RICHARD WILKINSON

Evolution in the fast lane

It's usually portrayed as slow and steady, but that couldn't be further from the truth. **Michael Le Page** reports

MICHAEL BELL has his children to thank for his discovery. Back in 1990, they were getting restless as he was driving past Loberg Lake in Alaska. Bell, a biologist who studies the evolution of sticklebacks, had not planned to collect any fish, as the native sticklebacks had been exterminated in 1982 to improve the lake for anglers. "But we saw the lake, and we had to do something," Bell says.

To Bell's surprise, they found that marine sticklebacks had recolonised the lake. This in itself was not all that unusual: marine sticklebacks can live in fresh water, and most freshwater species are descended from marine ones that colonised streams and lakes as the ice retreated at the end of the last ice age.

But there was something odd about these sticklebacks. Ten thousand years on from the ice age, freshwater sticklebacks are quite different from their sea-going ancestors. The most obvious change is loss of armour plates, which seem to take longer to develop in fresh water. In lakes, lightly armoured fish may outgrow and outcompete fully armoured fish.

This trait was assumed to evolve slowly, over thousands of years, so Bell was surprised to find that some of the fish he caught in Loberg

Lake had fewer plates. In 1991 he asked a friend to collect some more fish. Sure enough, more had lost their armour.

Bell, who is based at Stony Brook University in New York, began collecting sticklebacks every year. Each time, he found more lightly armoured fish. By 2007, 90 per cent were of the low-armour form. Far from taking millennia, the trait had evolved in a couple of decades (see diagram, page 34).

Compared with the gradual process described by Darwin, this is evolution at warp speed. What is really startling, though, is that far from than being exceptional, high-speed evolution is starting to look like the norm. Very few biologists set out to look for evidence of ongoing evolution, but wherever they do, they find it – from weeds and pests to fish to humans (see "We are evolving too", page 36). It now appears that whenever the environment changes in any way, life evolves. Fast.

Such findings throw up a paradox. The two main ways to study evolution – the fossil record and comparisons of genomes of living organisms – suggest that the process is gradual, with some species barely changing over tens of millions of years. If evolution is as rapid as some biologists now claim, how come the fossil record and genetic studies suggest it is usually very slow?

Reports of rapid evolution go back a surprisingly long way. It turns out that British entomologist Albert Farn wrote to Darwin in 1878 to point out that darkly coloured annulet moths were becoming more common than lighter moths in areas blackened by pollution (*Current Biology*, vol 20, p R95). This was nearly 20 years before it was first suggested that the famous peppered moths were turning black for the same reasons.

> **"Wherever people look for rapid evolution, it's there. Very fast change can occur in very short periods"**

In 1897, it emerged that several insect populations were becoming resistant to insecticides. By the 1930s, more examples had surfaced, such as scale insects developing resistance to hydrogen cyanide.

Over the following decades, biologists stumbled upon more and more examples. A few became famous, such as the peppered moth, but all were regarded as curiosities. "People went, 'wow, that's amazing, that must be the exception'," says Michael Kinnison of the University of Maine in Orono, one of the first researchers to set out specifically to look at evolution in action.

Today, there are probably thousands of examples, and a growing number of biologists think that far from being an exception, rapid evolution is common. "Wherever people look for it, it's there," says Kinnison. "Very fast change can occur in very short periods." And thanks to advances in genetics, we are beginning to understand how it is possible.

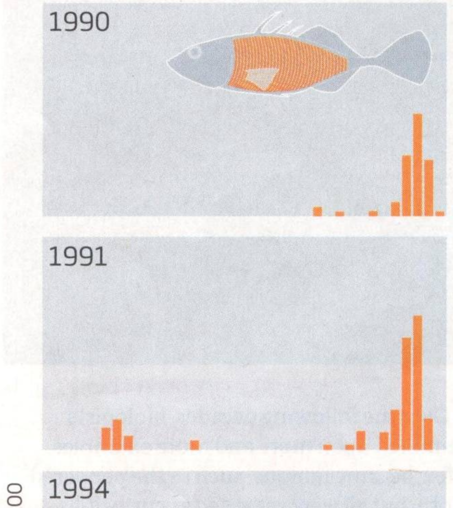
Bell's stickleback record remains one of the best-documented examples. Besides losing armour, the fish have also acquired other traits typical of freshwater fish, such as smaller gills. Their immune systems have also evolved to cope with different threats. Similar changes have happened in a stickleback population in an inlet in Norway that was recently cut off from the sea (*Proceedings of the Royal Society B*, vol 278, p 233). ›

From genetic studies we know that armour loss is due to mutations in a gene called *EDA*, which plays a role in skin development. These mutations are also found in marine sticklebacks, although they are very rare. They persist at low levels because the trait is recessive, meaning fish lose their armour only if they inherit two mutant copies of the gene.

But once the sticklebacks move into fresh water where less armour is an advantage, the mutations are desirable and rapidly become more common as natural selection does its work. This explains how the same trait evolved repeatedly as sticklebacks colonised lakes after the ice age (*Science*, vol 307, p 1928).

Ready, steady, evolve!

Freshwater sticklebacks are known to evolve from heavily armoured marine forms. Samples from Loberg Lake in Alaska show that it can happen in less than 20 years



SOURCE: MICHAEL BELL, STONY BROOK UNIVERSITY

Such pre-existing genetic diversity seems to be what allows populations to evolve rapidly. Support for this idea comes from a study of sticklebacks in Cook Inlet, Alaska, which recently switched to living in fresh water. The armour of these fish has hardly changed at all, and Bell's team has found that they are less genetically diverse than those in Lake Loberg.

While rapid evolution usually involves existing mutations, new ones can play a role too. For instance, the mosquito *Culex pipiens* evolved resistance to organophosphate insecticides when an unusual mutation produced several copies of one gene, enabling it to make more of an enzyme that could break the pesticides down. This new mutation has spread worldwide (*Nature*, vol 350, p 151).

In the right circumstances, even new species can evolve in next to no time. In 1866, farmers in the US reported that an unknown maggot was attacking their apples, a crop introduced two centuries earlier. Entomologist Benjamin Walsh suggested that the "apple maggot" was a strain of the native hawthorn fly that had switched diets. Walsh had previously suggested this kind of process could lead to speciation.

We now know that Walsh was right. Genetic studies have shown that the hawthorn fly appears to be in the process of splitting into two species (*Annual Review of Entomology*, vol 47, p 773). What's more, the parasitic wasps whose larvae feed on the maggots are also splitting into two species (*Science*, vol 323, p 776).

More examples keep turning up. A species of fish in a lake in Nicaragua has split in two in only 100 years. The new variety has evolved a narrower, pointier head and fatter lips, ideal for nibbling insects from crevices. The original variety has sturdier jaws and extra teeth to crack snail shells. Lab studies suggest the strains do not mate with each other even when put together, which would mean they are on their way to becoming separate species.

Yet another example comes from the famous Galapagos finches. Since 1973, husband-and-wife team Peter Grant and Rosemary Grant have been studying the finches on the island of Daphne Major, in one of the few long-term studies of ongoing evolution. Their work was made famous in *The Beak of the Finch* by Jonathan Weiner.

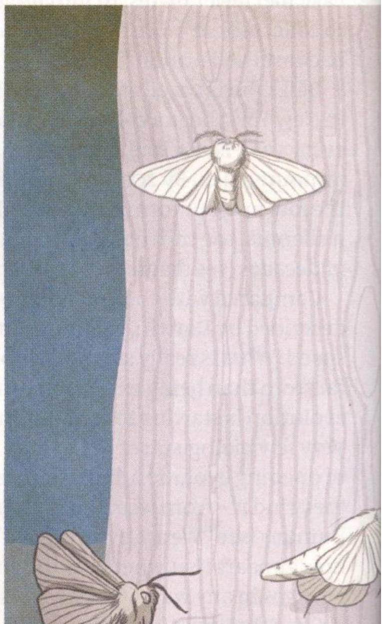
They reported last year that a new species of finch might be evolving. In 1981, a medium ground finch (*Geospiza fortis*) from another island reached Daphne Major and interbred with the local birds, producing offspring with unusal beaks and songs. After four generations, following a severe drought that killed many birds, this new strain stopped interbreeding with the other finches. It's not clear why interbreeding stopped, but if the birds continue to shun the locals they will become a new species.

As the list of examples grew, Kinnison and his colleagues began to pull them together and look at what they tell us about evolution. "We started to realise that maybe this was not the exception, that this was the norm."

In fact, he now argues that the term "rapid evolution" is misleading, because it implies evolution is normally slow. Instead, he and his colleagues prefer "contemporary evolution".

Nowadays, most biologists with a background in evolution appreciate this, Kinnison thinks. Of course, proving that contemporary evolution is the norm in a world of millions of species is a challenge. To those who remain sceptical, though, Kinnison's response is simple: "Take a look."

"We started to realise that maybe rapid evolution was not the exception, it was the norm"



RICHARD WILKINSON

EVOLVE TO AVOID THE HEAT

If species can evolve very rapidly (see main story), does that offer them a way to cope with sudden environmental change? It's an intriguing possibility, but as yet nobody really knows. "Some animals will be able to change fast enough, but others will not," says Michael Kinnison of the University of Maine in Orono.

For example, most bird and mammal species have already suffered a huge loss of genetic diversity as a result of human pressures, so they are not well placed to evolve in the face of dramatic climate change.

According to Ary Hoffmann of the University of Melbourne and Carla Sgrò of Monash University in Clayton, both in Australia, rapid evolution is likely to help some species survive but we don't yet have enough information to identify the winners and losers, nor to take evolution into account in programmes designed to reduce biodiversity loss (*Nature*, vol 470, p 479).

If rapid evolution really is the norm, how come fossil and genetic studies suggest it is slow? The answer may be that new species and traits not only evolve rapidly, they also disappear fast too and do not leave their mark on the fossil or genetic record.

The best example also comes from the Galapagos. In 1977 a drought on Daphne Major wiped out plants that produce small seeds, and many of the ground finches that fed on them died. Those with larger beaks that enabled them to feed on bigger seeds did better, and within a few generations beak size had increased by around 4 per cent.

The wet year of 1983 saw small seeds become abundant again and soon beak size had shrunk again – evolution had gone into reverse (*Science*, vol 296, p 707).

Speciation can also go into reverse. On the nearby island of Santa Cruz, two incipient species are collapsing back into one. Work in the 1960s showed the finches on this island had split into large and small-beaked strains, specialising in different-sized seeds. Now most have medium-sized beaks, probably as a result of people feeding birds rice, making small or large beaks less of an advantage.

Many other examples are being discovered. Lake Victoria in east Africa is home to more than 500 species of cichlid fish, many of which split off in the past 15,000 years. Now many species are merging back together.

The reason is that females recognise males of the same species by their bright colours. As the lake has become murkier due to human activity, females are increasingly breeding with the wrong males, giving rise to hybrids that eventually replace the two original species (*Molecular Ecology*, vol 17, p 30).

This evolutionary toing and froing may well be the norm. As a result of fluctuating selection pressures, populations probably evolve rapidly in one direction and then the other, ending up back where they started.

Evolutionary yo-yoing can also be driven by the interactions between species, not just external factors like the weather. Around a decade ago, Nelson Hairston's team at Cornell University in New York began experimenting on single-celled algae and tiny animals called rotifers that feed on them. They expected to see a classic predator-prey cycle – a decline in algae as rotifers increased, followed by a rotifer crash as they ran out of food, leading the algae to rebound, and so on.

In fact, they saw unexpected patterns. Sometimes rotifer numbers grew even when algal numbers remained constant. The reason, Hairston realised, was that these algae were evolving rapidly, alternating between putting resources into defence or into multiplying – which creates more rotifer food. Rotifer numbers sometimes increased at just the right rate to keep the rapidly reproducing algae in check. When the team repeated the experiments with genetically identical algal cells, to slow evolution to a crawl, they saw classic cycles (*Nature*, vol 424, p 303).

Hairston later discovered that theoretical biologists had predicted that rapid evolution could produce the kinds of patterns he saw. What remains unclear is how common it is in the wild. "It must happen sometimes, but how often? That's the $64,000 question," says Hairston.

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Galapagos finches are still inspiring discoveries into the processes of evolution

AP PHOTO/SCIENCE, B. ROSEMARY GRANT

One place this kind of cycle might be getting under way is the Hawaiian island of Kauai, where the crickets recently fell silent. In the 1990s, a parasitic fly arrived which tracks down male crickets calling for mates and deposits its egg on them. The larvae then devour the crickets alive. The cricket population plummeted.

In 2003, the island was still silent – so Marlene Zuk of the University of California, San Diego, was surprised to find plenty of crickets there. It turned out that almost the entire population had a mutation that alters the wings of male crickets and prevents them making any sound when rubbed together. The population has survived because a few males can still chirp. Silent males gather around these males and intercept potential mates.

For Zuk, the interesting question is what will happen next. At present, the crickets are heading down an evolutionary dead end. "I don't think that a completely silent population could survive," says Zuk. Instead, she suggests, we will see a predator-prey cycle driven by rapid evolution, similar to the ones Hairston observed. As silent males increase, parasite numbers may fall, leading to a rebound in singing males followed by a parasite revival, and so on (*Trends in Ecology & Evolution*, vol 22, p 226).

Switching direction

There is nothing new about the idea of an evolutionary arms race in which species have to continually evolve to keep up – it is called the Red Queen hypothesis. What is new, though, is the idea that not only can this kind of evolution occur far more rapidly than once thought, but that the runners in the race keep switching direction.

This has important practical implications. If you want to model pest outbreaks or the spread of parasitic diseases, say Hairston, you have to take evolution into account. "If you leave that out, you are going to get the answer wrong." As a result, the study of how contemporary evolution affects population dynamics has rapidly become a hot topic.

Put it all together and the picture of evolution that is emerging is radically different to the way most people envisage the process. As Kinnison puts it, the popular view of evolution is upside down. People think evolutionary changes are imperceptible in the short term but add up to big changes over millions of years. In fact, the opposite is true. It now appears that organisms evolve very rapidly in response to any changes in their environment, but in the longer term most evolutionary changes cancel each other out.

So the longer the period you look at, the slower evolution appears – a phenomenon first pointed out in 1983 by Philip Gingerich of the University of Michigan, Ann Arbor (*Science*, vol 222, p 159). At the time nobody believed it, but "people have recognised now that it was a very insightful piece of work," says Hairston.

"I think a superficial reading of the fossil record has given us a misleading picture of the evolutionary process," says Gingerich. "The changes seen over long intervals of geological time are not representative of what happens on a generation-to-generation timescale."

This is especially true of long periods with little or no evolutionary change. The conventional explanation for this stasis has been that evolution is usually slow because selection is usually weak. "But this is perfectly consistent with strong selection, providing it fluctuates," says Graham Bell of McGill University in Montreal, Canada.

Assuming it is right, this new picture of evolution should perhaps come as no surprise. We have always known that the "march of progress" is an illusion, that evolution is a random process with no purpose. Rather than going somewhere slowly, evolution usually goes nowhere fast. ■

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WE ARE EVOLVING TOO

Love takes many forms. Members of the Fore tribe of Papua New Guinea used to believe that when someone died, their loved ones should eat every bit of the body. The daughters ate the brain and sometimes fed titbits to their children (*Philosophical Transactions of the Royal Society*, vol 363, p 3721).

This tradition led to the spread of a degenerative brain disease called kuru. Like Creutzfeldt-Jakob disease, it is caused by a rogue prion protein that accumulates in the brain. Kuru killed nearly all the young women in some villages. But a few did not succumb. They were the descendants of a person born around 200 years ago with an unusual mutation in the prion protein that stops it going rogue. As kuru became widespread, the mutation rapidly became more common. Half of the women in the areas most affected now carry the mutation, which has not been found anywhere else in the world. If the tradition of cannibalism had not been stopped in the 1950s, it would have become even more common among the Fore (*New England Journal of Medicine*, vol 361, p 2056).

The emergence of kuru resistance is one of the clearest examples of very rapid human evolution but it is far from the only one. Around 3000 years ago, the ancestors of Tibetans split from the population that gave rise to the Han people of China. As soon as they began living at altitude, the population began to adapt. While some of the adaptations are a result of living in the mountains - a bit like altitude training in athletes - some are genetic.

One variant in a gene controlling the production of red blood cells, for instance, is found in 78 per cent of Tibetans but just 9 per cent of Han people. And the process has not stopped. "We think the selection process is ongoing," says Rasmus Nielsen of the University of California, Berkeley, who led the study (*Science*, vol 329, p 75).

More evidence comes from a study of Tibetan women living above 4000 metres. Those with high levels of oxygen in the blood had 3.6 surviving children on average, whereas those with low oxygen levels had just 1.6, due to much higher infant mortality. That suggests the genetic variant thought to be responsible for higher blood oxygen levels is being passed on in greater numbers and becoming more common (*Proceedings of the National Academy of Sciences*, vol 101, p 14300).