Following the Scent of Avian Olfaction

Researchers are gaining greater respect for a bird's ability to follow its nose, a skill that may help it find food or navigate over long distances

It turns out Toucan Sam may not have been a liar after all. In the 1970s, the bright-billed cartoon spokesbird for Kellogg's Froot Loops cereal boasted in television ads that he could "follow his nose" to the cereal's "delicious fruit smell." But amused biologists called Sam a sham: The conventional wisdom, based on studies of brain anatomy, held that most birds had little or no sense of smell.

Since then, however, researchers have steadily pecked away at that idea. They've shown that even birds with relatively small olfactory bulbs—the brain tissue responsible for discriminating a sickening stench from a fragrant aroma—can not only sense odors, but also use them to find food, select prime nesting material, and navigate across vast stretches of unknown terrain. "We're realizing that avian olfaction isn't some strange minor quirk confined to a few species," says behavioral ecologist Tim Guilford of Oxford University in the United Kingdom. Such findings not only show that olfaction plays a major role in the behaviors that birds need for survival, but could also have practical applications in conservation and farming.

The once widespread notion that few birds could follow their beaks rested on studies of bird brains and the views of a few influential natural historians. Prominent 19th-century bird artist John James Audubon, for instance, popularized the misconception that vultures don't use smell to find the reeking carcasses that make dinner after he conducted an experiment in which he presented black vultures with covered and uncovered bodies; they flocked only to the flesh in plain sight. And early anatomists noticed that birds had smaller olfactory bulbs than mammals do and thus concluded that smell likely played little role in the life of birds.

By the 1960s, however, such broad-brush findings were giving way to a more complicated picture. In widely cited work published in the late 1960s and early 70s, Betsy Bang, who was affiliated with the Woods Hole Marine Biological Laboratory in Massachusetts, measured the size of the olfactory bulb relative to overall brain size in 151 bird species. She found that whereas olfactory tissue took up as little as 3% of the brains of small forest-dwelling songbirds such as the black capped chickadee, the bulbs accounted for up to 37% of the brains of some seabirds, such as the snowy petrel that patrols the South Polar seas. During the same period, ornithologist Ken Stager of the Los Angeles County Natural History Museum showed that the turkey vulture, unlike Audubon's black vultures, could find food by smell. Indeed, Stager noted that some clever engineers had harnessed the vulture's olfactory prowess to find leaks in natural gas pipelines: The sight of circling vultures could lead work crews to leaks, presumably because gas is "flavored" with ethyl mercaptan, a chemical that smells like carrion.

Meanwhile, behavioral neuroscientist Bernice Wenzel of the University of California, Los Angeles, was finding that pigeons—which rank somewhere in the middle in Bang's bulb-size study—could detect even subtle scents. When the birds were placed in a box with a steady airstream, their heart and respiration rates would jump when Wenzel released various odors. "I was dimly aware that avian olfaction had been looked at by a few odd folks, but the issue was very much up in the air," the retired researcher recalls. She and a procession of collaborators went on to study smell in other species. "Every bird we tested, regardless of bulb size, showed some reaction" to odors, Wenzel says.

Take a whiff. White-chinned petrels *(top)* appear to use dimethyl sulfide to find prey, while gray-headed albatrosses *(right)* don't.

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As the evidence that birds can smell began piling up, researchers began pinning down the role of olfaction in bird behavior. Homing pigeon aficionados, for instance, had had a long-standing controversy over whether the birds use olfactory clues to find their way over unfamiliar ground back to their coops. Over the last decade, however, researchers have repeatedly shown that pigeons whose sense of smell is blocked by wax or an anaesthetic placed in their nostrils take significantly longer to find home base—or fail completely. And last year Italian researchers, including Anna Gagliardo of the University of Pisa, showed that young birds with damaged olfactory tissues are unable to learn to navigate from visual landmarks alone. "Pigeons appear to be able to extrapolate a map of unfamiliar environments by sensing incoming odors from different wind directions," says Guilford, though they probably also rely on visual guideposts closer to home.

Smell also helps some birds build their nests, chemical ecologist Larry Clark of the U.S. Department of Agriculture's National Wildlife Research Center in Fort Collins, Colorado, discovered in the 1980s. He found that European starlings rely on smell to find the green plants they commonly weave into their nests—material that helps reduce potentially harmful microbe and parasite populations. He also found hints that just as the song centers in the brains of some male canaries shrink after the mating season, the olfactory bulbs of starlings atrophy when the nesting season is over.

Exactly which odors starlings, pigeons, and other birds home in on remains mostly a mystery. But in 1993, a serious accident at sea led olfaction specialist Gabrielle Nevitt of the University of California, Davis, and colleagues to the discovery of at least one important cue for some seabirds. While Nevitt was aboard an antarctic research cruise, a storm dislodged a heavy tool box and sent it hurtling into her kidney. The injury confined the researcher to her bunk, giving her plenty of time to ponder how antarctic seabirds such as petrels and albatrosses, which have among the largest olfactory bulbs, locate small patches of shrimplike prey in the vast polar seas. Not only do the birds have few apparent landmarks to guide them, but the patches frequently move, making the task akin to find a moving needle in a haystack.

Building on studies by Wenzel and others, Nevitt believed the birds were homing in on a chemical signal, but no one had managed to identify the compound that piqued the birds' interest. Then, during a stop in Punta Arenas, Chile, a research team including atmospheric chemist Tim Bates of the National Atmospheric and Oceanic Administration's Pacific

Marine Environmental Laboratory in Seattle, Washington, boarded the ship.

Nevitt says Bates "was just being nice" in chatting with the injured interloper he discovered in the team's quarters. But Bates says he found Nevitt's olfaction problem interesting. "I told her that if I had to put a bet on [an oceanic] compound that had an odor, it would be dimethyl sulfide (DMS)," a gas given off by phytoplankton, microscopic plants that live in surface waters. He gave Nevitt a map of a DMS plume over Antarctica's Drake Passage, which showed that the compound concentrates over zones of upwelling and mixing, where the phytoplankton concentrate. "It changed the way I thought about the problem," Nevitt recalls. "I realized the birds were navigating through an olfactory landscape," complete with low-concentration valleys and DMS-rich mountain peaks. The tiny crustaceans eaten by the seabirds can also elevate DMS levels when they chow down on phytoplankton, providing a potentially solid food clue for the birds.

Sniffing out the good. European starlings use smell to find beneficial nesting material, but appear to lose that ability when breeding is done.

Nevitt was eventually able to document that several kinds of petrels and prions, another type of seabird, home in on DMS-laced vegetable oil slicks more often than odorless control slicks. But the preliminary findings, published in *Nature* in 1995, raised new questions. How, for instance, do the birds follow the changing gradients of DMS in the often turbulent atmosphere, where odor plumes can become fragmented? One possibility, she says, is that the odor cue prompts the birds to execute a search pattern, such as a broad turn, just as some salmon automatically swim against the prevailing current upon encountering a desirable odor. Over the next year, Nevitt and ornithologist Henri Weimerskirch of France's CNRS research agency in Villiers will look for such response patterns as they use satellites to track snowy petrels and other antarctic seabirds on their foraging trips. They will also block some birds' sense of smell to see if that alters the foraging strategy.

While petrels may follow their noses to food, chickens apparently call on olfaction to help them avoid eating bad-tasting insects. Guilford and colleagues have shown that chicks presented with bright, contrasting colors typical of insects that produce noxious odors won't reject the offering unless they can sense both odor and color. Such "multimodal" responses are also being studied by Lesley Rogers and colleagues at the University of New England in Armidale, Australia, who are using combinations of odors and colored beads. Related studies that monitor where olfactory stimuli are processed in the brain have also produced hints that chicks can develop "lateralized" olfaction, in which the right and left nostrils feed separate signals to the brain. In a kind of multitasking, cells in "the left nostril might be on the lookout for noxious odors, while the right is involved in something else," she says.

Other scientists are studying how chicken farmers might benefit from imprinting chicks on certain odors while they are still in the egg. Preliminary studies have shown that chicks exposed to odors in the final days of development—when tissue plugs melt out of nostrils and the chick begins breathing air that seeps through the eggshell—are attracted to the same smells after hatching. If the findings hold up, adding familiar odors to food and coops could improve production by reducing the stress the birds experience when confronted with new settings and foods, notes poultry scientist Bryan Jones of the Roslin Institute in Midlothian, United Kingdom.

And Nevitt speculates that olfaction studies might eventually influence conservation strategy too, by helping breeders of endangered birds provide the olfactory cues needed to get the young birds off to a good start. Rogers and others caution, however, that progress could be slow, because lab and field studies involving odors "are hellishly difficult to set up and control." Toucan experts, for instance, say figuring out whether real toucans use fruit odors in foraging could take years. But Guilford is upbeat about the prospect of learning more about how birds use smell. "There is plenty of room for speculation," he says, "and plenty more for experiments." –DAVID MALAKOFF

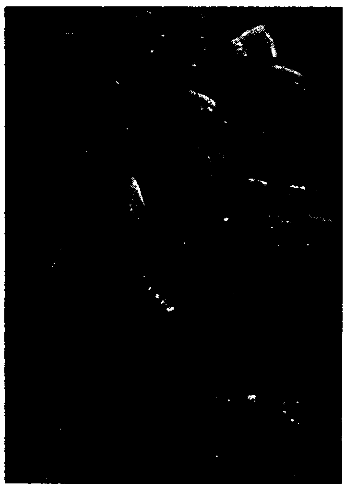
NEWS

Salmon Follow Watery Odors Home

Researchers are beginning to understand how salmon form the critical olfactory memories that guide them home from the sea to the streambeds where they hatched years before

While the smell of fresh-baked bread may pull us irresistibly down unfamiliar streets until we stand at the bakery door, that's about as much as we humans ever rely on olfaction to guide our travels. But for some animals, olfactory homing is a matter of life and death. Recent work has shown that some birds depend heavily on their sense of smell to find food and to navigate (see page 704). And salmon sniff their way back from ocean or lake to the streambed where they hatched, guided by an odor signature derived from the unique mix of elements such as plants, animals, and soils in their home stream and imprinted on their memory years earlier.

The survival of a salmon population depends on the fish's ability to return to their birthplace to spawn, because many of their physical and behavioral traits have been selected over generations for the survival advantage they provide in that particular stream. Now neuroscientists and fisheries biologists are learning just how salmon form the olfactory memories that guide them home. They are uncovering the physiological changes that prepare young salmon for olfactory imprinting and are finding out when in the animals' life cycles those changes occur. They are also gleaning clues to the biochemical basis of imprinting.



Homeward bound. Migrating salmon like these follow olfactory cues.

This work should help the management of salmon and their close relatives, though not necessarily of all fish that use olfactory homing. Some, such as lamprey eels, find spawning sites by sniffing out pheromones, an achievement that appears to be instinctive rather than learned.

Nevertheless, salmon represent an important and frequently threatened species, and conservation managers are eager to put the

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