Mussels against the ropes

Professor Emily Carrington studies the ecomechanics of mussels to assess the effects of ocean acidification and climate change on these organisms. Her work is helping to further understanding of mussels and their dependent species, and also has implications for coastal economies

Could you provide a brief overview of your current research activities?

We are continuing our work on the effects of environmental stressors on byssus (filament) strength and are now considering the effects of food supply and physiological state on the mussel. We have found that the effects of pH and temperature are not always additive, as these two factors target different parts of the byssal fibres. The results vary according to seasons, which probably reflects shifts in the allocation of energy between growth and reproduction. We are also extending our laboratory findings out to the field by collaborating with local mussel farmers.

How did you develop your interest in marine ecomechanics?

Growing up near Detroit, Michigan, one of my favourite activities was the factory tour at the Ford Motor Company, watching how piles of raw materials turn into shiny new machines. Like many of my generation, I watched a lot of Jacques Cousteau documentaries and developed a curiosity for the oceans. But I never dreamed I could combine these two interests as a career. It was during a field trip to the wild outer coast of Vancouver Island that I began to make the linkage between mussel ecology and mechanics, or ecomechanics.

Your lab work suggests that mussel byssi are weakening as a result of climate change and ocean acidification; what are the environmental and economic implications?

Byssus weakening reduces the retention of mussels on culture ropes by up to 20 per cent, cutting into yields at harvest. Reduced retention can also be problematic in coastal ecosystems, where mussels form the foundation of many temperate marine communities. They form dense aggregations – mussel beds – that provide habitat for well over 100 other species and food for many others.

What can be done to counteract the environmental and economic impact of mussel byssal weakening?

On mussel farms, early warning systems for the onset of unfavourable conditions would be valuable; farmers could temporarily shift to more labour-intensive practices to maintain high yields, such as using nets to catch fallen mussels. They could also potentially move their farms to more benign locations, but this is often difficult with coastal permitting regulations. For natural populations, protecting habitats where mussels can survive will be critical, as well as reducing other stressors such as fresh water runoff. Reducing emissions of CO_2 into the atmosphere would slow the incredible rate at which our oceans are changing.

Why is byssus strength also of interest to materials scientists?

Most man-made adhesives require the two surfaces to be dry; add water before the adhesive sets and it fails. Mussels, however, adhere strongly to wet surfaces with materials that are not toxic or immunogenic. For these reasons, research on mussel byssus has inspired a number of efforts to design new medical adhesives. Mussels are also remarkable for their ability to attach to just about anything, including Teflon, which makes them a nuisance when they clog water supply lines or foul ship hulls. So there is considerable interest in the design of surfaces that are resistant to fouling.

Do you collaborate with other projects/ laboratories in the course of your investigations?

I share research techniques with other mussel biologists and also collaborate with scientists from other disciplines – materials science, biochemistry, ecology, oceanography and aquaculture. My lab recently started to work with local mussel farms – Penn Cove Shellfish and Taylor Shellfish in Washington – after they reported episodic 'fall-off' from their culture ropes. Understanding what triggers this weakening of mussel attachment should lead to solutions that increase profits for mussel farms. The coralline algal project depends heavily on collaboration with Patrick Martone at the University of British Columbia, an expert in algal biomechanics.

Are there any particular upcoming events or conferences that are relevant to your research interests?

One upcoming conference that will feature a broad range of cutting-edge research on ocean acidification is the American Society of Limnology and Oceanography (ASLO) Ocean Sciences Meeting in Honolulu, Hawaii, in February 2014.

What are your plans for future projects and areas of investigation?

The Holy Grail is to understand the linkages among environmental conditions, byssus assembly and mechanical performance. Our next step will be to explore in more detail how environment influences byssus assembly using genomic and proteomic techniques. This work will be conducted in collaboration with Professor Herbert Waite from the University of California Santa Barbara, a biochemist who has been fascinated by mussel byssi for even longer than I have.

Mollusc mechanics

Using engineering principles to seek answers to ecological questions, researchers at the **University of Washington** are hoping to discover the extent to which rising CO_2 levels are causing ocean acidification and affecting coastal marine ecosystems, particularly the impact on organisms such as mussels

CARBON DIOXIDE IS a naturally occurring gas in the trace elements of the Earth's atmosphere. However, since the advent of the industrial revolution, various forms of human activity such as cars, aviation and power generation have started to contribute significantly to CO_2 concentrations. Anthropogenic CO_2 enters the atmosphere and is then absorbed by the surface of the ocean, which lowers the pH value of seawater and leads to increased acidification. Research has shown that levels of CO_2 are higher than at any time in the past 650,000 years, while acidification of the Earth's oceans is occurring at its fastest rate in 50 million years.

This acidification represents a serious threat to coastal marine ecosystems. In addition, many human communities depend on these resources for their livelihoods. For example, the cultivation of mussels for human consumption is an important area of employment in many coastal regions throughout the world and the mussel aquaculture industry is estimated to be worth over US $1.5 billion annually.

HANGING BY A THREAD

At the University of Washington's Friday Harbor Laboratories (FHL), Professor Emily Carrington is Principal Investigator of the Effects of Ocean Acidification on Coastal Organisms: an Ecomaterials Perspective project. FHL is a world-renowned facility for the study of ocean acidification, biomaterials and fluid dynamics. Located on San Juan Island, about 70 miles north of Seattle, FHL has excellent access to a broad diversity of marine organisms.

The project's primary goal is to study the ways in which ocean acidification is affecting organisms living in rocky coastal areas and how this changes the functioning of the surrounding ecosystem. By applying engineering principles to ecology, Carrington and her team are able to track how the various tissues that make up the organism perform when faced with adverse changes in habitat.

Mussels are well known for their ability to cling tenaciously to the rocks of coastal areas. They achieve this feat by secreting byssal threads from a gland located in the organism's foot. Commonly known as the mussel's beard, these proteinaceous strands are composite materials that vary in strength according to season and surroundings.

For a long time, researchers had assumed that the strength of byssal fibres was directly related to the strength of waves. However, experiments in the lab proved this hypothesis to be incorrect: "We designed laboratory assays to show explicitly how water motion stimulated thread production, and were surprised by how uncompelling our results were," admits Carrington.

TENSOMETER TRIALS

Instead, Carrington turned her attention to other factors that might affect the strength of byssal fibres: "Our latest laboratory studies have shown two environmental factors – temperature and pH – weaken mussel byssus by 40-60 per cent. Moreover, these factors act on different parts of the thread," explains Carrington.

The increased CO_2 content and rising temperature of seawater changes the structural properties of byssal threads. For mussels, the strength of tethers and adhesives of their byssal threads to attach themselves to rocks is critical, as dislodgement is often fatal. On the other hand, the 'fall off' of mussels from rope cultures can lead to a significant loss in revenues for commercial growers.

To shed light on these issues, Carrington and her colleagues use a recording force gauge to prise mussels away from rocks. They also measure water conditions in the area, including temperature, pH and salinity. The researchers collect individual byssal fibres to take back to the laboratory to measure with a sophisticated tensometer, which is able to measure strength, extensibility and toughness.

MATERIAL INTEGRITY

Building on her previous work on byssus strength in bivalve molluscs, Carrington's latest project aims to determine how the increasing acidification of the ocean impacts the integrity of biomaterials and how these effects scale up to influence species interactions and community structure. The project targets three model systems: bivalve mussels; the prey of predatory whelks; and calcified coralline algae. Each of these organisms produces at least one biomaterial that serves a critical ecological function.

Carrington and her team study the shell, periostractum (the shell covering) and byssus

Acidification of the Earth's oceans is threatening to have a catastrophic impact on marine ecosystems in the decades ahead

of mussels *Mytilus californianus* and *M. trossulus*. In particular, the researchers note the variations in the ways mussels produce and maintain these structures according to the season and changes in water temperature and food supply.

The favoured prey of predatory whelks are mussels and barnacles, so the biomaterial of interest is their protective shell. The group tests the defensive capabilities of the shells under various conditions to gauge the extent to which shell toughness is correlated with ocean acidification.

PREY HANDLING TIME

The researchers also measure prey handling time: this involves starving whelks for a week to ensure a good predatory response, and then presenting them with barnacle prey in seawater of different CO_2 concentrations. By studying these encounters the researchers can assess the time it takes a snail to devour individual items of prey. A whelk will rasp steadily for hours, boring a hole through the shell or ligament to access the soft body parts inside.

In the project's final model system, the researchers study the affects of increasing ocean acidification on coralline algae. Lower pH could potentially affect the ability of this red alga to calcify, potentially rendering it more vulnerable to grazing snails and sea urchins. The team is also measuring the effect of ocean acidification on the ability of coralline spores to attach to rocks or other hard substrata.

OAEL

To carry out the study, Carrington capitalised on the capabilities of the new Ocean Acidification Environmental Laboratory (OAEL) at FHL. The multi-user experimental facility comprises an analytical chemistry laboratory, indoor mesocosms fed by a custom seawater-CO_2 blending system and temperature control, laboratory space, as well as outdoor in-water mesocosms. Led by Carrington, OAEL Director, this state-of-the-art ocean acidification facility offers unique research and instructional opportunities for experimental manipulations with onsite monitoring of carbonate system parameters.

Carrington's team uses the indoor mesocosms to house the organisms under independently controlled pH and temperature conditions. They also process water samples, from field sites and laboratory experiments, by measuring pH, pCO_2, alkalinity and total CO_2 in the analytical chemistry laboratory.

CHANGING HABITATS

While the disintegration of calcium carbonate in coral reefs through acidification has 'grabbed' the headlines recently, Carrington's application of ecomechanics in her study of the mussel and other organisms has demonstrated that acidification of the Earth's oceans is threatening to have a catastrophic impact on other marine ecosystems in the decades ahead. "Mussels are a key food source for many mobile predators, such as crabs, lobsters, sea stars, fish and birds, so mussel byssal weakening could potentially have huge cascading effects on the environment," states Carrington.

More positively, Carrington's work is improving understanding of the effects of global climate change on coastal marine ecosystems, which should pave the way for better management options for mussel farmers. "Mussels are both ecologically and economically valuable, so these are important questions today and in the future as our coastal habitats change," asserts Carrington.

INTELLIGENCE

EFFECTS OF OCEAN ACIDIFICATION ON COASTAL ORGANISMS: AN ECOMATERIALS PERSPECTIVE

OBJECTIVES

To determine how ocean acidification affects the integrity of biomaterials and how these effects scale up to influence species interactions and community structure.

KEY COLLABORATORS

Dr Michael O'Donnell, Senior Scientist, California Ocean Science Trust, USA

Laura Newcomb, doctoral student; **Matthew George**, doctoral student, **Emily Roberts**, research technician, University of Washington, USA

Dr Patrick Martone, Associate Professor; **Rebecca Guenther**, doctoral student, University of British Columbia, Canada

PARTNERS

Penn Cove Shellfish LLC,

Taylor Shellfish Farms

The Washington Ocean Acidification Center

FUNDING

National Science Foundation – award no. EF-1041213

CONTACT

Professor Emily Carrington
Professor of Biology

Friday Harbor Laboratories
University of Washington
620 University Road
Friday Harbor, Washington 98250
USA

T +1 206 221 4676
E ecarring@uw.edu

faculty.washington.edu/ecarring

EMILY CARRINGTON is Professor of Biology at the University of Washington. Her research is based at the Friday Harbor Laboratories in the San Juan Islands, where she leads a marine biomechanics research group and directs the Ocean Acidification Environmental Laboratory. For over two decades, she has focused on the mechanical design of marine invertebrates and macroalgae, especially those that thrive in one of the most physically challenging habitats on Earth, the wave-swept rocky intertidal zone. Her work on the ecomechanics of mussels links materials science, fluid mechanics, organismal biology and environmental science to develop mechanistic understanding of how coastal organisms will fare in changing ocean climates.

UNIVERSITY of WASHINGTON