Researchers identify behavioral adaptations that may help Antarctic fishes to adapt to warming Southern Ocean

In a new study published in PLOS ONE, Michael Friedlander and his team at the Fralin Biomedical Research Institute describe how Antarctic fishes with and without hemoglobin react to acute thermal stress. The findings characterize species-specific behavioral responses that may help these endemic species withstand the impacts of climate change

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At first glance, Antarctica seems inhospitable. Known for howling gales and extremely cold temperatures, the continent is blanketed with a mile-thick ice shelf. Occasional elephant seals and seabirds fleck the glacial shorelines.

Yet dipping below the waves, the Southern Ocean teems with biodiversity: vibrant swaths of sea ice algae and cyanobacteria, swarming krill and crustaceans, bristling kelp forests, gigantic polar sea spiders and sponges, whale pods, and abundant Antarctic fish fauna.

These fishes play a vital role in the Southern Ocean's food web of 9,000 known marine species, yet their subzero haven may be at risk. A 2021 climate analysis posited that by 2050 some areas of the Antarctic continental shelf will be at least 1 degree Celsius warmer.

Researchers from Virginia Tech's Fralin Biomedical Research Institute at VTC have published a new study in PLOS ONE describing how two species of Antarctic fish –

one with hemoglobin in its blood cells and one without – respond to acute thermal stress.

The research team, directed by Virginia Tech Vice President for Health Sciences and Technology Michael Friedlander, observed that both species responded to progressive warming with an elaborate array of behavioral maneuvers, including fanning and splaying their fins, breathing at the surface, startle-like behavior, and transient bouts of alternating movement and rest.

“Remarkably, our team found that Antarctic fishes compensate for increasing metabolic demands by enhancing respiration through species-specific locomotor and respiratory responses, demonstrating resilience to environmental change and possibly to global warming," said Friedlander, who is also the Fralin Biomedical Research Institute’s executive director, senior dean for research at the Virginia Tech Carilion School of Medicine (VTCSOM), and a professor in the College of Science's Department of Biological Sciences.

"Ambient warming presents a multi-faceted challenge to the fish, including increased temperature of the central nervous system and target tissues such as skeletal and cardiac muscles, but also reduced availability of dissolved oxygen in the water that passes through the gills during respiration. While these findings suggest that Antarctic fishes may be able to behaviorally adapt somewhat under extreme conditions, little is known about the effects of environmental warming on their predation habits, food availability, and fecundity," Friedlander said.

Iskander Ismailov, the study’s first author and a research assistant professor in Friedlander’s laboratory during the study, said “Behavioral manifestations that we’ve described show that these fishes have powerful physiological capacities to survive environmental changes."

Through millions of years of isolation from the rest of the world – corralled by the Antarctic Circumpolar Current – Southern Ocean fish species have become well adapted to their frosty ecosystem.

Blackfin icefish, Chaenocephalus aceratus, one of the two species studied by the team, have unique opalescent blood. These fish are among the few known vertebrates lacking hemoglobin, a molecule in red blood cells that efficiently carries oxygen from the lungs of land-dwelling vertebrates, or from the gills of aquatic vertebrates, throughout tissues in the body. Instead, blackfin icefish transport oxygen dissolved in blood plasma, harboring roughly 10% of the oxygen carrying capacity of hemoglobin.

Oxygen is more soluble in cold water, allowing white-blooded icefish to thrive in the Southern Ocean. As water temperature rises, however, these species experience increased metabolic demand, potentially making white-blooded fish more vulnerable to global warming. To test this hypothesis, the team examined five specimens of white-blooded blackfin icefish and five red-blooded black rockcod, Notothenia coriiceps, in a climate-controlled shoreline laboratory that circulated, and progressively warmed, saltwater straight from the Southern Ocean.

The fishes acclimated to the lab conditions, before being transferred to the experimental tank, where water temperature rose from -1.8 degrees Celsius to 13 degrees, at a rate of 3 degrees per hour. The researchers captured extensive video recordings, allowing them to examine and quantify the fishes' motility, breathing rate, maneuvers in the tank, and fin movements.

As the water temperature rose, the white-blooded icefish displayed intensive pectoral fin fanning – a behavior previously observed in icefish during egg guarding – that the researchers suggest may help facilitate respiration. By contrast, the red-blooded fish employed complex maneuvers, including pectoral fin fanning and splaying, followed by startle-like C-turns, which may augment gill ventilation, according to Ismailov.

"The findings provide a new perspective on the effects of rising temperature on these highly cold-adapted species," said George Somero, professor emeritus of marine biology at Stanford University and a leader in studying how marine life adapts to thermal stress, who was not involved in the study.

Preparation for the expedition began in early 2014. The research team designed, custom-built, and shipped laboratory equipment to Palmer Station in Antarctica before living there for three months in 2015. The journey included a flight to Punta Arenas, Chile, then crossing the Drake Passage by boat during the austral fall.

Ismailov was the first to arrive, setting up experimental rigs. Six weeks later, he was joined by Jordan Scharping, then a second-year VTCSOM student conducting research in Friedlander's lab. The pair worked in overlapping 12-hour shifts running experiments in the laboratory at near-freezing temperatures.

"Dr. Friedlander drew me to this project. I remember him presenting the Antarctic project proposal to us medical students and everyone just lighting up about it. It was an incredible opportunity and I appreciate him giving it to me," said Scharping, who is now a physician at Northwestern Memorial Hospital.
Researchers were responsible for collecting their own fish specimens during a series of four, week-long fishing trips. At sea, with the help of the research vessel crew, the researchers worked around the clock – sometimes during harsh conditions.

"One stormy night while we were fishing, a two-story wave overtook the stern, drenching me from head to toe in ice-cold seawater – the captain of the boat stopped the fishing after that," Ismailov recalled. "As a graduate of medical school, I never could have imagined that my career would lead me to Antarctica to study fish, but this research project has become one of the most extraordinary and memorable in my life."

The field work was funded by a National Science Foundation Grant awarded to Elizabeth Crockett, professor emerita at Ohio University, and Kristin O'Brien, professor at the University of Alaska Fairbanks. Crockett and O'Brien – both former graduate students of Bruce Sidell, who was trained by C. Ladd Prosser – invited Friedlander to join the expedition along with collaborators from the University of British Columbia, the University of Leeds, and Valdosta State University.

But the underpinnings of this recent study started 45 years ago. Friedlander, then a graduate student under the mentorship of Prosser at the University of Illinois at Urbana-Champaign – a pioneer in the field of comparative animal physiology and thermal biology – conducted research to advance experimental approaches to evaluate how temperature change affects molecular, cellular, and behavioral processes in an entire organism. Their landmark study, published in the Journal of Comparative Physiology in 1977, examining the common goldfish, was lauded by Somero in a 2015 review in the Journal of Experimental Biology.

"I find it gratifying that the pathbreaking studies of temperature effects on goldfish behavior carried out by Dr. Friedlander several decades ago have evolved into this fascinating new work on fishes of the Southern Ocean," Somero said.

While the research team observed that stenothermal Antarctic fishes show a remarkable capacity to withstand acute thermal stress, Ismailov warns that these vulnerable species still need protection.

"There's a history of severe overexploitation in the Southern Ocean in the '70s and '80s due to unregulated commercial fishing. These activities had depleted the populations of some fish species so badly that the prospects of their recovery are still unclear," Ismailov said.

Friedlander expounds on this, noting that all species play important roles in a fragile ecosystem.

"If left unregulated, anthropogenic activities could produce irreversible damage, impacting not just icefish, but many other species in the Antarctic food webs as well. By doing these types of proof of principle experiments now to begin to understand the physiological repertoire available to species at risk, we can begin to make more informed predictions about what sort of perturbations within complex ecosystems that climate change may trigger, and what type of reserve and adaptive capacity individual species may deploy," Friedlander said.

"Behavior is the ultimate manifestation of alterations in the function of molecules, cells, and entire systems in a living organism and thus can serve as a powerful readout of the underlying effects of thermal challenge."

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