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. 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 better understand why some fish species successfully adapt to climate change and why others do not. 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
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
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

A universal response of animals to
changing temperature is the
restructuring of the molecules that
make up their cell membranes.
Students collect information at Héraðsvötn, meaning “waters of Héóbr”, a river in Northern Iceland.

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 Abroad 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 Undergraduate Research Awards. Five students participated in the Guerrieri Undergraduate 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 Sauðárkrókur, 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 Hofn are also organized. During the weekends, the team has the opportunity to visit Reykjavík 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.

**IN THE FIELD**

**Dr. Eugene Williams and some of his student scientists**