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An Evolve-By Date

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Olivia Judson on the influence of science and biology on modern life.

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Yesterday, Tuesday, Nov. 24, was The Big Day: it was exactly 150 years since Charles Darwin's "On the Origin of Species" was first published. In this book, Darwin described how evolution by natural selection works — and presented a huge body of evidence, drawn from every field of biology then known, that evolution can account for the patterns we see in nature.

I've written before about what an important book it was and why it mattered so much, so I won't do that again now. Instead, I want to mark the occasion by looking at the limits of evolutionary potential.

To see what I mean by this, consider the following paradox. Whenever we do evolution experiments in the laboratory or on the farm, we can cause pronounced and rapid change in the traits we are interested in — we can evolve bigger horses, smaller dogs, cows that make more milk, viruses that thrive at higher temperatures and so on. In the laboratory, in other words, evolution has huge potential. But if it has that much potential — how come organisms keep going extinct in nature? In other words, why does evolution keep failing?

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The question matters as never before. We humans are busily changing the environment for most of the beings on the planet, and often, we are doing so very fast.
To know what effect this will have, we badly need to know how readily different creatures can evolve to deal with changes to their environment. For if we're not careful, many groups will soon be faced with an evolve-by date: if they don't evolve rapidly enough to survive in this changing world, they will vanish.

The basis of evolutionary potential is clear enough in principle. Whether a population can evolve to cope with new circumstances depends on how much underlying genetic variation there is: do any

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individuals in the population have the genes to cope, even barely, with the new environment, or not? If not, everybody dies, and it's game over. If yes, evolution may come to the rescue, improving, as time goes by, the ability of individuals to cope in the new environment. What determines the extent of the underlying genetic variation? Factors such as how big the population is (bigger populations usually contain more genetic variation) and how often mutations occur.

Let me give an example of how this works. Imagine you have a population of algae that have been living for generations in a comfy freshwater pool. Now suppose there's a ghastly accident and, all of a sudden, the pool becomes super-salty. Whether the algae will be able to survive depends on whether any individuals already have any capacity to survive and reproduce in salty water. If none of them do, they all die, and the population goes extinct. But if some do, then the survivors will reproduce, and over time, beneficial mutations will accumulate such that the algae get better and better at living in a high-salt environment.

This isn't just hypothetical: many experiments have taken organisms, be they algae, fungi or bacteria, from an environment to which they are well-adapted to one where they are not, and watched what happens. The result is reliable: at first, they tend not to cope that well (measured, as usual in evolution, by their ability to survive and reproduce). However, as long as the environment doesn't change again, their coping ability rapidly improves: within a few tens of generations, beneficial mutations appear and spread, and the organisms evolve to become much better at handling their new circumstances.

But here's the thing. A big drawback of experiments of this type is that the initial change the organisms experience is not that severe — it is not, in fact, so severe that no one can cope, and the population goes extinct. The reason is simple: if the population immediately goes extinct, you have no experiment (at least, not one you can publish). Which means that we have the illusion that evolution is more powerful than it is: we keep studying evolutionary rescues, not evolutionary failures.

Moreover — and this also has a bearing on the matter — where no previous capacity exists, evolving a brand new trait can be a slow and haphazard affair. Suppose you put bacteria into test tubes where their usual sugar source is in short supply, but an alternative one — which they can't consume at all — is abundant. (If you put them with just this alternative source, they would all die of starvation at once.) Then, you can watch how long it takes for the bacteria to evolve so they can digest the alternative. The answer, in one famous case, was more than 31,000 generations! Which just goes to show: just because a particular trait would be useful does not mean that it will soon evolve.

To me, all this is a bit sobering. If most organisms have to wait 31,000 generations to evolve a useful new trait — they will probably go extinct first. Worse, many natural populations are shrinking fast, further reducing their evolutionary potential. In short, we can expect that — if the environment continues to change as rapidly as it is at the moment — many creatures will fail to meet their evolve-by dates.

Notes:

As far as I know, the idea of evolutionary failure was first discussed by Bradshaw, A. D. 1991. "Genostasis and the limits to evolution." Philosophical Transactions of the Royal Society of London, Series B 333: 289-305. This paper also contains some good examples of organisms in nature failing to adapt. The problem of extinction in the context of adaptation has been more recently discussed by Bell, G. and Collins, S. 2008. "Adaptation, extinction and global change." Evolutionary Applications 1: 3-16. See also, Bell, G. and Gonzalez, A. 2009. "Evolutionary rescue can prevent extinction following environmental change." Ecology Letters 12: 942-948.

For a review of experiments in evolution — and for evidence that, for a wide range of organisms, a sudden change in the environment usually results in the pattern I described, see Elena, S. F. and Lenski, R. E. 2003. "Evolution experiments with microorganisms: the dynamics and genetic bases of adaptation." Nature Reviews Genetics 4: 457-469.

For bacteria taking more than 31,000 generations to evolve the ability to digest a new source of sugar, see Blount, Z. D., Borland, C. Z. and Lenski, R. E. 2008. "Historical contingency and the evolution of a key innovation in an experimental population of Escherichia coli." Proceedings of the National Academy of Sciences USA 105: 7899-7906.

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