the vertebrate tree of life that attracts people's interest," he

said. "Everyone wants to know what's around them."

And it's not just fish; name a type of animal, and you're bound to find organizations of enthusiasts, scientists and amateurs alike, who simply can't get enough of them. A quick Google search yields the Coleopterists Society (beetles), the Global Penguin Society, and the Queensland Frog Society, to name a few. "If you take a random sampling of humans and even sample randomly among cultures, you're going to have people that want to know all the different plants and animals. You just do. And you see this over and over again," said Near. To him, that's a reflection of the "biophilia hypothesis" of the great biologist E.O. Wilson: there's something inherent about being an organism that makes you want to know other organisms. Taxonomy is one of humanity's earliest and most fundamental ways of obtaining that knowledge.

As the November snow lay white and heavy on top of Cambridge, I found myself making the trip to Harvard to once again look at Felipe Poey's fish samples. Their immaculately clean bones and neatly printed labels make it clear that for Poey, taxonomy wasn't just a profession - it was his way of life. Every morning he rose early and trundled down to the fish market in Havana, where he would chat with the fishermen and pick through their catches to see if there were any new species he could record and send to Agassiz. He was paid well and respected for doing what he loved, by his fellow Cubans and the scientific community at large. That way of doing taxonomy for a living has

now all but disappeared, the last few devotees clinging like anemones to slippery sea rocks as the tide of progress ebbs farther and farther away.

But as the waves move away from one shore, they wash up on another. Taxonomy is now entering a molecular phase that promises advances far beyond anything Poey and his contemporaries could have imagined. And just as all of the oceans are interconnected, so taxonomy unites different aspects of what it means to be human - our impressively scientific minds and our equally powerful imaginations.

What would Poey have made of the argument between morphology and molecules? He probably would have observed it with mild interest, given a little shrug of his shoulders and gone back to wrapping up his latest specimen. Taxonomy may have moved far beyond anything he would recognize were he alive today, but for Poey, the preservation of his samples in Harvard's archives probably would have been all the recognition he needed. He was "simple, direct, unaffected, but possessed of a quiet dignity, [...] certainly one of the most delightful men I have ever met," wrote David S. Jordan in his 1884 biographical sketch of Poey. "Of all men I have known, he has best learned the art of growing old."

Hopefully we can learn to accept with equal grace our place in the great tree of life, both that which science tells us and that which we determine for ourselves. I prefer being a human most of the time, but occasionally it's kind of neat to be a lungfish.

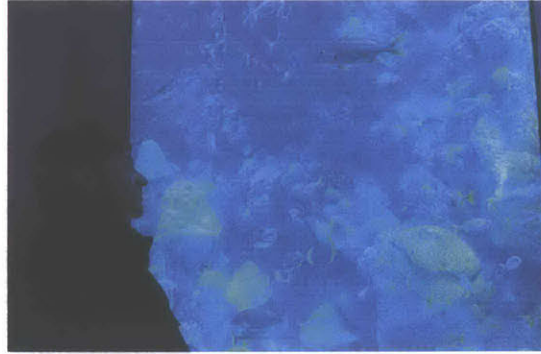


Figure 4: A visitor at the New England Aquarium.

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Images

- Figure 1: Hoegg, Simone et al. “Comparative phylogenomic analyses of teleost fish Hox gene clusters: lessons from the cichlid fish *Astatotilapia burtoni*.” *BMC Genomics* Issue 8:317 (2007). <http://www.biomedcentral.com/1471-2164/8/317>.
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<http://www.faculty.biol.ttu.edu/strauss/pubs/Papers/1990StraussBond.pdf>
- Figure 3: Copyright 2014 Lindsay Kirlin Brownell.
- Figure 4: Copyright 2014 Lindsay Kirlin Brownell.

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About the Author

Lindsay Brownell grew up outside of Detroit and graduated from Davidson College in 2010 with dual degrees in English and Biology. After teaching English in Switzerland, working at Google for two years and traveling as much as possible, she remembered that science writing existed and decided to attend MIT for her master's degree. She will be spending the summer of 2014 as an intern at the European Molecular Biology Laboratory in Heidelberg, Germany, traveling some more and then coming back to Boston to see what life is like outside the Science Writers' Lounge in Building E14. Her favorite movie is *The Lion King* and she enjoys climbing trees and dancing.