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Mother Nature's Engineering

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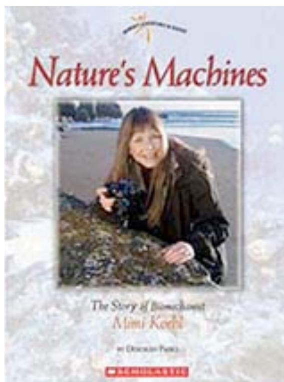

Mimi Koehl has won many accolades for her research, including a MacArthur "genius" award in 1990. She is also the heroine of *Nature's Machines*, a children's book about her life and work. *Image: courtesy Mimi Koehl*

At the bottom of the ocean, a lobster follows its nose. In the dim vastness of the seafloor, the smell of prey is the most reliable guide to a good meal. But tracing a faint plume of scent to its source is no mean feat when currents are swirling odor molecules hither and yon.

The noses of lobsters are stick-like antennules bearing rows of odor-sensing hairs. To home in on prey, lobsters sniff by flicking their noses up and down like a fly fisherman working a stream. Berkeley professor of integrative biology Mimi Koehl sees the similarity between these "hairy little noses" and many other types of feathery and bristly structures.

Koehl used odor labeled with fluorescent dye and a laser to illuminate how lobster noses trap a scent molecules in turbulent water currents. *Image: courtesy Mimi Koehl*

Animals from crabs to fanworms, moths to barnacles also have appendages bristling with arrays of fine filaments. They sweep these combs or brushes through the air or water, or hold them up in the wind or waves to catch food or oxygen, or to meet a mate.

Koehl is studying how structures such as hairy limbs help organisms survive in a demanding environment. Gleaning design principles from living things is her stock in trade. Koehl is now working to disseminate this approach more broadly as a cofounder and instructor at CiBER, Berkeley's new Center for Interdisciplinary Bio-inspiration in Education and Research.

"I look across living things and ask, is there a kind of structure that gets used over and over again by different groups of organisms to do something important?" Koehl says. In this way, she can separate features that are species-specific from those critical to get the job done.

"For me, it's very important to observe organisms in their natural habitats and measure the aspects of their physical environment that impinge on them when they function," Koehl says. "If you really want to understand which aspects of an organism's structure affect its performance, you need to know what it does in nature."

Koehl studies organisms in natural habitats to better understand how their bodies interact with the environment. Here, she is examining how kelp on Tatoosh Island, Washington, withstand the crashing ocean waves. *Image: courtesy Mimi Koehl*

Using high-speed video, Koehl recorded live lobsters as they sniffed. With each flick of the antennule, the lobsters made an extremely rapid downstroke, followed by a much slower upstroke. But how did these movements affect the flow of water within the tuft of sensory nose hairs?

To find out, Koehl built a robotic lobster with a body made from the molted shell of a real lobster. Removing the nose antennules from lobsters bought at the fish market, she affixed them to robotic arms that would wave them up and down at a programmed pace. Koehl then put the robot downstream from an odor source in a big flow tank where she could mimic the turbulent water flow in a lobster's seafloor habitat. She labeled the odor with a fluorescent dye plume so she could see it, and turned out the lights. As the robo-lobster sniffed, she used a laser beam to illuminate just the paper-thin slice of water where the skinny antennule was flicking. Any dye molecules in the slice glowed, allowing Koehl to track the odor concentrations captured by the antennule with great precision.

She found that the rapid downstroke pushes old, stale water out from between the hairs as a new water sample enters. On the slower upstroke, this fresh sample remains trapped in the tuft of sensory filaments so the lobster can process the odor. Calculations of the fluid dynamics confirmed her findings.

"They're sniffing, just like we do. They're taking a discrete odor sample with each flick," Koehl says. "If you're trying to locate something, you want to know what it smells like now versus when you were someplace else."

Koehl is co-founder of Berkeley's new Center for Integrative Biomechanics in Research and Design, or CiBER. As part of a new CiBER lab course, she shows students how to measure water flow and turbulence in Strawberry Creek while assessing the hydrodynamic forces a crayfish would experience in the stream. *Image: Simon Sponberg*

By altering the dimensions, hair arrangement, and movements of her model, Koehl could observe how lobster noses performed against crabs, shrimps, and even the antennae on moths.

Her findings can help engineers develop sniffing robots that could be used to detect mines threatening harbors, sources of toxic waste, or other hazards.

"By understanding how nature's structures operate in messy real-world habitats, I provide design principles that can be used by people developing devices that must operate in complex environments," Koehl says. "We're using biological structures as inspiration for manmade designs."

Related Web Sites

- Koehl Lab
- "Lobster sniffing: how lobsters' hairy noses capture smells from the sea," by Robert Sanders, Berkeley NewsCenter, 30 November 2001
- "How Does a Lobster's Nose Know?" by Christian Heuss. ScienceNotes 2002.
- Mimi Koehl—The nature mechanic