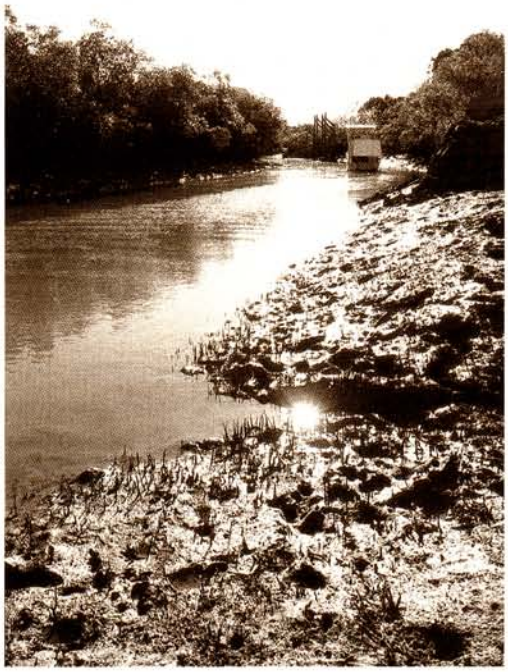
DIVERS IN REVERSE

The Improbable Mudskipper

BY JOE HLEBICA

Imagine a fish that breathes air. Now imagine that this same fish can also dance, fight, and climb trees! You may be surprised to learn that nature has already designed this improbable creature; it is called a mudskipper. Adaptations of mudskippers and other air-breathing fishes to life both in water and on land – earth's two most fundamentally different habitats – have captured the imagination of Scripps graduate student Nancy Aguilar.

Aguilar's research takes place in a cluttered laboratory in Scripps's Scholander Hall, part of the Center for Marine Biotechnology and Biomedicine (CMBB). Stepping inside the laboratory on a cool, foggy morning, she is greeted by the intense heat, light, and humidity of an artificial tropical environment. The creatures' mud-filled habitat – consisting of a shallow, round, three-foot-wide tank screened by sheets of black plastic and illuminated by heat lamps – duplicates the environment of the tropical mangrove swamps and tidal mudflats that are home to 35 species of mudskipper throughout the Indo-Pacific.

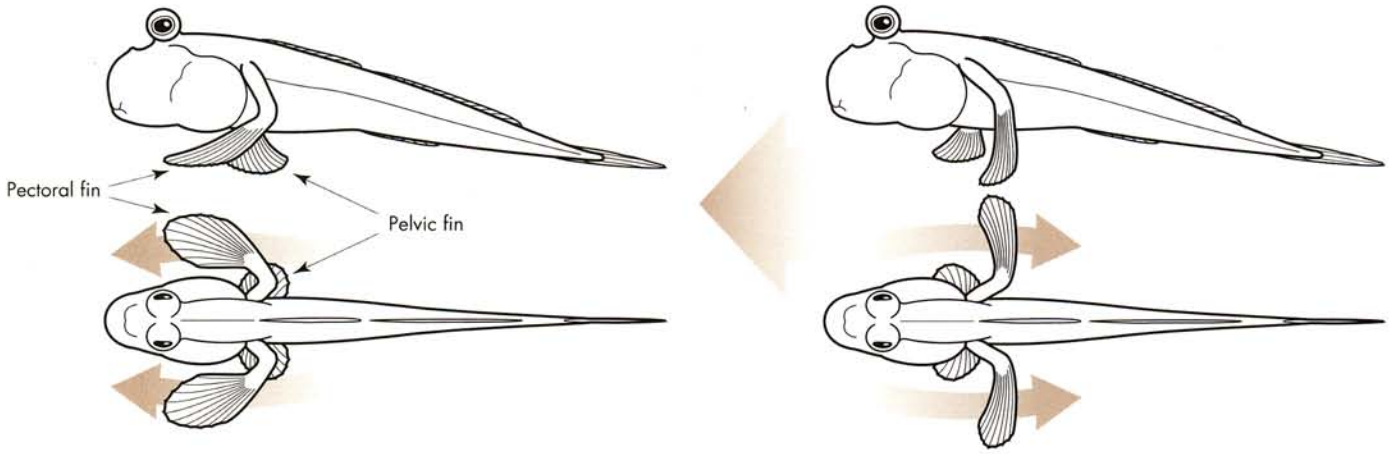


Mudskippers are commonly found in tidal mangrove habitats like this location in the northern tropics of Australia.

A shipment of mudskippers has recently arrived from West Africa. Styrofoam™ air-freight containers sit empty on the floor, and a dozen specimens a few inches long now scurry around inside an aquarium. Placing a few blood worms on her open hand and dipping it into the shallow water, Aguilar encourages a small mudskipper to climb into her palm to feed.

She explains how monitoring cardiorespiratory responses in an animal of this size can be both painstaking and frustrating. "Because electrode pads are bigger than mudskippers, they can't be attached to the animals in the usual way. The trick then is getting the animal to stay on top of the pad."

Aguilar believes the payoff should prove worth the effort. By studying mudskippers and other fishes from the goby family with different air-breathing adaptations, she hopes to increase understanding of how the physiology of air breathing developed, and how it affects the ability of certain fishes to endure low-oxygen situations. If measurements of heart and respiration rates, blood-oxygen binding properties, and biochemical responses are successful, they



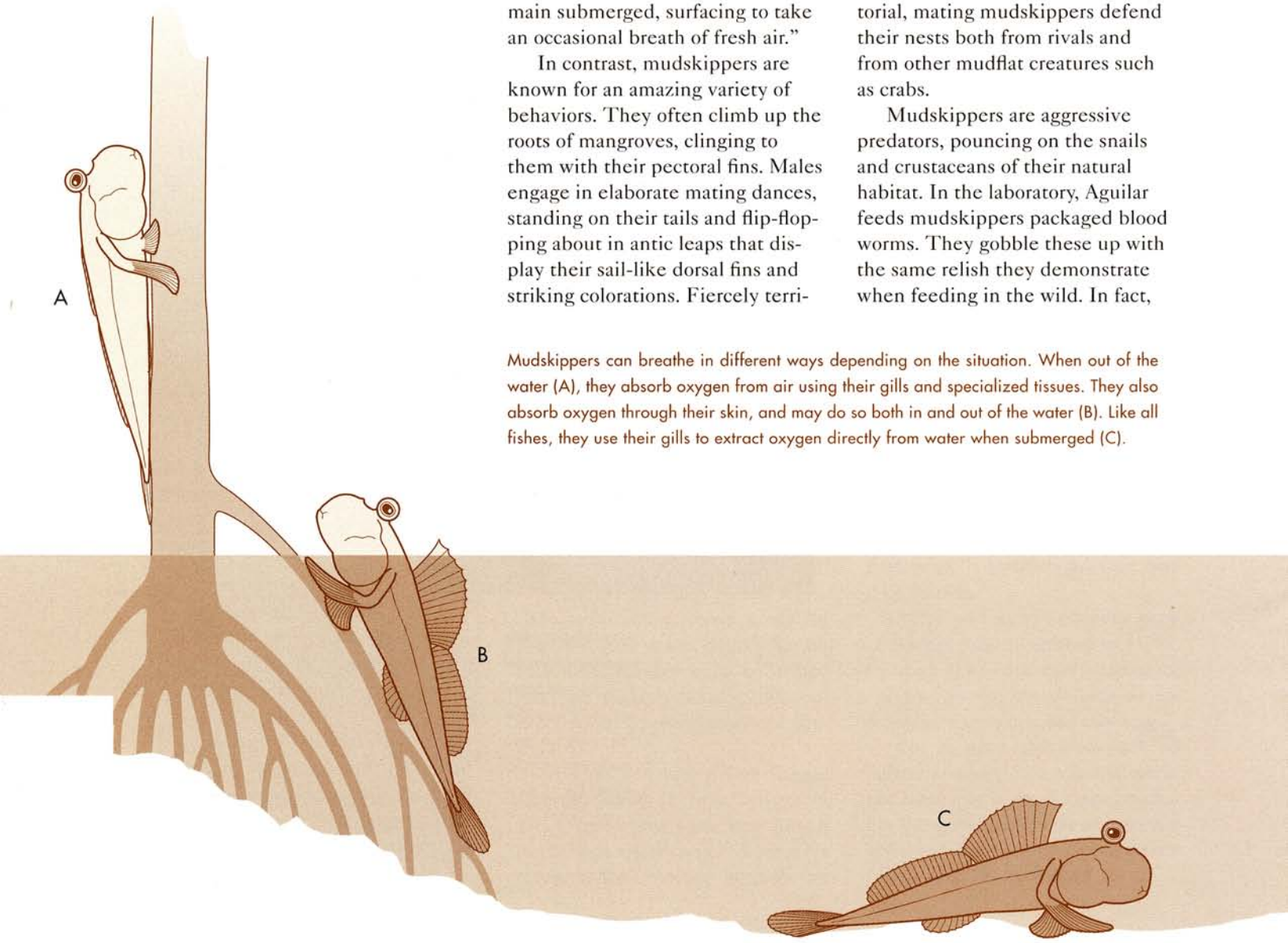
Mudskippers have remarkable adaptations for terrestrial locomotion. Their pelvic fins act like crutches, supporting the body while their pectoral fins "row" the body forward. In this way, mudskippers can scurry across surfaces with astonishing speed. They can also use their fins to climb tree roots and stems.

may indicate how efficiently oxygen is used and delivered to tissues in the mudskipper's body.

"The ability to breathe air is the most obvious characteristic that sets mudskippers apart from other fishes, but they are not alone in this," says Aguilar. "Many members of several families of fishes are also able to breathe air. What makes mudskippers so interesting to me is that they are so active on land. Other air-breathing fishes begin to breathe air when there is not enough oxygen in the water for them to survive, but very few ever leave the water. Instead, they remain submerged, surfacing to take an occasional breath of fresh air."

In contrast, mudskippers are known for an amazing variety of behaviors. They often climb up the roots of mangroves, clinging to them with their pectoral fins. Males engage in elaborate mating dances, standing on their tails and flip-flopping about in antic leaps that display their sail-like dorsal fins and striking colorations. Fiercely territorial, mating mudskippers defend their nests both from rivals and from other mudflat creatures such as crabs.

Mudskippers are aggressive predators, pouncing on the snails and crustaceans of their natural habitat. In the laboratory, Aguilar feeds mudskippers packaged blood worms. They gobble these up with the same relish they demonstrate when feeding in the wild. In fact,



Mudskippers can breathe in different ways depending on the situation. When out of the water (A), they absorb oxygen from air using their gills and specialized tissues. They also absorb oxygen through their skin, and may do so both in and out of the water (B). Like all fishes, they use their gills to extract oxygen directly from water when submerged (C).

mudskippers adapt relatively well to captivity, and are a popular item in pet shops. Aguilar has one caution: "I don't like to handle the big ones; their bite can break the skin." This comes as a surprise considering a 'big one' is only about six inches long, and has the pop-eyed appearance of a lovable cartoon character.

Aguilar observes that mudskippers will come onto the land even if there is more than enough oxygen in the water for survival. They are able to take advantage of this amphibious lifestyle by being adapted for respiration in three different ways: they can extract oxygen directly from water through their gills, as do other fishes; they can absorb oxygen through their skin; and they can take air into their opercular chambers (containing the gills), absorbing oxygen directly into the gills as well as specialized tissues along the chamber wall. Laboratory observations have shown that mudskippers are perfectly capable of an entirely aquatic existence and they suffer no apparent ill effects when submerged in water for indefinite periods.

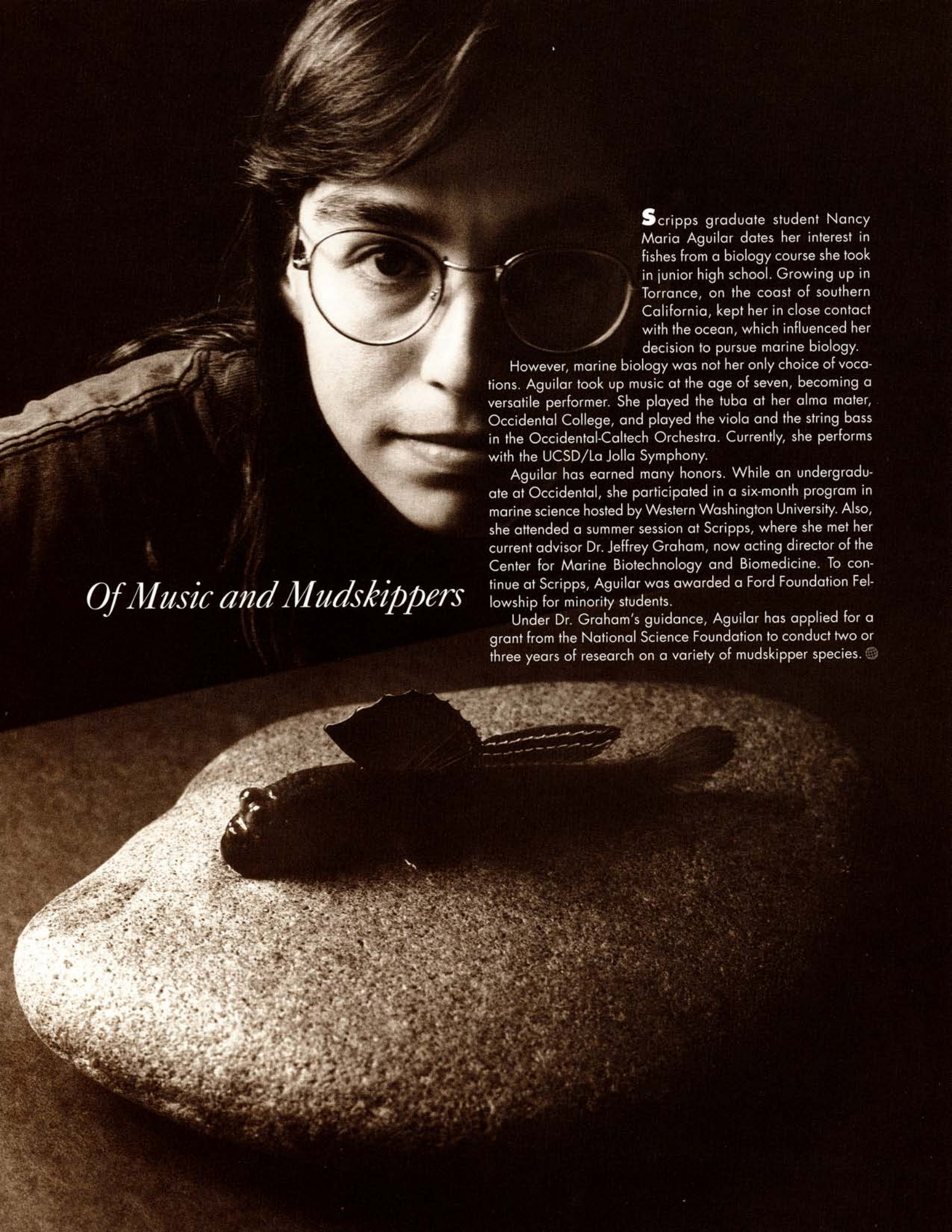
Another distinctive adaptation of mudskippers is their peculiar eyes. Aguilar's advisor, CMBB Acting Director Dr. Jeffrey Graham, has described how, unlike other fishes, mudskippers are able to see in all directions. "Using voluntary muscles, they raise and lower their protruding eyes and rotate them rapidly, like turtles. They can move their eyes independently of each other, much like a chameleon. Periodically, the mudskipper remoistens its eyes by retracting them into small water-filled cups that lie below the head." There is a drawback to this adaption for seeing in air, however. Like human eyes, the eyes of mudskippers have become adapted for aerial vision and cannot focus when submerged. Thus, the world beneath the surface appears to them as a blur. This may be another reason why they seem so at home on land.

By studying mudskippers, Aguilar hopes to increase understanding of how the physiology of air breathing developed.

Mudskippers bask in the heat of an artificial habitat in a laboratory of the Center for Marine Biotechnology and Biomedicine at Scripps.

Mudskippers and other air-breathing fishes have long been subjects of research at CMBB (formerly the Physiological Research Laboratory [PRL]). During the institution's 1966 Billabong Expedition to northern Queensland, Australia, subjects of study included respiration in mudskippers. The late Dr. Per F. Scholander, who was the expedition's principal investigator and the first director of PRL, is said to have mused that, "Mudskippers are reverse divers; they leave the water and dive into the air."

Aguilar is currently studying two species of mudskipper. One, the small brown mudskipper (*Periophthalmus barbarus*), is a species highly active on land during low tides. Like other mudskippers, it makes burrows for shelter during high tides. Even when the oxygen content of the water in its burrow becomes very low, *Periophthalmus* will usually remain hidden. The blue-spotted mudskipper (*Boleophthalmus boddarti*) differs



Of Music and Mudskippers

Scripps graduate student Nancy Maria Aguilar dates her interest in fishes from a biology course she took in junior high school. Growing up in Torrance, on the coast of southern California, kept her in close contact with the ocean, which influenced her decision to pursue marine biology.

However, marine biology was not her only choice of vocations. Aguilar took up music at the age of seven, becoming a versatile performer. She played the tuba at her alma mater, Occidental College, and played the viola and the string bass in the Occidental-Caltech Orchestra. Currently, she performs with the UCSD/La Jolla Symphony.

Aguilar has earned many honors. While an undergraduate at Occidental, she participated in a six-month program in marine science hosted by Western Washington University. Also, she attended a summer session at Scripps, where she met her current advisor Dr. Jeffrey Graham, now acting director of the Center for Marine Biotechnology and Biomedicine. To continue at Scripps, Aguilar was awarded a Ford Foundation Fellowship for minority students.

Under Dr. Graham's guidance, Aguilar has applied for a grant from the National Science Foundation to conduct two or three years of research on a variety of mudskipper species.

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behaviorally from *Periophthalmus* in that it spends less time on land and more time in its burrow.

While Aguilar is interested in knowing why mudskippers venture onto land, she is specifically interested in knowing how the physiology of the mudskipper differs from that of other related fishes. These include the longjaw mudsucker (*Gillichthys mirabilis*) found on southern California mudflats. It is known as a facultative air-breather; this means that if oxygen in the water is too low, it will surface to take a breath of air, though it rarely leaves the water. The mudsucker is believed to live in burrows, though little is known of its burrowing habits. The blind goby (genus *Typhlogobius*), found throughout southern California's coastal waters, lives under rocks in burrows that contain very low oxygen. The blackeye goby (*Coryphopterus nicholsi*) lives in deeper waters (30-90 ft) with usually high oxygen content. Unlike mudskippers and the mudsucker, these two gobies do not breathe air.

What does Aguilar hope to learn by comparing the air-breathing responses of mudskippers to these related fishes? One goal is to understand how mudskippers specifically respond to oxygen in the water and on land. Another goal is to determine what is unique about how they cope with stresses such as chemical build-up in their tissues in low-oxygen situations, and how oxygen is bonded in their blood.

"A question I am frequently asked is whether or not mudskippers are going to become frogs or some other amphibian. The answer is no; mudskippers are not developing in any direction that we can predict. However, we might be able to look at mudskippers and use them to help us understand what kinds of changes took place in the first fishes that crawled out of the water and onto land 350 million years ago," says Aguilar.

Though never far from the water's edge, mudskippers seem quite comfortable with life on land.

Though the structures of many extinct plants and animals are preserved in the fossil record, Aguilar points out that their physiology is not. "However," she adds "by studying the physiology of existing organisms, we can make some educated guesses as to what extinct animals were like, though we may never know for sure."