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PLAINFIN MIDSHIPMAN FISH: SONGBIRDS OF THE SEA

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YOUNG REVIEWERS:

ISAAC
AGE: 15

MAYA
AGE: 15

Most of us have heard birds sing during the spring breeding season. Did you know that some fish also sing to attract mates? We study plainfin midshipman fish, a fascinating fish that makes its home along the Pacific Coast of North America. The big male fish sing during the summer months and their sound-producing muscles get bigger in the summer, probably to make them sound more attractive to females. Female midshipman fish go through seasonal changes, too. In the summer their hearing improves, which helps them pick the right male to mate with. We study hearing in female plainfin midshipman, measuring how their ears respond to sound and how the number of hearing cells in their ears changes between winter and summer. We want to know how seasonal changes in hormones affect hearing in this "songbird of the sea".

DO FISH SING?

Like humans, animals need to communicate with each other. Instead of using words, animals might sing, dance, or offer gifts. We hear birds singing in the spring, but some fish actually sing, too! Plainfin midshipman fish, a type of fish that lives along the North American coast of the Pacific Ocean, sing at night during the summer breeding season (Figure 1). Midshipman songs sound like a deep hum and are loud enough to be heard out of the water. There are two kinds of male midshipman fish: parental males and sneaker males. Parental males sing or "hum" to attract females to their nests (**listen here to hear the hum**). We still do not know what features of the male's hum make him more or less attractive to a female, but we do know the hum is important for female mate choice. Sneaker males do not hum. Instead, they disguise themselves as females to sneak into the nest and fertilize eggs while the parental males are busy wooing females [1]. Sneaker males also make sounds, as do females. However, they can only grunt, which sounds similar to a frog croaking. Grunts are used to indicate displeasure and may be the midshipman fish's equivalent of shouting at another fish rather than engaging in a fist (fin?)fight.

Figure 1

Figure 1

Midshipman fish. Parental males can grow as large as 15 inches (38 cm) long; females and sneaker males are a bit smaller (Photo credit: Gabriel Ng. Used with permission).

AUDITORY PLASTICITY

Changes in the ear or in the ability to hear.

Some animals experience fascinating seasonal changes to their bodies, such as changes to their vocal systems. For example, songbirds show seasonal changes in brain regions that control their vocal muscles [2]. Midshipman fish also undergo interesting seasonal changes to their bodies. Parental males hum during the summer breeding season because they develop strong humming muscles every spring. Similarly, female ear structure changes during the breeding season, to better detect male hums [3]. This ability to change their hearing is called **auditory plasticity**. Humans and many other animals experience various types of auditory plasticity, and

HORMONE

Chemical messengers produced by the body. **Testosterone** and **estrogen** are two major hormones that are important for reproduction.

SWIM BLADDER

A gas-filled body part used by most fish to control their ability to float in water. Some fish also use the swim bladder to make sounds.

MITOCHONDRIA

The energy-generating "factory" inside cells.

factors like **hormones** are responsible for some of these changes. By understanding how female midshipman fish experience hearing changes, scientists may be able to use that information to better understand how other animals and humans hear.

HOW DO FISH SING?

When two people talk to each other, they vibrate their vocal cords and use their mouths to create sounds other people can understand. Fish do not have vocal cords, but some species can still make sounds! Midshipman fish make sounds with their **swim bladders** [1]. Swim bladders are like balloons—they are gas-filled organs that fish use to regulate their position in the water, so they do not float to the surface or sink to the bottom. Some fish, like midshipman, have muscles surrounding the swim bladder that vibrate and make sounds (Figure 2). During the summer, parental males have bigger muscles that allow them to hum. But in the winter, these muscles shrink, so they can only grunt.

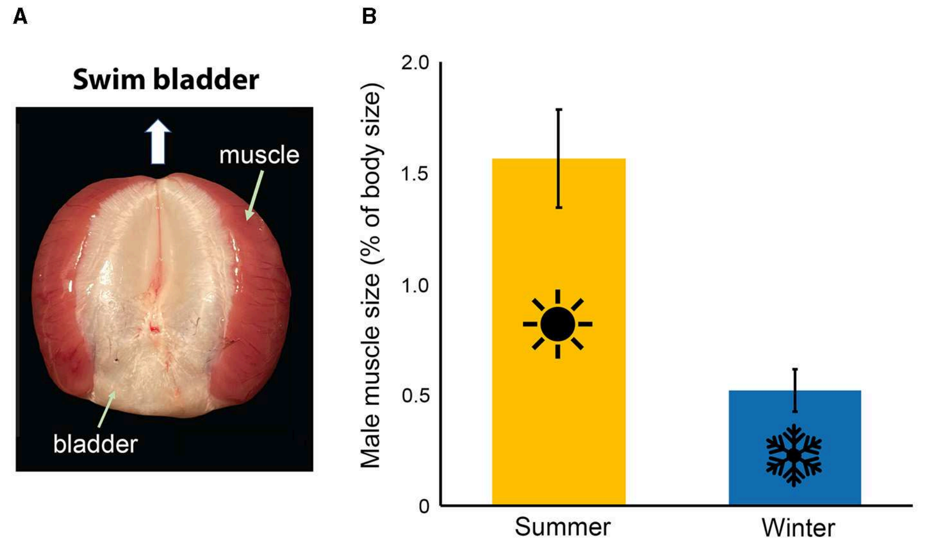

Figure 2

Figure 2

(A) A swim bladder from a parental male midshipman fish. The pink crescents on the sides are the sound-producing muscles. The white arrow points toward where the fish's head would be located. **(B)** Parental male swim bladder muscles are larger in the summer than in the winter. We weighed the muscles and compared muscle weight to the fish's body weight. In the summer, the sound-producing muscles take up around 1.5% of the male's body weight, while in the winter the ratio drops to 0.5% (data and image provided by Loranzie Rogers, used with permission).

HOW DO PARENTAL MALES CHANGE SO THEY CAN HUM IN SUMMER?

In the spring, the hormone testosterone [4] causes the muscles surrounding the male's swim bladder to change. Testosterone allows the muscles to become larger and to use more cellular energy, which means larger **mitochondria** [1]. Mitochondria are structures inside cells that make energy for the cells, and larger mitochondria produce more energy. The extra energy produced by larger mitochondria is required for male sound-producing muscles to vibrate for hours at a time—long enough to impress a female! Females go through changes too, but instead of sound-production changes, females experience changes in hearing.

HOW DO FISH HEAR?

HAIR CELL

A cell with finger-like structures on its top, found inside an animal's ear. These "fingers" are moved by sound, allowing hair cells to send sound information to the brain.

All vertebrate animals have inner ears that contain **hair cells**, which detect sound. Although ear structures can be very different between vertebrates (like fish vs. mice, for example), they all have hair cells that send sound information to the brain. Humans and other mammals have bones in the middle ear, which vibrate the eardrum to detect sound traveling through air, sending that sound information to the inner ear. For fish, sound travels through water and then directly through the fish to reach the inner ear, and this does not require special bones or eardrums. Instead, fish have a large, stone-like structure that moves against hair cells when sound vibrates their ears.

HOW DOES FEMALE HEARING CHANGE IN SUMMER?

Female midshipman fish can hear better during the summer, to better detect singing males (Figure 3) [5]. We can measure hearing in midshipman fish by putting electrical probes into a female's ear. We can then play sounds of various intensities for the fish to hear. The electrical probes measure the ear's response to the sounds we play. Sound intensity (loudness) is measured in decibels (dB)—but it is not a linear scale! Instead, loudness is measured on a logarithmic scale, which means that 80 dB is about *three times* louder than 70 dB. We found that, in the summer, females can hear quieter sounds than females can hear in the winter, with a difference of 10 dB. This result tells us that summer females can probably detect the humming of male fish from farther away, helping the females to find and choose a mate.

SACCULE

Part of the inner ear that fish use to hear. The saccule contains hair cells.

We do not know all of the possible causes of this change in hearing, but our prior research offers important clues. In the summer, female midshipman fish have more hair cells in their **saccule**, which is the major sound-detecting organ in their inner ear (Figure 3) [3]. Having more hair cells probably means more chances to detect a sound, although there is not a clear relationship between the number of hair cells and changes in hearing sensitivity. The increase in hair cells in female ears is caused by an increase in the hormone estrogen during the spring. As the amount of estrogen in a female midshipman fish increases, so too does the number of hair cells.

FUTURE DIRECTIONS

For our current research, we are trying to understand how estrogen causes changes in the number of hair cells in the inner ears of female

Figure 3

(A) Hearing ability changes yearly in female midshipman fish. Shorter bars indicate higher sensitivity because less intense sound is needed to generate an electrical response. Female hearing is better in the summer—the shorter bar means the fish can hear a quieter sound. **(B)** In the boxes, each green dot is a separate hair cell seen under a microscope. We counted hair cells from seven equally sized regions in each female, then added those counts together to generate the graph. Summer females have around 10% more hair cells in their saccules than winter females.

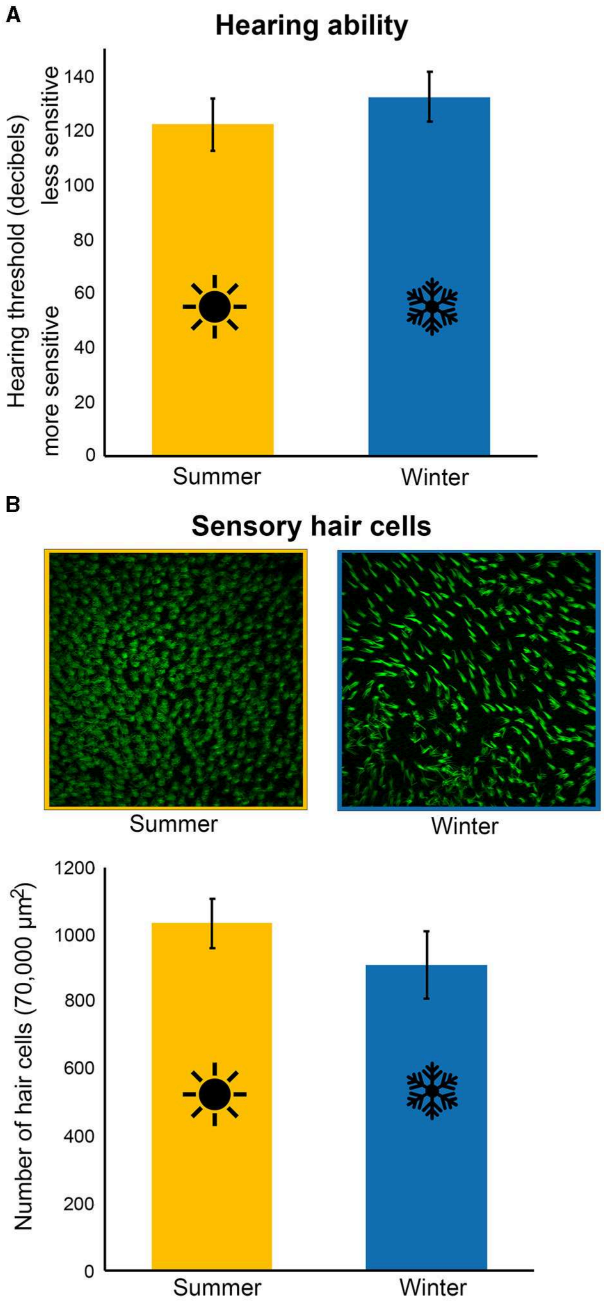

Figure 3

midshipman fish. We know there is a balance between new hair cells being added and old cells being removed, and we want to know how estrogen tips that balance.

It is really a basic math problem. Does estrogen cause more hair cells to develop (more addition)? Does it protect the existing hair cells, so they survive better (less subtraction)? Or does estrogen do both? Our research helps us understand how hormones regulate hearing in midshipman fish, and our findings might apply to other animals that have seasonal differences in hearing, like some frogs and birds. Our work may also help us learn how hormones can affect hearing in humans, by showing how estrogen can regulate hair cell survival. There is so much we can learn by studying singing fish—both about fish, and maybe, about humans.

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

ISAAC, AGE: 15
My name is Isaac. When I am not in school you can find me playing basketball, running, reading, or listening to music.

MAYA, AGE: 15
Hi, I am Maya! I love science (especially biology and psychology) and the arts (I am a vocalist and also play violin, enjoy performing in musical theater, a dancer, and an avid artist). I am fascinated by the variety of ways that animals and people communicate—and it was really fun to learn about courtship in singing fish.

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Coty is a Ph.D. student in the Coffin Lab at Washington State University Vancouver. His research focuses on how estrogen and other hormones interact with hair cells. When Coty is not in the lab he enjoys working out, reading, public speaking, and being outside.

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I am a research technician in the Coffin Lab at Washington State University Vancouver. I study hearing loss in rats, mice, salmon, killifish, zebrafish, plainfin midshipman, and even bats! My favorite part of my work is everything—working with different species, collaborating with people from all over, and creating pretty images. In my spare time I love rock climbing, skiing, watching movies, and reading.

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Leila is a researcher in the Coffin Lab at Washington State University Vancouver. She is interested in how hormones are related to enhanced auditory sensitivity in zebrafish and plainfin midshipman fish. Outside of lab, Leila enjoys aquarium care, playing guitar, and writing.

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I am a lab manager at Washington State University Vancouver, where I also received my Bachelor's in Biology and my Master's in Biology. I study hearing loss and inner ear cells in rats, mice, zebrafish, plainfin midshipman, and bats! My favorite part of my work is admiring the beautiful inner ear under the microscope, discovering something surprising, and mentoring students in the lab. When I am not in the lab, I am writing about science either on my blog or for other outlets. I also enjoy rock climbing, surfing, and home renovation.

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ALLISON B. COFFIN

Allison (Alli) Coffin is a neuroscience professor at Washington State University in Vancouver, WA (USA). Alli's research examines how different factors like medicines, noise, and hormones affect hearing, and how we can develop medications to prevent hearing loss or regenerate hearing after damage. She is also the co-founder and president of the Association of Science Communicators, an international non-profit that supports the science communication community to increase the impact of science in society. In her spare time, she loves reading, motorcycling, working out, dancing to live music, and snuggling her cats. *allison.coffin@wsu.edu