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UConn Marine Science Professor Hans Dam uses a microscope to examine a sample of copepods grown in his lab. Photo: Nancy Balcom

Experiment with tiny marine creatures reveals future cost of climate change

by Judy Benson

Acartia tonsa is smaller than a grain of rice and barely visible to the naked eye in the marine waters where it lives. Nonetheless it is an important little creature.

"You have to train your eye to be able to see it," said Hans Dam. "But it's superabundant almost everywhere in coastal zones around the world, especially in estuaries."

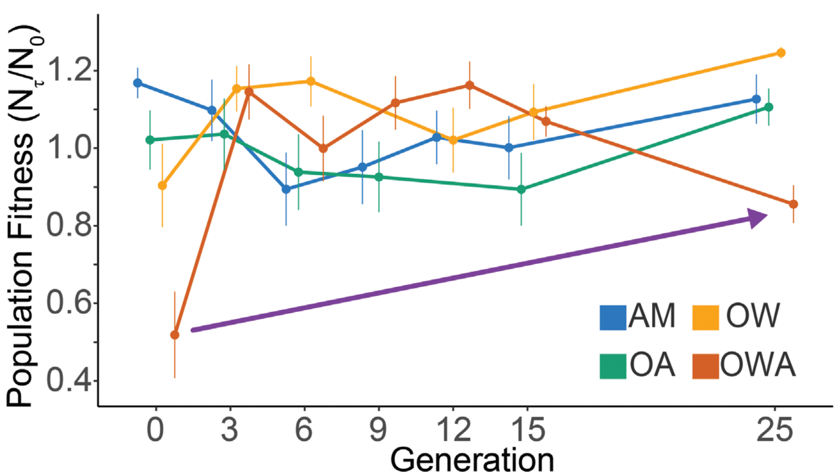
These torpedo-shape organisms are one of the many species of copepods, a group of zooplankton that can be thought of roughly as the sea's equivalent of insects— "the little things that run the world," in the oft-quoted words of biologist E.O. Wilson. Like other copepods, it has a uniquely florid physique, with long curving tentacles, bristly appendages on its sides and hairlike structures that cascade from its tail like the flowing fur of a Pekingese.

The copepod *Acartia tonsa* as seen under a microscope. Photo: Pelagic Invertebrate Collection at UC San Diego's Scripps Institution of Oceanography

"It's eaten by a lot of forage fish," Dam said. "If this species went extinct, you'd have a serious problem for fish and for the food base the little fish support. They're one of the things that makes the ocean ecosystem function."

Dam is a biological oceanographer and professor of marine sciences at UConn. Six years ago, he and several colleagues embarked on a research project with these copepods that took them physically no farther than the lab at UConn Avery Point where they are based and the waters of Long Island Sound at the southern edge of the campus, where they collected the base population. The research showed that over 25 generations, with exposure to simultaneous stressors of warming water temperatures and higher levels of acidification as greenhouse gas emissions elevate earth's CO_2 levels, these copepods can adapt—for a while. It documented evolution of a species in real time, providing a complex picture of how nature is changing with the climate, but at a cost.

"It's like if you lose your job, and then the bank forecloses on your mortgage," said James deMayo, who was a leading member of the research team, while completing his doctorate in oceanography at UConn. "There are things you can do to sustain yourself in the short term, but you can't continue long term."



Population fitness of the copepod *Acartia tonsa* versus generation under ambient (current) average temperature and CO2 levels (AM); ocean warming conditions (OW); ocean acidification conditions (OA); and both ocean warming and acidification conditions (OWA). The purple line shows that while fitness decreased after the 12th generation, it was still considerably higher than at generation zero. Fitness is a measure of the ability of the population to increase. Above 1 the population grows, and below 1 it decreases with time. Shown are the mean and 95% confidence error around the mean. Adapted from Dam et al, 2021.

These findings have far-reaching implications as a lens into the future ocean under climate change. It generated attention around the world after the first article about it was published in the journal *Nature Climate Change* last year and versions translated into Italian, French and other languages.

"This was a once-in-a-career publication for most of the people involved," said Michael Finiguerra, UConn associate professor in residence of ecology and evolutionary biology and one of the

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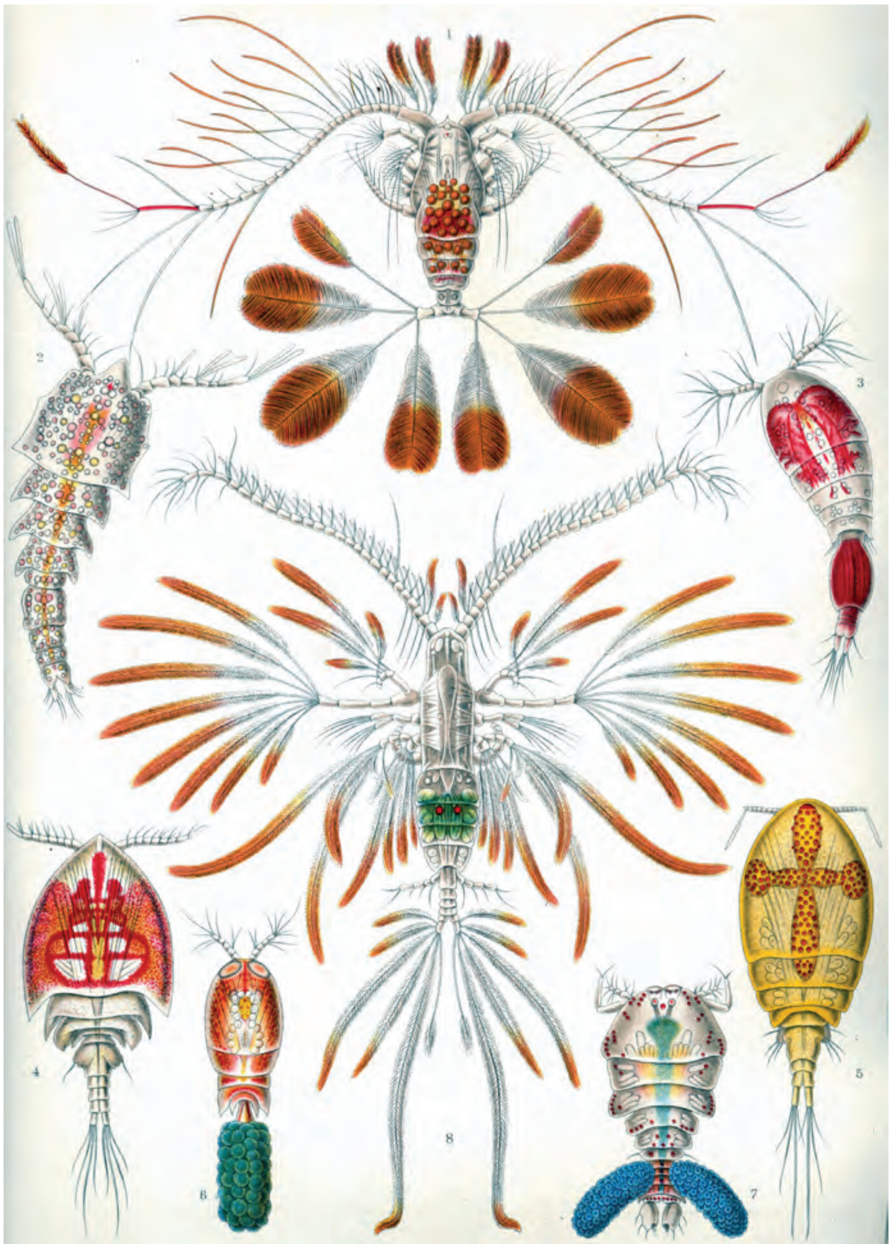
nine authors of the article. These included deMayo, Dam, their UConn colleague Hannes Baumann and Xuejia He of Jinan University in China. Two researchers from the University of Vermont, Melissa Pespeni and Reid Brennan, also collaborated on the project and joined the other four in exploring other aspects of the findings in a second article recently published in *Nature Communications*.

Baumann began working with Dam in 2016, using funding from Connecticut Sea Grant to design and pilot the project. Dam had worked with copepods in the past, but this undertaking required building new types of equipment and creating new experimental protocols to allow multiple generations of copepods to be grown in the lab, subjected to different temperatures and water chemistry, then compared. That's where Baumann's expertise working with fish populations came in.

"We developed the basic rearing enclosures to make this even feasible," said Baumann, associate professor of marine sciences at UConn.

These were four plexiglass chambers, each about the size of a stack of three large pizza boxes. In each were 60 petri dishes where copepod eggs grew into adults over their two- to three-week life spans. Each of the incubators mimicked a different set of climate conditions: one for current average water temperature of 18° C (about 64° F) and atmospheric CO_2 levels of 400 parts per million; one for water temperature of 22° C (about 72° F) and current CO_2 levels. A third had the current average temperature but CO_2 levels of 2,000 parts per million, and the fourth had both the higher temperature and the higher CO_2.



This illustration of several species of copepods was one of more than 100 of terrestrial and marine animals created by German scientist and artist Ernst Haeckel in the late 1800s. Source: Wikimedia Commons

"We blew streams of air with higher CO_2 content into the boxes, and it would dissolve passively into the petri dishes," Baumann explained.

Once validated, the project received National Science Foundation funding that supported it over the next five years. It was a "massive undertaking, a huge team effort," Finiguerra said, requiring multiple generations of copepods being kept alive in the lab, then collecting data for each generation on five species fitness traits—survival to maturity; egg production; egg hatching survival; development; and male-female ratio. That was deMayo's main responsibility, with the help of several others including UConn Marine Sciences Research Assistant Lydia Norton and Postdoctoral Research Associate Gihong Park, who were also co-authors of the *Nature Climate Change* article. Now a post-doctoral fellow at the University of Colorado, deMayo said the copepods required attention daily over the five years he worked on the project.

The often-painstaking work yielded important information for understanding how creatures are adapting to the changing environment. In sum, the research showed copepods subjected to just one variable—either higher temperature or higher CO_2—were able to adapt and maintain population health within the first few generations. But when both variables were introduced in tandem, the population declined sharply in the first generation, with half of hatched eggs not surviving to maturity compared to more than 75 percent survival in current conditions.

By the third generation, survival rates recovered close to original rates. But the phenomenon was short-lived. By the 25th generation, the research showed, only about one-third of the animals survived to maturity. In the wild, predation, pollution and other stressors would be added to the mix, setting up a world with too few copepods to support healthy populations of fish and other marine life.

"There are limitations to their ability to maintain their adaptation response," deMayo said. "This puts into perspective that when you pile stressors on top of each other, you get unexpected results."

Baumann said the study was unique not only in the number of generations of copepods involved, but also in tracking their response to two stressors in tandem. As scientists, government leaders and the public try to understand and respond to climate change, he said, this study provides a better guide for the future because it avoids simplistic all-or-nothing conclusions.

"It's not all gloom and doom, but we don't want to come off saying 'don't worry about it,'" he said. "It's more complicated. We have copepods adapting rapidly to these new conditions, but the adaptation is not complete."

Over the course of the project, volumes of data were collected on the copepods that will continue to be analyzed and are likely to yield more significant findings, Baumann said, some of it involving molecular DNA analysis to determine how copepod genes adapted. That work is being led by Pespeni and Brennan of the University of Vermont.

"This is evidence of the unpredictability in the responses of marine populations to changing ocean conditions," said Cristian Vargas, marine biologist and professor of environmental sciences at the Universidad de Concepción in Chile. "It is important that stakeholders, policymakers and the general society be aware that the ocean is changing in multiple ways, through changes in ocean temperature, oxygen content, ocean acidity and other ways, and it is extremely important to conduct realistic experiments on temporal scales relevant to animal biology and evolution and dramatic changes in the ocean realm."

Marine Sciences Research Assistant Lydia Norton draws phytoplankton from the cultures to feed copepods for the experiments. Photo: Nancy Balcom

MORE INFORMATION:

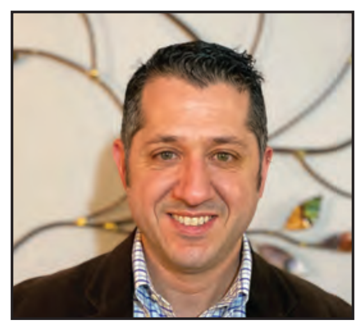
"Rapid, but limited, zooplankton adaptation to simultaneous warming and acidification," in Nature Climate Change: https://www.nature.com/articles/s41558-021-01131-5

"Loss of transcriptional plasticity but sustained adaptive capacity after adaptation to global change conditions in a marine copepod," in Nature Communications: https://rdcu.be/cH8GO

Hannes Baumann

Hans Dam

James deMayo
Photo: Jake Snyder, Redskies Photography



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