



## Understanding Effects of Global Climate Change on Arctic Fishes

*Have some species of fish living for thousands of generations in an environment free of thermal variability lost the ability to adapt to climate change? A team of student and faculty scientists from Salisbury University and Hólar University College in northern Iceland investigate the impact of global warming on the diversity of fish species in Arctic regions.*

The current rise in oceanic temperature may dramatically affect the quality and diversity of life in many aquatic ecosystems, particularly in the Polar Regions, which tend to be more vulnerable to climate change than other regions. Recent data suggest that Arctic ecosystems have been severely disturbed by the rapid climate change that scientists have been tracking for several decades. Fish are among the species most dramatically affected by these changes.

Changing surface temperature is a natural characteristic of our planet. Over geologic time, the Earth has experienced periods of thermal fluctuation when life has flourished and when life has almost been completely eliminated. Currently, there is compelling evidence suggesting that global surface temperatures are increasing at a geologically rapid rate. What makes the current situation unique (and troubling) is that, unlike in the past, the temperature increase is occurring in the absence of any obvious natural input such as volcanic activity or meteoric collision.

In 2009, a report focusing on the biological consequences of recent climate change in the Arctic concluded that Arctic ecosystems have been severely perturbed by rising temperatures. As the temperature rises, the abundance and diversity of fish species and the distribution of fish populations are likely to change. The ability of animals to respond to rising environmental temperature is a major determinant of the disposition or survivability of a species during periods of geologically rapid climate change. While increasing temperature may be harmful to tropical animals because they live at temperatures close to their upper limits, temperate and polar species are equally at risk if they have lost the ability to acclimatize to new temperatures. For example, fishes inhabiting waters that do not normally undergo fluctuations in temperature may be sensitive to climate change if they have lost the ability to appropriately adjust their metabolisms and cellular structures.

Arctic fishes may be particularly sensitive in this regard because they have been living in a cold environment for thousands of generations. When challenged with a changing environment, the fish can either



Gullfoss ("Golden Falls") is one of the most powerful waterfalls in Europe.

As the temperature increases, some fish species will successfully adapt, others will not. Some may disappear altogether. This raises economic as well as environmental concerns as the reduction of fish diversity may negatively affect economies based on food production by Arctic and sub-Arctic fisheries. One key to the solution is to better understand why some fish species successfully adapt to climate change and why others do not.

swim to a new location with different conditions or remain in place. If they remain where the conditions are changing, they can either tolerate the change or acclimatize to it. The fluctuation in climate is tolerable if the metabolic and physiological machinery of the cells of the organism can continue to operate in a manner consistent with the continued survival of the cells (and organism).

Acclimatization, or the physiological adaptation of an animal or plant to changes in climate or environment, implies that metabolic and physiological adjustments must be made because the fluctuation lies outside the range of immediately tolerable conditions. Adaptation to the new condition implies a permanent and irreversible change in the organism's genome that permits continued survival and permanent and irreversible change within the boundaries of survivability. A universal response of animals to changing temperature is the restructuring of the molecules that make up their cell membranes. The purpose of this restructuring is to maintain an appropriate physical environment, or molecular order, within the cell membrane during temperature change. There are many such restructuring reactions and it is believed that they do not occur in chronological sequence, but instead proceed at different rates, begin at different times and have different durations after exposure to the new temperature. Some of these molecular remodeling events seem to have evolved as "emergency" responses that are later augmented or supplanted by other changes that persist until the next thermal challenge is encountered.

SU bioscience professor Dr. Eugene Williams and his team of scientists comprised of students and faculty from Salisbury University and Hólar University College (HUC) have taken an innovative approach to studying the long- and short-term effects of climate change on fish. Over the next three summers, the team will travel to Iceland to examine populations that have not experienced significant change in environmental temperature for many generations and conduct laboratory and field research to determine if such fish can tolerate temperature fluctuations. The team will also examine the extent to which some species have adapted to the temperature of their environment, along with the presence

Students (from left) Dan Wilkerson, Erin Williams, Kelly Beall, Ana Wiseman and Katie Green perform a bird count at Kolkuós (Northern Iceland, near Hólar). The horses, who have no reason to fear humans, came to investigate the researchers.



or absence of molecular, cellular and physiological mechanisms that facilitate acclimatization.

Few populations of fish have experienced constant temperature for extended periods, especially over many generations. Fishes living in the very deep sea, where it is constantly cold, are one example; others are fishes living in very stable warm or cold springs. Fish in these habitats are either difficult to capture or are exceedingly rare. However, there are two aquatic environments where water temperatures have remained nearly constant for thousands of years: those at the Earth's poles. Polar regions have been cold for a very long time and the range of temperature change has been very small. Fish have thrived in the icy polar waters for thousands of years.

"The analyses we wish to perform would be most robust if they were carried out using populations of a single species that has endured for many generations under different thermal regimes; a species that may have diversified, but that has not yet evolved into new species," explained Williams. The Icelandic Arctic charr is such a species, and it is very well-suited for the studies the team has undertaken. The charr appears to be rapidly diversifying, but it has not yet split into separate species and retains a high degree of phenotypic plasticity, the biochemical or physiological properties or characteristics that enable it to adapt to environmental change. The body shape, feeding habits and habitat temperatures make the Icelandic Arctic charr an ideal specimen for this study, as these characteristics provide evidence of the species' ability to adapt to climate change.

As the glaciers melted away from Iceland around 12,000 years ago, populations of

Icelandic Arctic charr were the only vertebrate inhabitants of myriad newly formed lakes, streams and rivers. These waters varied widely in resource type, stability and habitat diversity, which presented the charr with many novel opportunities for colonization. Under such conditions, these populations of fish have dramatically diversified in order to take advantage of various habitats and resources.

The Icelandic Arctic charr has also been found to thrive under a wide range of habitat temperatures with different populations occupying lakes with extreme temperature variances. Populations are found in spring-fed lakes that are constantly cold, as well as shallow lakes and ponds where water temperatures can vary from 2-3 °C to 20 °C or more in the summer. Scientists believe that these conditions may have existed for the past 10,000 years or so, which is sufficiently long enough for the fish to adapt to such dramatic climate changes, but apparently not long enough for them to have formed new species.

It is well known that salmonids (salmon, trout and charr) from diverse environments are exceptionally adept at adapting to new

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Students collect information at Héraðsvötn, meaning “waters of Héraðs,” a river in Northern Iceland.



temperatures. This attribute can be observed in individual fish and also in cells isolated from fish and maintained in culture. For example, cells isolated from rainbow trout have been shown to begin reorganizing and restructuring their cell membranes within six hours of transfer to a novel temperature. These characteristics of Icelandic Arctic charr make them ideal for studying the effects of climate change on the Arctic fishes. Individuals of the same species that have experienced very different thermal habitats for thousands of generations can be directly compared.

Williams and his team explore the molecular, cellular and physiological mechanisms that affect the fishes' ability or inability to acclimatize. “We believe charr from stable thermal environments will be unable to tolerate novel temperatures or restructure their cell membranes in response to a thermal insult,” said Williams. In the course of exploring this hypothesis, the team examines the mechanisms that permit cells, and therefore fish, to endure altered temperatures.

These experiments are the core of an international, student-training program between Williams and collaborators at HUC in northern Iceland. Under the supervision of Williams and his colleagues, students from both universities carry out the experiments as part of a student-training program focused on international science, collaboration and cooperation. The SU team works in partnership with colleagues at HUC. Drs. Skúli Skúlason and Bjarni Kristjánsson are fish ecologists and evolutionary biologists interested in speciation. They provide expertise in the areas of fish population structure and dynamics.

During the academic year, students focus on analyzing frozen fish tissues and

cells in culture. During the summers, the research involves experiments with live Arctic charr and the collection and preservation of tissue samples for later analysis. For each of three summers, research teams are made up of one or two graduate students from HUC and three to five undergraduate students from SU who spend six weeks at HUC.

### Faculty/Student Research Collaboration

All of the experiments are carried out by a team of students from SU and universities in Iceland and other countries under the supervision of faculty from SU and HUC. Each student is engaged in meaningful scientific research throughout the program. During the academic year, students work in the laboratory at SU. During six weeks in each of the three summers, SU students work closely with a team of international students and faculty from HUC. A major objective of this project is to expose these young scientists early in their careers to a diverse community of globally engaged scientists so that they learn how to participate and operate in an international research environment.

Taken together, the field experiments in Iceland and the lab experiments conducted at SU produce a “big picture” that is made of relatively straightforward and manageable projects that enable students to participate in important and relevant research and understand it as they contribute to it. The variety of experiments allows each student to have his or her own independent project, which contributes positively to the culture of research fostered by the University. These experiments provide students with opportunities to conduct rigorous experimental

measurements, interpret and analyze the results, decide what steps to take next, and ultimately disseminate their work to the broader scientific community by making presentations at local, regional and national meetings.

Williams and his colleagues have developed a set of experiments designed to challenge and engage the students. Many of these projects center on a fascinating phenomenon seen in Mývatn, a lake two hours from Hólar. Two natural springs feed the lake on its east side. One of these is a cold spring at a constant 6.6 °C and the other, only 5 kilometers away, delivers a constant supply of water at 27 °C. Lake water leaves via the River Laxá on the west side. This arrangement sets up a large temperature gradient in the shallow lake water between the springs and to the river. The fish that live there can behaviorally select their preferred temperature and are easily accessed with hand nets. This natural situation is a veritable gold mine for potential research projects dealing with behavior, ecology, physiology, cell biology and more.

The unique student/faculty collaboration gives students access to mentors with wide-ranging expertise, from molecules to ecosystems and including invertebrate and fish thermoregulatory behavior. Researchers are very confident that they can help all students who choose to work on the projects of their own design fashion interesting, meaningful and scientifically valuable endeavors.

### Paving the Way for Study Aboard Science Programs

As part of its 2009-2013 Strategic Plan, SU identified international education and study abroad for students as a top priority. In particular, the University recognizes the need for study abroad experiences for science, technology, engineering and mathematics (STEM) students. According to several studies conducted by the Institute of International Education, since 1996, United States students in the sciences have been seriously underrepresented among those participating in study abroad programs. Students of the social sciences and fine arts and from business programs made up more than 60 percent of all students who studied abroad. Students from the physical and life

sciences never comprised more than 9 percent of the total in any of those years. This program helps improve that situation. In addition, instead of going to major population centers like London or Paris, students involved in this project travel the unique and less-well-tread grounds of north Iceland. Williams is confident that this program will encourage a good portion of students to pursue careers as scientists and give them self-confidence and other tools that are critical in successful science careers.

### Enhancement of Student Professional Network

The daily interactions over a six-week period between undergraduates, graduate students and faculty from the U.S., Iceland and other nations build long-lasting personal and professional relationships that help serve both the students and faculty as well as encourage the students to mature into capable researchers. Initially, the camaraderie of this network of science colleagues encourages students to stay in science as a career. Later, these relationships and interactions make the transition from undergraduate to graduate to practicing scientist easier by giving them trusted colleagues from whom to seek advice and counseling during those transitions. The network relationships developed in this program are integrated into other student/professional networks in place at SU. For example, SU has a student chapter of the Washington Academy of Sciences (currently the only student chapter in existence) and participates in the Undergraduate Affiliate Network of the American Society for Biochemistry and Molecular Biology.

### Faculty Mentoring and Student Research

As part of the student training program, a major mentoring activity will be guiding students through an international collaboration involving scientists from very different scientific disciplines and from different cultures. Survey data indicate that students believe the most important part of their research experience is the relationships they form with their mentors. Throughout this project, students are

engaged in every aspect of the scientific endeavor. "I provide as much help and guidance as each individual requires for each endeavor, and I remind them that what they are currently learning in the classroom and laboratory is not the 'final product,' but only the first pieces of a larger picture," commented Williams. "I teach them that the skills and techniques they are learning are tools that they can put in their personal toolbox – tools that can be deployed in the future to contend with whatever scientific problem they are addressing."

Williams has a strong track record for building solid professional mentoring relationships with his students. In the past 11 years, 28 undergraduate students under Williams' supervision have presented the results of their research at 19 major meetings. Thirteen of those students presented their work at the meetings of professional societies, including the American Physiological Society, the American Society for Biochemistry and Molecular Biology, the American Association for Gravitational and Space Biology, and the Society for Integrative and Comparative Biology. Many more have presented at local and regional meetings. Since 2004, 42 of Williams' students were granted a total of \$11,187 in Henson School of Science and Technology Undergraduate Research Awards. Five students participated in the Guerrieri Summer Research Program and were collectively awarded \$14,816, four students used the \$2,000 they were awarded through University Student Academic Research Awards to travel to meetings, and several were successful at procuring funds from sources off campus, including two \$6,000 Colgate-Palmolive Fellowships and a \$500 Sigma Xi Grant-in-Aid of Research.

In 2005, Williams was awarded the Outstanding Research Mentor Award at SU, and in 2006, he was the recipient of a University System of Maryland Board of Regents Excellence in Mentoring Award.

### Cultural Transition From the U.S. to Iceland

To help the student researchers prepare for their trip to Iceland, SU hosts a series of seminars and open discussions describing

what the students can expect to encounter in Iceland. Participating faculty show photos of previous visits and discuss the food, dormitory and hotel accommodations, travel arrangements, currency, laundry, electrical issues (plug adaptors and transformers), and many of the details of Icelandic culture that may not be immediately obvious when they arrive (e.g., no tipping at restaurants and shoes are to be removed when entering homes). Most everyone in Iceland speaks English, so there is usually not a serious language barrier. In addition, Icelanders are very welcoming. They seem to genuinely like visitors and they put a lot of effort into seeing that their guests are well cared for and happy.

Williams and his colleagues strongly believe that the cultural experience of visiting Iceland is also a very important aspect of student training. Students have daily 30-minute lessons in Icelandic language and are immersed as much as possible in Icelandic culture. Group trips to see the work of local artists displayed in Skagafjörður Library and Archives, in the Safnahús in Sauðárkrúkur, and to the Glaumbær Folk Museum (with an 18th century turf-house farm) are included. Trips to Mývatn, Thingvallavatn, Thingvellir, Hvalfjörður, and the cities of Blönduós and Hofsós are also organized. During the weekends, the team has the opportunity to visit Reykjavik to explore the world's most northern capital city. Students also frequently enjoy horseback riding, river rafting and many hiking trails close to campus of HUC.



Dr. Eugene Williams and some of his student scientists