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TOXIC MEALS FOR SEABIRDS AND SEALS: MONITORING MERCURY IN THE SAN FRANCISCO BAY

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YOUNG REVIEWER:

ETHAN

AGE: 8

Mercury is a metal pollutant that travels thousands of miles through air and water. It flows along rivers to lakes, estuaries, and the sea, cycling between animals and their environments. Extensive mercury mining during the Gold Rush left lasting impacts on the San Francisco Bay Delta, one of California's largest wetland habitats and home to thousands of species. Burning fossil fuels in cities like San Francisco also releases mercury, leading to its buildup in local food chains. Mercury accumulates from plankton to fish to top predators like sharks and seals, where it reaches potentially harmful levels. Mercury never fully breaks down and continues cycling in ecosystems, even reaching migratory animals living offshore in the Pacific Ocean. Scientists collect samples from wildlife to uncover clues about mercury sources and threats to human health. This article explains

the mercury problem and why we track this invisible pollutant in the San Francisco Bay.

WHY IS MERCURY SO HIGH IN THE SAN FRANCISCO BAY?

The answer to why mercury levels are so high in the San Francisco Bay (SFB) lies in a story of grit, greed, and gold. Gold discovery in the Sierra Nevada mountains during the mid-1800s drove thousands of people to California to stake their claims. The landscape was quickly changed as tunnels were dug, rivers dammed, and forests logged. In addition to altering the land forever, the California Gold Rush left behind an unexpected and invisible toxic partner: mercury. People used liquid mercury, a naturally occurring element that sticks to gold, to collect gold from mined rock and river sediment. Mercury waste was carried into streams and rivers and swept out to the SFB, a critical habitat for wildlife and important source of seafood. Though the Gold Rush took place over 100 years ago, rivers still carry mercury from remote areas to the Bay [1]. This historic mining, combined with other sources, have led to mercury levels high enough to threaten SFB wildlife and prompt seafood warnings [2].

THE MERCURY CYCLE

How is mercury that was used over a century ago still at high levels in the SFB? Mercury is a toxic metal element and is impossible to destroy. It gets released through natural processes and human activities. Natural sources of mercury include volcanoes, forest fires, and hydrothermal vents in the ocean floor. Humans release mercury into the environment by burning fossil fuels like petroleum and coal. Mercury easily evaporates into the atmosphere and can travel around the world before clinging to water droplets and falling back to Earth in rain and snow. When mercury collects in water bodies like lakes, rivers, and bays, certain **anaerobic bacteria** (single-celled organisms that do not depend on oxygen to survive) transform it into **methylmercury**. This especially toxic form can be absorbed by plants and small organisms, then accumulate in the food chain (Figure 1).

When it comes to studying pollutants, there are two important concepts: **bioaccumulation** and **biomagnification** (Figure 1). Animals absorb more and more mercury from their food, and it builds up in tissues as they age. This process is called bioaccumulation. Small fish feeding at the bottom of the SFB food chain, like anchovies and smelt, have lower mercury levels than larger predatory fish like halibut. Top predators like sharks and harbor seals have the highest mercury levels in their bodies. Increasing mercury levels with increasing steps in the food chain is called biomagnification.

ANAEROBIC BACTERIA

Single-celled bacteria that do not depend on oxygen to survive. Some anaerobic bacteria that live in aquatic sediments produce methylmercury.

METHYLMERCURY

A mercury atom attached to a chemical group called a methyl group. This form is absorbed into plants and animals and builds up in food chains.

BIOACCUMULATION

The gradual increase of a toxin or substance (such as methylmercury) in an individual's tissues over time.

BIOMAGNIFICATION

The increase in levels of toxins or substances in animals that feed at higher levels of the food chain.

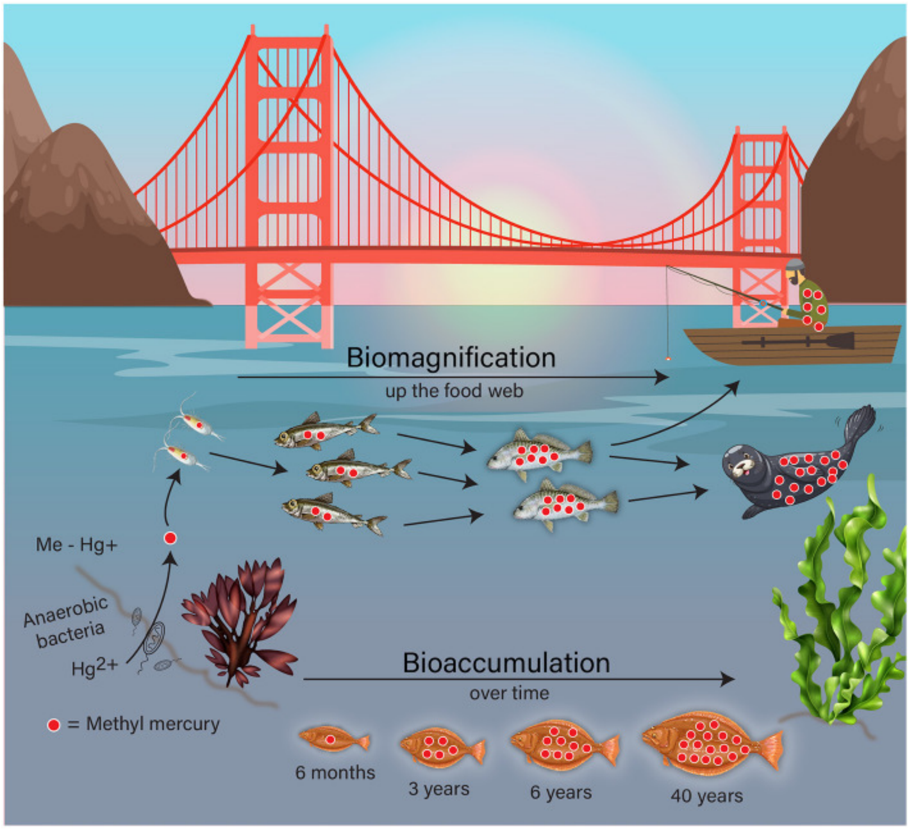

Figure 1

Figure 1

Elemental mercury (Hg^{2+}) is converted by anaerobic bacteria in sediments to methylmercury (Me - Hg^{+}), which is absorbed by plants and small aquatic organisms. Methylmercury accumulates up the food chain, reaching higher levels in top aquatic predators such as seals, through a process called biomagnification. Methylmercury also increases within an individual animal's body over time as it ages. This is bioaccumulation (Image credit: Irma Macias, Metropolitan Water District (MWD) of Southern California External Affairs).

MONITORING MERCURY IN SAN FRANCISCO BAY WILDLIFE

Because of historic mercury mining, SFB Estuary prey fish have mercury levels three to six times higher than similar species on the U.S. East Coast [3]. The U.S. Environmental Protection Agency considers fish with <0.2 milligrams of mercury per kilogram of muscle to be safe for human consumption [2]. Some large, long-lived fish such as white sturgeon and striped bass have mercury levels twice as high as this limit [2]! Scientists care about mercury levels in fish to protect human health, but they also care about wildlife health. One study estimates that one in four fish from the SFB have mercury levels high enough to harm their growth, reproduction, and survival [3]. Some seabirds such as terns have enough toxic mercury in their blood to harm their reproduction. Mercury can also pass from a mother bird to her eggs! Some mercury levels found in SFB tern eggs make scientists worry about whether they can hatch and survive.

Researchers measure mercury and look for health effects in top predators like seabirds and seals because these animals are more likely to have high methylmercury levels. Methylmercury tends to build up in body parts containing keratin, a hard, waterproof protein that makes up hair and fingernails. Seal fur and bird feathers are

Figure 2

Figure 2

Different fish contain different levels of mercury and certain people, including growing kids like you, are more likely to be harmed from eating food containing mercury. Be sure to check local advisories to make sure the type and amount of fish you are eating is safe (Image credit: Irma Macias, MWD of Southern California External Affairs, designed with advice from the California Office of Environmental Health Hazard Assessment).

also made of keratin, so they are excellent samples for monitoring methylmercury [3]. Scientists also test blood, muscle, fat, and feces to assess methylmercury levels in the body. By comparing levels among various animal populations, scientists map mercury across locations and habitats to track ecosystem health and identify new "hot-spots," or areas with high mercury levels.

WHICH FISH ARE SAFE TO EAT?

The benefits of eating some fish can outweigh the risks. Fish provide important nutrients like omega-3 fatty acids, which are good fats needed for brain and heart health. It is all about moderation; *how much* and *what types* of fish you eat. Methylmercury travels from the digestive system to the blood and easily enters many cells in the body, including the brain. Babies and children are considered sensitive groups because their brains are still growing, so pregnant or breastfeeding women and kids under 18 should be careful about their seafood consumption [1]. The California Office of Environmental Health Assessment[1] monitors mercury levels in the SFB and recommends how much seafood from specific locations can be safely

[1] Available online at: https://oehha.ca.gov/fish/advisories.

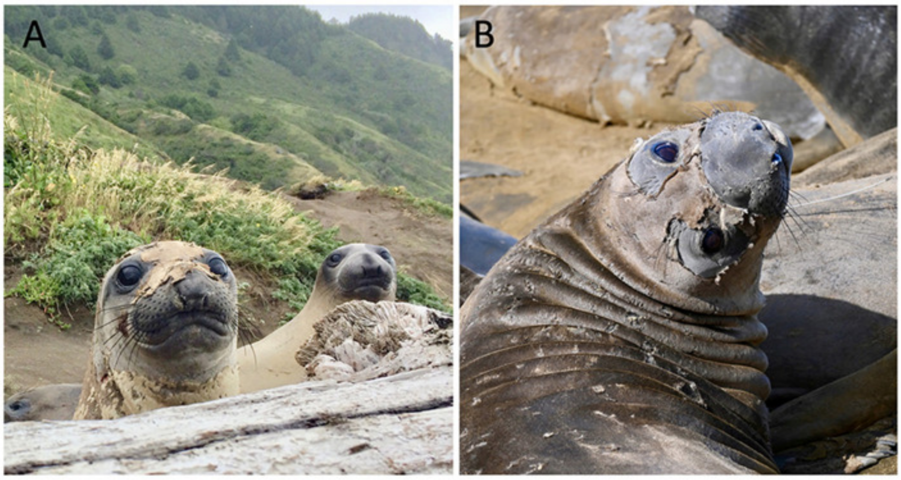

Figure 3

Figure 3

These photos show the elephant seal catastrophic molt. **(A)** A juvenile elephant seal going through its yearly molt next to a freshly-molted friend. **(B)** Another molting seal shedding its mercury-rich fur (These photos were taken under NMFS Permit #19108. Credit: Costa Lab/Claire Nasr and Dan Costa).

eaten in the "Good Catch California" advisory program (Figure 2). For example, rock crab and chinook salmon are low enough in mercury that sensitive groups can eat two servings a week. On the other hand, sharks and surfperch have such high mercury levels that they should never be eaten by sensitive groups. It is always good to know which fish are safe, so check seafood advisories before eating fish from your local waterbodies. Of course, fish are caught and shipped all over the world. The Monterey Bay Aquarium's Seafood Watch program[2] can help you make safe and sustainable choices when looking through your restaurant menu.

[2] Available online at: https://www.seafoodwatch.org/.

WILDLIFE PARTICIPATE IN THE MERCURY CYCLE

If mercury in the body cannot be completely broken down, where does it go next? The more we study mercury, the more we discover interesting roles animals play in transporting mercury between habitats and locations. Migrating animals that travel long distances each season assist in mercury recycling by feeding in one place and transporting mercury with them to new locations. Salmon, for example, hatch in freshwater before migrating to the ocean, where they feed on fish that contain mercury [4]. When it is time to find a mate, they (and mercury they built up) swim up rivers to reproduce. Their life cycle is then complete. Salmon may die, but their mercury lives on! Their bodies release mercury back into the environment [4], where it can be picked up by animals that eat them. Hatched salmon from rivers also pick up mercury before migrating back out to sea. Imagine the thousands and thousands of salmon migrating up the Sacramento and San Joaquin rivers to reproduce each year, bringing mercury with them.

Mercury released from historic mining and ongoing human activities extends beyond the SFB Delta, reaching animals that live and feed offshore in the Pacific Ocean. Northern elephant seals spend most of their time in the open ocean, diving and feeding on mercury-rich fish and squid. Each year, thousands of seals return to colonies in California to "molt," or shed their coats (just like dogs and cats shed their fur). But instead of slowly shedding year-round, elephant seals go through what is called a catastrophic molt (Figure 3), during which they shed and regrow their skin and hair in just a few weeks! This means a year's worth of mercury-rich hair from thousands of seals is quickly dropped off on beaches. Molted hair contains 3.5 milligrams of mercury per kilogram of hair, which is 10 times higher than mercury levels in fish that are safe for humans to eat! The molted hair breaks apart, leading to seawater mercury over 10 times higher than seawater found at nearby beaches without elephant seals [5]. Remember how mercury never breaks down? It becomes available to animals at the base of the food chain, like crabs and mussels, who start the bioaccumulation chain all over again. It is important for scientists to identify these mercury recycling centers because seafood in these areas could have toxic mercury levels and endanger human health.

ONE PLANET, ONE HEALTH

The One Health concept is that humans, animals, and their environments are closely linked. If we work to make one healthier, the others become healthier too. If one is sick, it means others are at risk of getting sick as well. Certain animal species share food, water, and habitats with human populations. We call these **indicator species** because they are exposed to similar pollutants and can signal if there is a problem in the environment. Marine mammals and seabirds serve as important indicator species in the SFB. When we consider how widespread mercury and other pollutants are, keeping an eye on their presence in wildlife is essential for keeping an eye on the health of the environment and the humans that share it. This is a big problem, so what can you do? To help reduce mercury emissions, participate in activities that use less fossil fuels, like biking or walking instead of getting a car ride. To protect the safety of your environment, reduce, reuse, and recycle mercury-containing products such as batteries and fluorescent light bulbs. To protect your safety, be conscious of your seafood consumption and help your family support sustainable aquaculture and fisheries with low mercury levels. Everyone's actions make a difference.

INDICATOR SPECIES

Species used to study the health of habitats. They are usually the first species affected or the most sensitive to environmental changes, like decreasing water quality or food availability.

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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 REVIEWER

ETHAN, AGE: 8

My name is Ethan. I play the piano and take martial arts classes. I like science and reading. My favorite thing to do is to celebrate my friends' birthday parties and to play soccer with my team. I have two miniature Holland Lop bunnies. I love sharks and when I am old, I want to be a conservation biologist.

AUTHORS

JENNIFER COSSABOON

I am a doctoral student researcher in the Aquatic Health Program at the University of California, Davis School of Veterinary Medicine. My fascination with wildlife health and toxicology began while working with seals and sea lions in Monterey Bay and Alaska. I was inspired to earn an M.S. in Public Health Sciences from San Diego State University, where I tracked emerging pollutants in Southern California marine mammal species and the endangered California condor. I am now pursuing a D.V.M./Ph.D. to pair research tools with clinical skills and continue researching the role of contaminants in animal and human diseases. *jcossaboon@ucdavis.edu

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Shawn Acuña is a Senior Resource Specialist for Metropolitan Water District of Southern California. He has almost 20 years of experience in the field of fish biology and environmental science. He has a B.S. in Aquatic Biology from UC Santa Barbara and an M.S. in Animal Biology and Ph.D., in Ecology from UC Davis. He has expertise in gross pathology, histopathology, and nutrition and health biomarkers and has conducted field and laboratory studies on environmental stressors. His currently works on stressors and stressor effects in the San Francisco Estuary to inform sustainable management of the estuary.

BRUCE G. HAMMOCK

I am an aquatic biologist at UC Davis. I am particularly interested in applying science—including ecology, toxicology, hydrology, and statistical modeling—to environmental problems. Some of my recent work has linked the proximity and extent of tidal wetlands to the foraging success of an imperiled fish. Another recent study explored the causes of the collapse of the pelagic food web in the San Francisco Estuary. Most recently I compared the sensitivities of a wide range of biomarkers to fasting in Delta smelt, a locally endemic, imperiled fish.

TOMOFUMI KUROBE

I am an assistant professor in aquatic toxicology at the University of California, Davis. I have been investigating various ecological issues including impacts of contaminants (e.g., pharmaceutical and personal care products, algal toxins, pesticides) on aquatic organisms such as phytoplankton, copepods, and fishes. My goal is to mitigate ecological issues using scientific knowledge. Are you interested in water quality? Please email me: tkurobe@ucdavis.edu. ORCID ID: https://orcid.org/0000-0003-3906-1989.

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I am an environmental toxicologist at U.C. Davis. My research focus is assessing ambient water quality and ecosystem health. I evaluate the effects and interactions of environmental stressors (e.g., pesticides, herbicides, and chemicals of emerging concern) on Delta fishes, invertebrates, and algal species through the use of toxicity testing. These experiments are conducted both in the lab and in the field. I have been with UC Davis for more than 20 years, first getting my bachelor's degree in English, then my master's degree in Animal Biology. I started working here as an undergrad student and now manage the Aquatic Toxicology Laboratory.

SWEE J. TEH

Swee Teh, Ph.D. is director of the Aquatic Health Program at the University of California-Davis School of Veterinary Medicine. He is also director of the Aquatic Toxicology Laboratory; a state-certified laboratory engaged in monitoring and assessing ambient water quality and aquatic ecosystem health. He has published over 100 research articles in peer-reviewed journals. His research interests are aquatic health, including the effects and interactions of physicochemical and contaminant stressors (toxicant, carcinogen, and endocrine disruptor) on aquatic organisms and ecosystems. He has been married to his wife Foo-Ching for 39 years. They have two grown children who live in California.