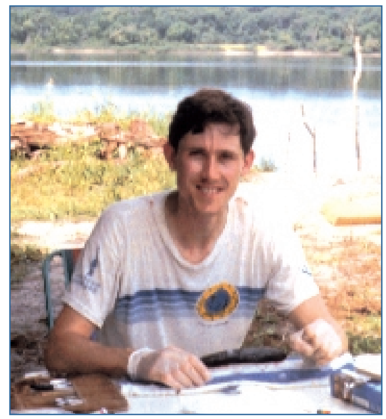
# INTERVIEW WITH A RESEARCHER

## Let's Talk With Ian Harrison About How Marine Animals Breathe



### What is breathing?

We usually think of it in terms of getting oxygen from air. Breathing is about gas exchange. In the sea, this involves getting oxygen out of water rather than air, but it's all gas exchange.

### What's different about breathing in a marine environment?

All marine organisms have to deal with the fundamental nature of water. It's 800 times more dense than air and about 50 times more viscous (resistant to flow). And water only has about 1 percent of oxygen by volume, compared to air, which has about 21 percent. So marine vertebrates have to work much harder than terrestrial ones to pump this medium, which is low in oxygen, through their bodies. They're using up 10 percent of their oxygen just in the process. And anything that's quite active, a fish in particular, has to do a lot of breathing to meet its metabolic demands. That's why fish pump water over their gills, inhaling through the mouth and exhaling through the gill slits, which appear as individual slits in sharks and rays, but are covered by the bony operculum in bony fishes. Fish pass a water current in a single direction, in through the mouth and out via the gill slits and opercula, unlike vertebrates like mammals and birds, which breathe in and out through the same orifice, the mouth.

Q&A INTERVIEW WITH A RESEARCHER

## Let's Talk With Ian Harrison About How Marine Animals Breathe

| MORE ON IAN HARRISON | |
|---|---|
| FIELD OF STUDY | Ichthyology |
| WHERE HE GREW UP | England; has lived full-time in the U.S. since 1996 |
| FAVORITE MIDDLE/ HIGH SCHOOL SUBJECTS | "Biology first and foremost—I was always interested in natural history. After that, geography. I was interested in far-off places, and maps are always interesting." |
| LEAST FAVORITE MIDDLE/ HIGH SCHOOL SUBJECTS | "Probably French—I was never good at languages at school, but I prefer them now. I found physics very difficult, but it was also very interesting, and you have to know a certain amount of physics when you scuba dive, which I do." |
| INTERESTS IN MIDDLE SCHOOL | "Bird-watching, badger-watching; cycling and swimming. I liked going bird-watching in England and France when we were on vacations." |
| INTERESTS TODAY | "I still enjoy swimming, snorkeling, diving when I get a chance. And hiking, when I also bird-watch." |
| LIFE LESSONS FROM THE FIELD | "You can spend years reading about any kind of organism and studying museum specimens, but it's not until you actually see them in the wild that you get a whole new perspective." |
| RECOMMENDED READING | "Gerald Durrell is good for anyone with a curiosity about natural history. For marine biology, *Old Four Legs* by J.L.B. Smith, the story of finding the coelacanth." |
| MAJOR INFLUENCES | "A high-school biology teacher was inspirational because he made biology real and relevant. He helped us make connections between the book and the real world." |

Q&A INTERVIEW WITH A RESEARCHER | Let's Talk With Ian Harrison About How Marine Animals Breathe

**AMNH:** Why is marine respiration an interesting thing to study?

**IAN:** It's interesting because of the various, very effective ways in which organisms overcome the problem of getting the oxygen they need. Most animals need a more specialized organ to extract the oxygen from water, and in a marine environment those are gills. (Although there are fish that breathe with lungs.) Gills are very complex, efficient organs, anatomically well structured for gas exchange. They have an extensive surface area that can very effectively extract oxygen out of water as it passes, in the same way that our lungs are full of alveoli, or tiny air sacs. Some invertebrates, like shrimps and lobsters, have external gills, usually formed from modified appendages on the thorax or abdomen. Water wafts across their gills; they don't inhale or exhale a water current through their bodies in order to breathe.

---

**AMNH:** How do gills work?

**IAN:** Typically, fish have four gill arches on each side of the head. Each gill arch has loads of little feathery filaments sticking off of it. Each filament has little projections coming off it, just a few cells thick, called secondary lamellae, which increase the surface area. When the water flows through the gills, it runs over the filaments and in between the lamellae, and that's where the gas exchange takes place.

Fish have another little physiological trick as well. The blood that flows through the lamellae is pumped in the opposite direction of the water flowing over the surface of the lamellae. This is called a counter-current. It ensures that, at any point, the water flowing over the secondary lamellae is relatively richer in dissolved oxygen than the blood flowing though the secondary lamellae. This maintains a large difference between the oxygen content in the blood and that in the water, so the exchange is as efficient as possible over the entire secondary lamellae.

---

**AMNH:** Do gills serve any other functions besides breathing?

**IAN:** Yes, they do a whole bunch of other things. Gills are also used in feeding because the water current often carries food as well as oxygen. The oxygen is extracted at the gill filaments, which project backwards. But there are usually several gill rakers, pointing forward from the gill arches, which can act like a filter and trap food particles. The next time you buy a whole fish from the market, pull out the bony operculum that forms the side of the head, and you will see the soft, darkish-red gill filaments projecting back, and the stiff, colorless rakers projecting forward on the outer gill arch. That's also a good way to see if your fish is really fresh  blood inside the gills should make them look nice and red.

The size and number of the gill rakers depend on what the fish eats. They can be long, fine, and closely packed, as in a fish called menhaden, which uses them for filtering tiny plankton; or they can be shorter and thicker, for trapping small fish; or even very stubby, for trapping and holding snails.

The other big function of gills is to maintain a physiological balance of tissue fluid and salt levels in the fish. Many marine invertebrates maintain their tissue fluids at the same ionic concentration as seawater. But in marine fishes, the ions in the blood and tissue fluids are less concentrated than in the salty medium they swim in. So there's always a tendency in marine fishes for water to diffuse out across large body surface areas like the skin and the gills (and the opposite tendency in freshwater fishes). Big gills are good for extracting oxygen but bad for water balance marine fish can lose a lot of water across the gills. So fish have to overcome that with things like mucus coverings around the gills. They also excrete salt across the gills, which helps them get rid of the extra salts that come from the seawater they ingest with their food. Freshwater fishes do the reverse the mucus protects water gain across the gills, which also absorb salts that are lost through the urine and feces. This ionic and osmotic regulation represents a significant physiological effort. The gills are very complicated purpose organs. Respiration is just one of their functions, and they do all of them very well.

---

**AMNH:** Do different marine organisms breathe in different ways?

**IAN:** Different species of fish have different gill development, depending on their modes of life. If you're a fast swimmer for example, a swordfish that actively hunts and pursues other fish then you have to breathe more efficiently, just as a 400-meter runner needs good lungs. Species like stone fish are the couch potatoes of the sea. They don't move around much, so they have gills that are much less extensively developed than the gills of, say, tuna, which are the greyhounds of the aquatic world and swim around very rapidly.

Some fish improve their respiratory capacity by running water over the gills more efficiently. Tuna, for example, swim forward fast with their mouths open so they don't have to work at pumping water, or opening and closing their mouths. This is called "ram ventilation" because they ram water through their mouths. It's an effective way to benefit from forward movement if you're swimming fast. Some fish are very well adapted for it, to the point where the filaments in the gills are closely meshed together to form a really effective sieve. Incidentally, it's a myth that sharks must keep swimming to breathe; they can pump water over their gills like bony fish do.

---

**AMNH:** Do fishes that don't swim fast breathe differently?

**IAN:** Fish also use other modes of gas exchange, such as relying on lungs or gas bladders, or by breathing across the skin. Mudskippers, which live around mangroves, are amphibious and may spend as much time out of the water as in it. They can hold some water in their mouths and swirl it around their gills for breathing, but they can also rely on their moist skin surface for gas exchange. And because they can rely on this alternative mechanism, the gills of mudskippers are not large.

---

**AMNH:** When do fish rely on breathing mechanisms other than gills?

**IAN:** Fishes that use alternate breathing mechanisms do so because of a constraint on the effectiveness of gill breathing. Amphibious fishes like the mudskipper need something besides gills for gas exchange when they are out of the water. Some freshwaters may be very low in dissolved oxygen, such as in peat swamps, so fishes in these environments are often adapted for air breathing; they use modified gas bladders and lungs. This is more common in freshwater fish. However, tarpon, which can be found in brackish waters low in oxygen, gulp air to fill a modified gas bladder that they use for gas exchange.

Some fish species also have specialized ways of carrying the oxygen in their blood once it's

Q&A INTERVIEW WITH A RESEARCHER | Let's Talk With Ian Harrison About How Marine Animals Breathe

been extracted from the water. For example, certain fishes from around Antarctica called ice fishes have no hemoglobin in their blood (unlike humans, who need hemoglobin to bind to oxygen). Hemoglobin is what gives blood its reddish color, so these fish which lack hemoglobin are white-blooded. (Their blood also contains a kind of antifreeze that prevents it from freezing in the frigid Antarctic seawater.)

---

**AMNH:** Do marine organisms breathe in different ways at different points in their life cycles?

**IAN:** The gills of most fish in the larval phase are really small. When fish are tiny, they have a large surface area relative to their body volume, so they can rely on gas exchange across this relatively large body surface to supply all the oxygen needed to meet their metabolic demands. It also helps that their skin is usually well supplied with blood vessels and has no scales, so oxygen can easily diffuse across it. The gills usually develop fairly quickly, however, and are soon large enough to handle the fish's oxygen requirements. At this point, the skin is usually becoming covered with scales and the amount of cutaneous respiration drops off. Then, as the fish gets older, the rate of gill development slows.

Different fish have different respiratory requirements at different stages of life. For example, in the larval phase, flatfish swim about in the water column. Their gills develop relatively rapidly in size in order to meet the metabolic requirements of this somewhat active lifestyle. Then they go through metamorphosis, become flat in shape, settle on the bottom, and become sedentary. Because these adult fish are relatively inactive, the gills develop much more slowly relative to the fish's overall growth.

**AMNH:** Does the size of a marine organism affect its respiration?

**IAN:** If an organism is small enough, like most plankton and zooplankton, it can absorb oxygen across its body surface. That's all it needs. Some larger organisms, like jellyfish, also have a very simple gas exchange across the body surface they, too, meet their respiratory requirements simply by absorbing oxygen across the body surface. More advanced aquatic invertebrates usually possess a specialized organ for gas exchange. Gills are present, for example, in some mollusks and crustaceans (though they're not the same as gills in fishes).

Really small fish have a significant problem. They have enough of a gill area to meet their oxygen demands, which are quite high relative to their body size. (The smaller an organism, the higher its relative metabolism, in sea as well as air, although its absolute metabolism is small. A mouse has a very high rate of metabolism compared to an elephant that's why its heart beats so fast.) But very small fish have very small heads. There's a real crunch for space because other organs, like the brain and the eyes, also take up quite a bit of room. Very small marine fish also suffer from a greater potential loss of water from the gills, because their surface area relative to their mass is larger than that of bigger organisms. I've studied tiny gobies, and they might be operating right at the limits of the functional capacity of their gills, right on the brink of what's doable.

---

**AMNH:** You conduct research on gobies and mullets. Why did you choose these two groups of fishes to study?

**IAN:** I chose gobies because they include the smallest known vertebrates. I was interested in the problems of small size, including gill development. Also, gobies just happen to be extremely diverse. They occupy a huge variety of ecosystems, from coral reefs to mangroves to rock pools to freshwater rivers, and from in the tropics to cool temperate waters. This means that they've developed interesting adaptations to life in different habitats. It's interesting to study the evolutionary diversity of this group and describe how the different species are related to each other.

Mullets all tend to look the same, at least from the outside. This makes it very difficult to distinguish between different mullet species. My research involves looking for the internal and external anatomical features of that anatomical features that distinguish each species. Comparing these features makes it possible to see which species are more closely related, and thus to understand their evolutionary relationships. I also compare the geographic distribution of different species and make hypotheses about how the evolution of the species is related to the history of the Earth. For example, I can show that the ancestors of different groups of species lived in different ocean basins. Some groups of related species appear to have evolved from an ancestor in the Indian Ocean; others appear to have evolved in the Atlantic Ocean. Some species appear to have become somewhat isolated in the Mediterranean after it was cut off from the Indian Ocean and the Atlantic Ocean. We can compare these patterns with those of other groups of marine organisms, and use the data to build up an understanding of the biological and geographic history of the Earth.

---

**AMNH:** Why is it important to know how many different species of mullet exist?

**IAN:** One important reason is that if we want to monitor and conserve the species, we have to know what to look for. How many different species live in a particular area, and how can we identify them? (Being consistent in the way we identify and name species is crucial.) This allows us to track changes in fish populations over time. This is particularly important for species like mullets that are fished commercially, so we can monitor the effect of fishing on the numbers of species in any particular area.

It's also important to know the extent of genetic variation within and between species. I looked at commercially-fished mullet populations that live only a few miles apart along the West African coast in order to establish whether they were genetically distinct. If they really represent genetically isolated populations–and possibly distinct species–then they have to be managed as separate commercial fisheries, rather than as a single large fishery.

Also, a region that contains a large number of species, or has some species that are of particular interest for some reason (for example, the coelacanth) can be targeted as the focus for conservation work. It may help put an economic value on the area as a site for conservation and ecotourism. Tourists like to visit coral reefs because they have a large number of diverse species.

---

**AMNH:** Where do you do your fieldwork?

**IAN:** Right now I'm studying species from central West Africa, from Nigeria south along the coast to the Democratic Republic of Congo (formerly Zaire).

**INTERVIEW WITH A RESEARCHER** | **Let's Talk With Ian Harrison About How Marine Animals Breathe**

**AMNH:** What kind of equipment do you need to collect specimens?

**IAN:** It can be as elaborate as a fully equipped research vessel, or as simple as a bucket. A colleague of mine made collections just by walking along the beach and catching fish in rock pools by throwing a wet handkerchief over them. I've collected fish with my bare hands, but a seine net or a cast net does come in handy. In order to bring fish back to the museum to study, we need a preservative like alcohol. Paperwork is also very important you need official permits to collect fish.

A big part of collection is collaborating with people in different countries. I can learn so much information from the people who live there and really know the species and the ecology of the area. And, in return, I can help my colleagues abroad by giving them access to the expertise of the staff at the museum.

---

**AMNH:** Why is fieldwork so valuable?

**IAN:** It's not until you actually see animals in the wild that you get a whole new perspective, and it can be enormously useful. I had been studying preserved specimens of two species of mullets for a few years in the Royal African Museum in Belgium, and I had to look closely to tell them apart. I had to carefully count the fins and look at the teeth and scales. Then, when we went to collect them in Senegal, I could see some slight but very distinct differences in their overall coloration. The differences were enough to say, "This one's different from the other one; I don't have to do all the counts of fins and stuff." After that, I could just sort them as I pulled them in. And in the wild you see how things behave. One species is usually found feeding on sandy bottoms while another feeds on muddy bottoms, or one species is found only in estuaries and in the inshore seawaters while another is found in small lagoons or even swims upriver. All of this gives you a more complete understanding of what the species is and what they're doing.

---

**AMNH:** Did any individuals have a major influence on you?

**IAN:** I had an extremely inspirational teacher, when I was in high school, who made biology really interesting because he made it real and relevant. He taught us to connect what we learned in class to what we saw around us, and to be inquisitive about biology and ask lots of questions. Our biology class didn't stop when we left the classroom and went outside that's when it really started to come alive. If you went out for a walk, you'd look at the plants and be thinking, Ah, this kind of plant has this structure because of the way the cells are arranged in the stem. Or you'd be thinking, Why is this bird's wing shaped one way and another is shaped differently? Or, Why are some animals parasites, and what does that mean in terms of the natural history around them?

If you look at that last example, you find that whole ecological communities are shaped by the actions of parasites. There are parasites in fish that change their behavior so it's easier for seabirds to catch them: the fish swim closer to the surface. And the seabird populations in these areas are much higher than elsewhere because they can catch more fish. It's not just about the parasites, but about the whole ecosystem. Biology is this mass of questions, and that's what my teacher instilled in me. There's so much to find out. If you study something and don't get the result you were expecting, it means there's something else there to think about.