Termite of the sea's wood destruction strategy revealed

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Shipworms are worm-like, wood-eating marine clams that have damaged sea-going vessels and piers for millenia. In collaboration with a team led by Daniel Distel of the Ocean Genome Legacy Center of New England Biolabs at Northeastern University, US Department of Energy Joint Genome Institute (DOE JGI) researchers sequenced and analyzed the shipworm Bankia setacea to learn more about how it breaks down and digests wood. This information could prove useful for the industrial production of advanced biofuels from woody plant mass. Credit: Dan Distel, Ocean Genome Legacy Center of New England Biolabs

Shipworms, known as 'termites of the sea,' have vexed mariners and seagoing vessels for centuries. A recent study involving scientists from the Ocean Genome Legacy Center of New England Biolabs at Northeastern University, the US Department of Energy Joint Genome Institute, and other institutions has focused on the shipworm Bankia setacea to learn more about the enzymes it utilizes to break down wood for nutrition, information that may prove useful for the generation of biofuels.

The sight of termites anywhere near one's house is enough to raise a homeowner's concerns about the potential damage these insects might inflict. Shipbuilders and engineers have similar feelings about shipworms, worm-like wood-eating marine clams that have also been called the "termites of the sea." These bivalves left feeding channels in Greek and Roman ships from more than 2,000 years ago, ruined Christopher Columbus' 4th trip to the Caribbean in the early 1500s, instigated flooding of the Netherlands in the 18th and 19th centuries, and caused an estimated $15 million in damages to the wharves of San Francisco, California around 1920. It took the introduction of copper sheathing in the 18th century to slow the destruction they caused on naval vessels. However, from such destruction, something good may come: what vexed pre-18th century sailors may prove useful for the generation of biofuels.

For bioenergy researchers, including scientists from the U.S. Department of Energy Joint Genome Institute, a DOE Office of Science User Facility, the shipworm's destructive capabilities could prove useful for the industrial production of advanced biofuels from woody plant mass. Under the DOE JGI's Community Science Program, a team led by collaborator Daniel Distel, Director of the Ocean Genome Legacy Center of New England Biolabs at Northeastern University, has focused on the shipworm *Bankia setacea* to learn more about the enzymes it utilizes to break down wood for nutrition.

A digestive strategy unlike any other

In a study published in the online Early Edition of the *Proceedings of the National Academy of Sciences* the week of November 10, 2014, Distel and his DOE JGI colleagues described the novel strategy by which this mollusk breaks down and digests wood. "Most animals, including people, have beneficial bacteria in their digestive system to help them digest food and would quickly become sick and malnourished without them," Distel said. "But shipworms have no bacteria in the part of the gut where their food is digested. Instead, they house symbiotic bacteria inside specialized cells in their gills, a location far removed from the gut."

Think of shipworms as albino earthworms with an abrasive shell that allows them to burrow into wood. The wood particles that enter their mouths make their way into their stomachs, and it turns out the digestive enzymes need to make a similar trip. Through genome sequencing, proteomics, biochemistry, and microscopy, the team demonstrated that the wood-degrading enzymes produced in the gill bacterial community make the trip from the region known as the Gland of Deshayes to the gut in order to break down the mollusk's meal and convert the cellulose into sugars.

"No other animal in the world is known to rely on bacteria outside of its digestive system to produce its digestive enzymes and no other intracellular bacterium is known to produce enzymes that function in the outside world of the host," Distel said.

For the study, the team used shipworms from Puget Sound in northwestern Washington. Researchers isolated multiple bacterial endosymbionts from the gill tissues and sequenced their genomes, and also sequenced the collective "metagenome" of the gill microbial community. They also used proteomics to characterize the proteins found in the gill and cecum tissues and compare them with the bacterial genomes and metagenomes - demonstrating that the abundant digestive enzymes in the gut derive from gill endosymbionts.

A benefit of having digestive enzymes produced outside the gut

The team is still pondering the reasoning behind having the wood-degrading enzymes produced away from where digestion actually takes place, but they suggested that this strategy allows the shipworm to serve as a simple model system to work out the minimal enzyme requirements for efficiently breaking down cellulose. "Because only selected wood-degrading enzymes are transported, the shipworm system naturally identifies those endosymbiont enzymes most relevant to lignocellulose deconstruction without interference from other microbial proteins," they wrote in the paper. "Thus, this work expands the known biological repertoire of bacterial endosymbionts to include digestion of food and identifies new enzymes and enzyme combinations of potential value to biomass-based industries such as cellulosic biofuel production."

Thus organisms that used to be dreaded at sea may supply both insights and tangible tools for the generation of biofuels from woods on land.

To learn more, watch Dan Distel's presentation on "How to Eat a Wooden Ship: A Genomic View of Wood-Eating Bacterial Endosymbiosis in the Shipworm *Bankia setacea*" from the DOE JGI's Annual Genomics of Energy & Environment Meeting in 2011:

More information: Gill bacteria enable a novel digestive strategy in a wood-feeding mollusk, *PNAS*, www.pnas.org/cgi/doi/10.1073/pnas.1413110111

For more information about the CSP projects related to shipworms, go to http://jgi.doe.gov/why-sequence-the-shipworm-microbes/ and http://jgi.doe.gov/why-conduct-the-comparative-analysis-of-shipworm-microbiome/.

Provided by DOE/Joint Genome Institute