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Rapid Evolution Rampant at Sea

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Wrack Lines

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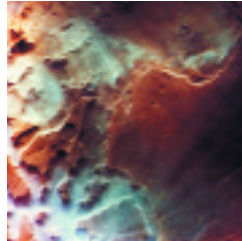
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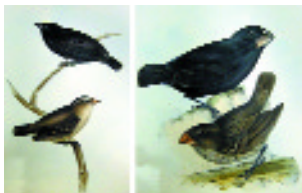
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Rapid Evolution Rampant at Sea

By Hans G. Dam

By some accounts almost half of all Americans believe that evolution is just a theory, not a fact. This is perhaps the most pervasive and dangerous misconception about the wondrous process that has shaped life as we know it. Another misconception, one that even Charles Darwin held to some extent, is that because evolution proceeds at a snail pace we cannot witness it in action. As author Steven R. Palumbi points out in his readable *The Evolution Explosion*, both of these misconceptions are dismissed by examples of “antibiotic resistance, the triumph of HIV over antiviral drugs,... and resistance of insects to nerve gas pesticides” all of which have happened in a few decades. Similarly, in his book *The Beak of the Finch*, Pulitzer Prize-winner Jonathan Weiner describes how evolutionary biologists are documenting evolution as it occurs among the celebrated Galápagos finches that inspired Darwin to formulate his famous theory of natural selection.



Darwin's finches

Most examples of rapid evolution are from land studies. But aquatic scientists are quickly realizing that rapid evolution is also rampant at sea. For instance, selective removal of large fish in commercial fisheries has led to



Because larger fish are more likely to be retained in fishing nets, reduction in average adult fish size has occurred over time in finfish like this Pacific salmon, as a result of selection against fast-growing individuals.
Photo: Oregon Sea Grant

dramatic changes in the size of some species. A delicious example (bad pun intended) is the 30% decrease in the mean size of pink salmon caught off British Columbia, Canada, since the 1950's, a fact documented by fisheries biologist W.E. Ricker.

Pink salmon are born in freshwater streams, spend their youth at sea and return after two years, when they mature, to their native streams to spawn. The return to the spawning grounds is such a Herculean effort that after spawning, the wasted salmon die. In this life-history pattern, salmon put all their eggs in one basket and the stakes for leaving offspring are immense. Fishermen have figured out this life cycle and understand that it is better to catch the salmon before they are physically wasted; hence, they set their gill nets on the path of salmon trying to return to their spawning grounds.

Because pink salmon returning to a spawning ground are all two years old, larger individuals are those that have grown faster.

Unfortunately for these fast growers, they are disproportionately retained in the gill nets. Relatively few of these fast-growing salmon ever get the chance to reach their spawning grounds to reproduce. In contrast, the slow-growing and smaller salmon pass through the nets to reach their spawning grounds, where they can produce offspring. Over the years, the proportion of slow-growing individuals has increased in the population, leading to a decrease in mean size of the fish caught in the gill nets.

In this salmon story, we can reason that the reduction in fish size with time has resulted from selection against fast-growing individuals, a case of natural selection. Natural selection is one of the main mechanisms of evolution.

The salmon story illustrates the essential ingredients for natural selection to occur: 1) variation in traits among individuals in a population (in this case size at

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maturity, which is driven by growth rate), 2) differential reproduction (here, slow-growing smaller individuals leave more offspring than fast-growing ones—larger ones), 3) Inheritance of traits (size at maturity is passed between generations).

Furthermore, the salmon story also illustrates a common feature to many historical sciences; that is, the phenomena of interest are inferred after the fact. It is possible, however, to predict the outcome of evolution and to carry out experiments to test these predictions. For instance, one prediction that has been confirmed experimentally by microbiologists is the evolution of bacterial strains resistant to antibiotics.

Can we experimentally study the evolution of resistance in natural populations at sea? In my own laboratory we are interested in finding out whether grazers evolve resistance to toxic dinoflagellates, a group of microalgae. Along the coasts of New England and eastern Canada, dinoflagellates of the genus *Alexandrium* produce a group of neurotoxins, called saxitoxins, which interfere with nerve-transmission signals, resulting in paralysis of those that ingest the toxins. Depending on how much toxin is ingested, effects range from slight stupor to death from asphyxiation, as breathing muscles fail to work. (Saxitoxin effects were first documented in people that had ingested shellfish that in turn had ingested *Alexandrium*; hence, saxitoxin poisoning is commonly known as paralytic shellfish poisoning, PSP.) Our interest in this topic is more than academic since New England fishermen lose millions of dollars annually when fishing grounds are closed due to dangerously high PSP toxic content in fish and shellfish. In addition to economic losses, PSP also

represents a threat to public health.

In our own work on grazer resistance to PSP toxins, we use copepods (a group of planktonic micro-crustaceans) as the grazers that face toxic *Alexandrium*. Because they are the most numerous animals on the planet and have short generation times (a couple of weeks to months, depending on temperature), copepods are an important and convenient subject for studies of evolution.

We chose to work on the copepod *Acartia hudsonica*, a ubiquitous species found along the eastern coast of the U.S. and Canada. Populations of *Acartia hudsonica* from Massachusetts to Nova Scotia are frequently exposed to blooms of toxic *Alexandrium*. South of Massachusetts, toxic *Alexandrium* blooms are rare or nonexistent. Sean Colin, a former doctoral student in my lab, and I reasoned that if resistance had evolved in the northern New England copepod populations, they would have higher reproductive rates when faced with toxic *Alexandrium* than copepod populations south of Massachusetts, which had not previously faced *Alexandrium*. This prediction was indeed borne out by laboratory experiments. When we repeated the experiments using a nontoxic food, there was no difference in reproductive rates between copepod populations that live north or south of Massachusetts.

Clearly, then, any differences between copepod populations had to do with their responses to the toxic dinoflagellate. Moreover, in these experiments we kept the several copepod populations under the same environmental conditions for several generations before running the experiments. Therefore, we were able to rule out the potential effect of the environment, or the effect of the interaction of the environment and genes, on the performance of the different populations.

Put another way, our results are more readily explained by genetic differences between the copepod populations. Thus, the lower reproductive rate in the copepod populations that are not typically exposed to blooms of the toxic dinoflagellate is consistent with the hypothesis that these

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Hans Dam, right, and Sean Colin, left, put samples into a "plankton wheel". Like a miniature ferris wheel, this equipment simulates the natural conditions in which plankton move with the flow of water.

Photo: Peg Van Patten, Conn. Sea Grant

populations have not evolved resistance.

A skeptical observer would argue that our experiments have yet to show evolution of resistance to toxic algae. Put another way, one can ask whether there is more compelling evidence of the evolution of resistance. The answer is yes, and is in the form of genetic selection experiments. In this case, we took a copepod population that had never faced *Alexandrium* and split it in two groups. One group was reared from eggs to adults on a diet free of *Alexandrium*. In the other group, 20% of the diet consisted of *Alexandrium*. We then measured, during five successive generations, the reproductive rates in both copepod groups when they were fed only *Alexandrium*.

In the future, will we observe more human health problems related to the consumption of fish loaded with toxins?

After only three generations, the group reared on the diet containing *Alexandrium* had higher egg production than the group reared in the *Alexandrium*-free diet. The most logical explanation for this observation is natural selection of resistant individuals in the group exposed to *Alexandrium*.

Clearly, our experiments show not only the existence of wild copepod populations resistant to PSP toxins, but also that such resistant can potentially evolve in a matter of a few generations. For

a scientist, this is exciting news from a purely intellectual point of view.

However, our findings also raise many interesting practical issues. For instance, if toxin-resistant grazer populations evolve, can they eventually act as biological pest controls?

One can envision a future in which toxic algae are kept from blooming by toxin-resistant grazers. This potential outcome is encouraging news.

On the other hand, the evolution of toxin-resistant grazers also means that fish that feed on these grazers will in turn have higher toxin content. Will we observe in the future more human health problems related to consumption of fish loaded with toxins? The same concern applies if instead of toxins we consider the evolution of resistance of organisms to pollutants such as heavy metals. The possible scenarios due to resistance outlined here show that evolution can have both positive and negative consequences for the quality of our environment.

A practical lesson for us all is that without understanding the evolutionary history of populations, we will be hard-pressed to come up with effective management plans for living marine resources. **WL**

The author thanks Dr. David Avery for comments and suggestions that improved this article.



Photo: : Amy N. Smith and Barbara Costas

New research shows that some marine zooplankton, such as this *Acartia hudsonica*, have adapted to co-exist with their prey, even when the prey are toxin-producing algae.

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For further reading:

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