‘Unnatural selection’: How humans are altering the evolution of other animals

The bouncing orange specks could be popcorn dancing on a hot plate. But there’s something odd about how they move. Individual kernels spin in tight circles. Pairs slow dance a *pas de deux*. A cluster performs one full rotation counter-clockwise before dispersing. Each collision sets off a new motion. They seem to be *behaving*.

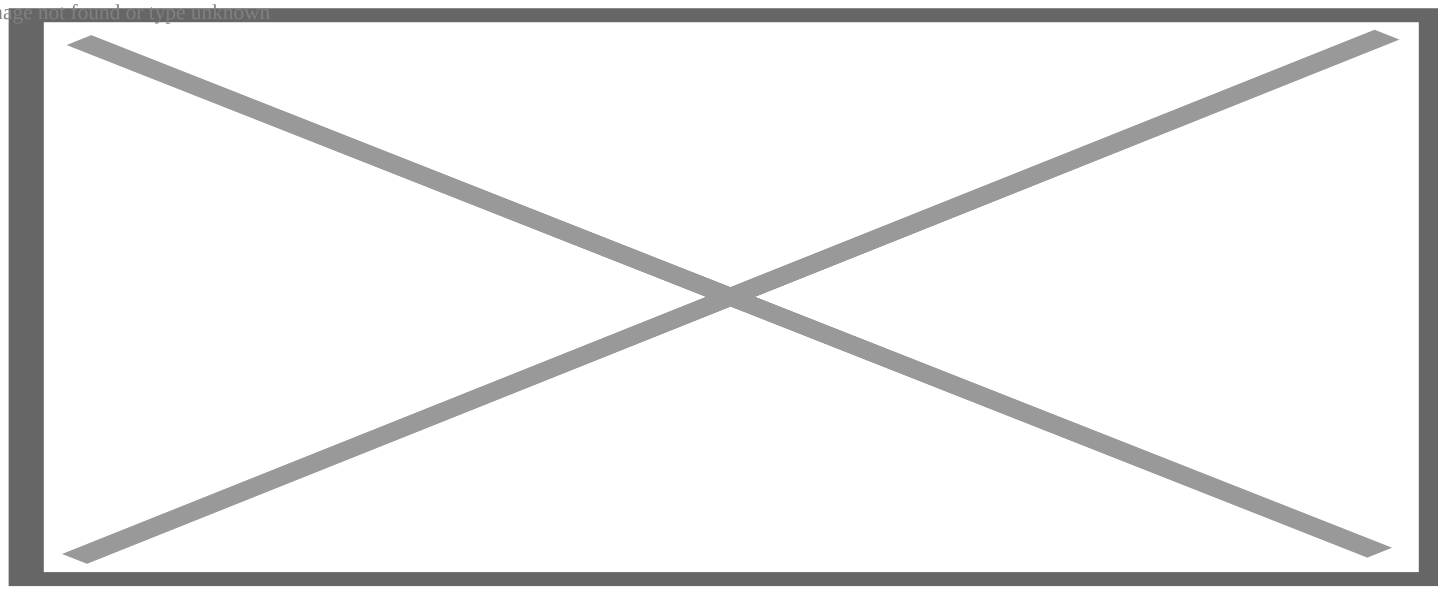
What look like popcorn kernels in this short video are in fact a swarm of microscopic “xenobots”: tiny living robots, assembled from frog cells.

While living robots might seem a strange concept, in fact the first robots were made of flesh, not metal. The word was coined in 1921, in a play by Czech playwright Karel ?apek. Rossum’s Universal Robots was a thought experiment along the lines of Mary Shelley’s Frankenstein, about a scientist’s desire to create artificial people. “Nature has found only one method of organising living matter,” declares Rossum, the scientist in question. “There is, however, another method, more simple, flexible and rapid which has not yet occurred to nature at all.”

“Imagine him sitting over a test tube and thinking how the whole tree of life would grow from him,” says another character.

In the century that followed, however, robots developed as things of steel and wire, rather than living tissue. “Engineering moved faster than biology,” says Douglas Blackiston, a developmental biologist at Tufts University. But biology is rapidly catching up. Blackiston is one of a team of scientists designing “xenobots”: tiny living robots, painstakingly constructed from tissue harvested from *Xenopus laevis*, the African clawed frog.

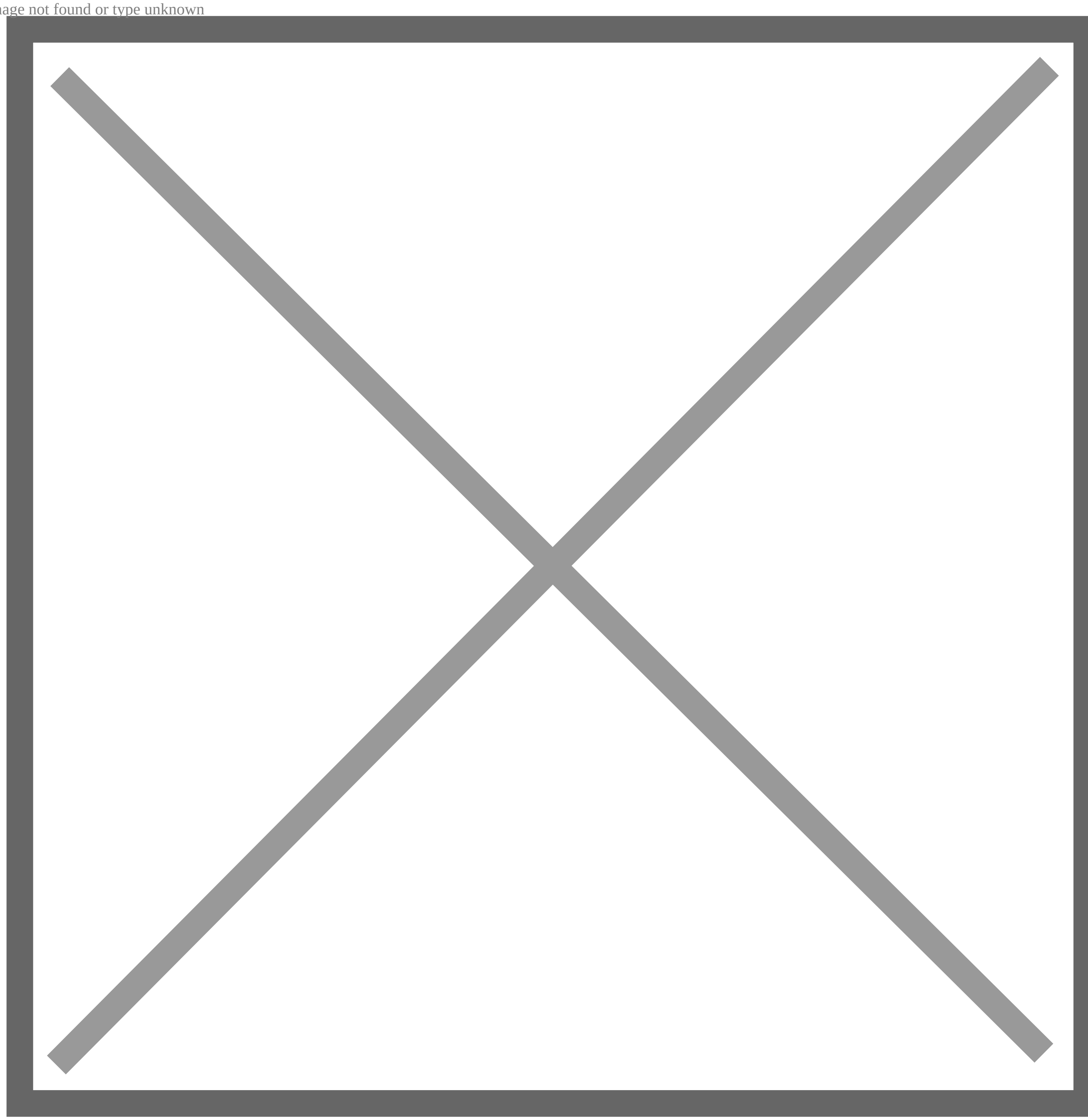
Image not found or type unknown



Xenobots, engineered from frog stem cells, take on different shapes. Credit: Wired

The first xenobots were revealed to the world at the start of 2020: minuscule cubes formed of skin cells and propelled by two stubby legs made of heart muscle. They were designed by a computer algorithm and hand-built by researchers with the objective to make the xenobots walk. (In a pleasing coincidence *Xenopus* means “strange foot.”) These organic automatons could also work together to move particles around their environment, and unlike mechanical robots they self-healed when injured.

Image not found or type unknown



The living robots created by scientists at Tufts University developed unique body features such as hair-like cilia to help them move. Credit: Douglas Blackiston/Sam Kriegman

But if the thought of organic robots is strange enough, things got really weird with the next generation.

“If I took all the parts of your car and hooked them randomly to one another, you’d expect it would be bad,” says Blackiston. “But it turns out biology has a lot more flexibility than that.” Xenobots 2.0 were formed from stem cells extracted from frog embryos and allowed to develop without relying on the algorithm. Independently, the cells began to develop entirely novel body plans. Hair-like motile cilia grew all over their surfaces – a feature usually found in the lungs, but these cilia were more like limbs, flailing rapidly to allow the xenobot to swim through its environment. In this video, a xenobot navigates a pretzel-shaped maze without touching the sides.

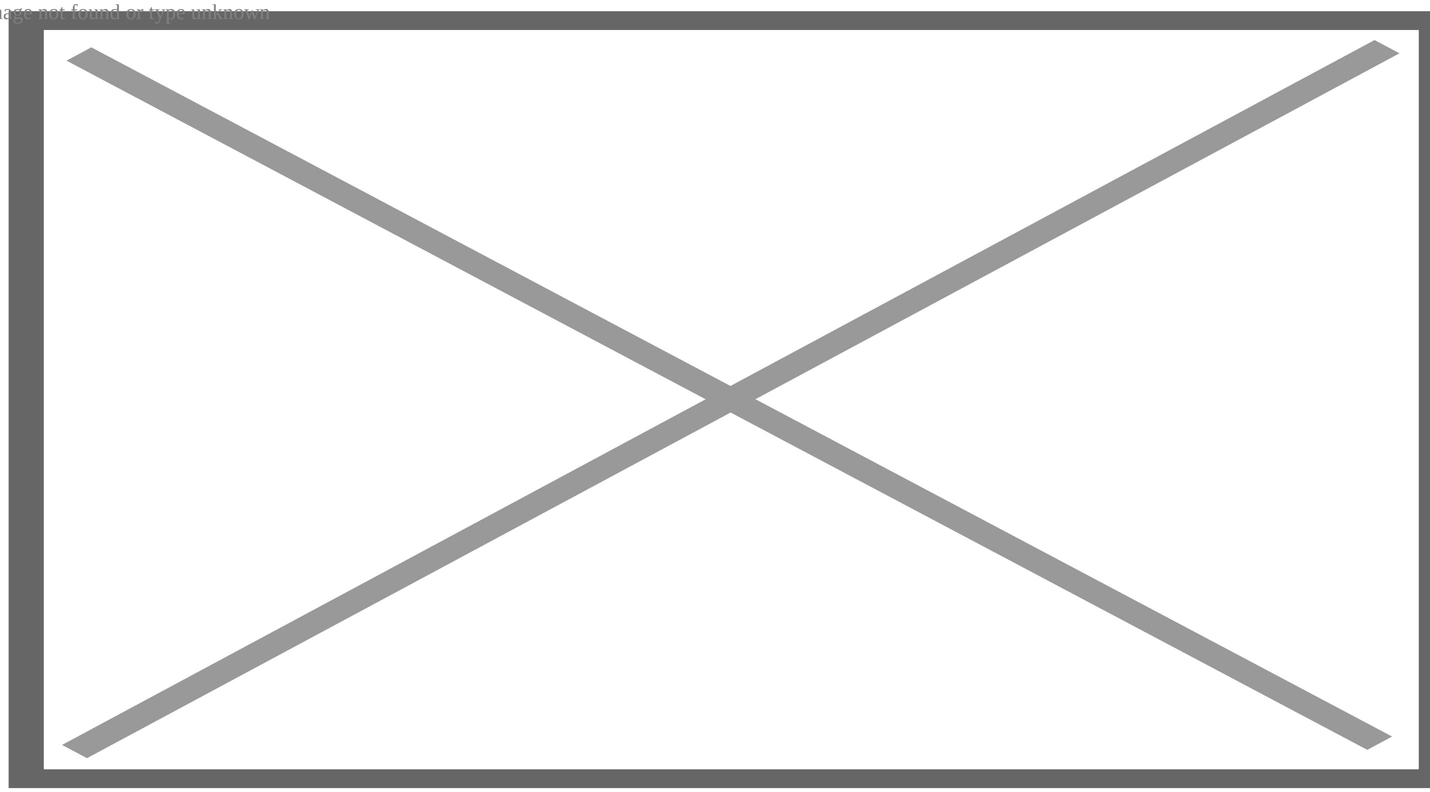
Rather than building a tadpole, the stem cells responded to the unique conditions of the laboratory environment to build bodies totally unlike their amphibian origins. They self-assembled spontaneously, leap-frogging (as it were) evolution.

Looking for a way to improve the xenobots’ performance further, Blackiston and his team asked the AI to come up with an improved design. The AI blueprint produced Pacman-shaped xenobots with indentations that look like mouths. This third generation had a further surprise: by gathering hundreds of stem-cells in their “mouths” they could mould new xenobots (as shown in the image at the top of this page). They had, in other words, evolved an entirely new way to reproduce, unlike anything seen elsewhere in nature.

Future generations could be developed by designing the environments they interact with. “Now that we’re understanding the inputs to the system,” says Blackiston, “we’re absolutely looking at how we might get the environment to help shape the designs themselves – chemical cues, sticky environments, compression, etc.”

Xenobots are “an imperfect organism”, he says. Although they meet most of the criteria for living systems, their reproduction involves making “functional self-copies” – assembling new versions that look and behave in the same way but aren’t identical.

Still, the creation of xenobots could be considered a microcosm of something happening far more widely across the globe as organisms respond creatively to the pressures we impose on them. All living things are in a constant negotiation with their environments and it’s this interplay that drives evolution. But as humans now dominate nearly every environment on Earth in one way or another, a new factor has entered the evolutionary equation – us.



Peppered moths are an iconic example of how evolution is driven by human pollution. Moths in polluted areas maintain darker colouration. Credit: Ilik Saccheri

Humans have shaped the bodies of other creatures at least since dogs were domesticated around 30,000 years ago. But the combination of industrialised farming, introduced species, urbanisation, pollution, and climate change are creating unprecedented selective pressures. We have become the world's greatest evolutionary force.

Evolutionary time – at least for larger, more complex organisms – can be slow. This leaves many animals unable to adapt fast enough to cope with a human-dominated planet, with extinction currently up to 1,000 times greater than the rate at which species might be expected to disappear without human interference.

But rapid change is also possible, via an inbuilt genomic plasticity that allows individual animals to draw on a range of body plans and behaviours best suited to new opportunities and pressures. So-called microevolutions can transpire in the time of just a handful of generations. Perhaps the most famous example is the peppered moth, which changed from a speckled white to a black colouration in response to soot and air pollution rising from the chimneys of the Industrial Revolution in Britain. Researchers at the University of Liverpool pinpointed the genetic mutation that caused the colour change and calculated when it may have occurred – 1819.

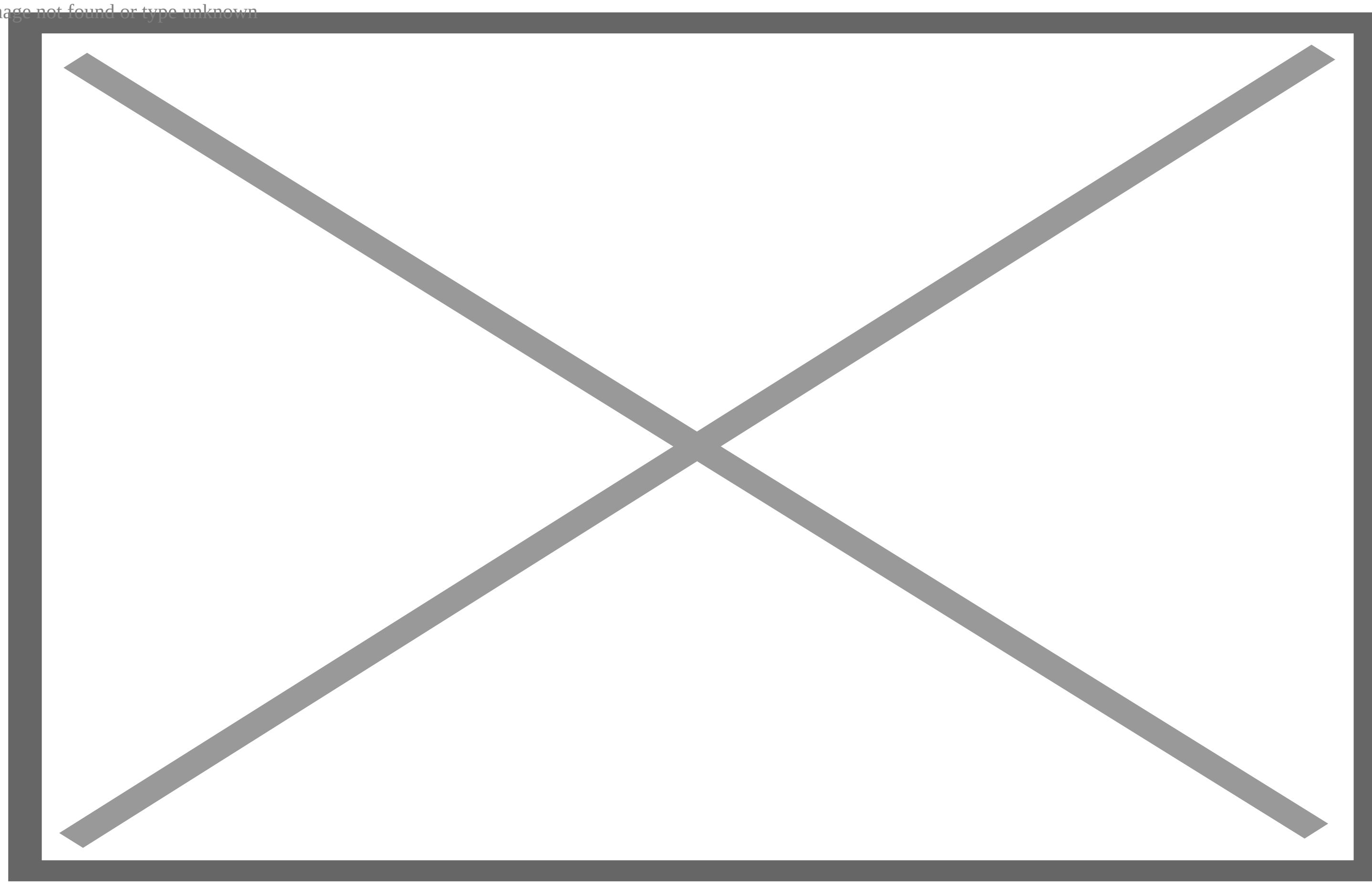
The peppered moth's changing colour was first observed in 1878, by a butterfly collector who shared his finding with Charles Darwin. The great man seems to have ignored the discovery, although it was later suggested by others as evidence for his ideas on natural selection. The “industrial melanism” of the peppered moth was, however, an example of unnatural selection. And it was only the beginning.

?apek’s robots

Karel ?apek’s play, Rossum’s Universal Robots (or RUR), is a pun on the Czech word *rozum*, or “reason”, and *Robota* meaning “serfdom”. The play is a “comedy, partly of science, partly of truth” – a Frankenstein story for the age of mass production that coincided with the Soviet era. Rossum’s robots are more akin to the replicants in Bladerunner than to C-3PO or WALL-E: bioengineered artificial humans, almost indistinguishable from the real thing, who do most of the world’s labour so that their masters can enjoy a post-work utopia. Inevitably, the plan goes awry. Humans grow lazy and infertile while the robots plot genocidal revolution. “We have made machines, not people, the measure of the human order,” ?apek later wrote, “but this is not the machines’ fault, it is ours.”

Human-induced trait change has been observed in animals on every continent other than Antarctica.

Image not found or type unknown



Turtle-headed sea snakes are quickly evolving darker coloration to accommodate ocean pollution.

Credit: PBS

Today, worker bees in industrial beehives – transported from farm to farm across the United States in convoys of trucks – are one-third larger than their wild cousins, and more docile. In the past 100 years, North American songbirds have modified the shape of their wings to cope with habitats fragmented by deforestation. Under pressure from poaching, Zambian elephants are born without tusks. Since the introduction of cane toads to Australia in 1935, originally to deal with beetle infestations in sugar plantations, the mouths of black snakes have shrunk as succeeding generations learned to avoid toad-sized prey, while the toads themselves have become cannibals, victims of their own success as predators.

Sea-snakes in Papua New Guinea have developed darker bodies and shed their skins more often in response to toxins in the zinc-polluted waters they inhabit. One species of mosquito has evolved to live only in the tunnels of the London Underground, and lost the capacity to breed with its surface-dwelling cousins. Similar declines in genetic diversity have been observed in mosquitoes in the New York and Chicago subway systems. Blackcaps have shifted their migration routes from the Iberian Peninsula to the UK as climate change extends their range.

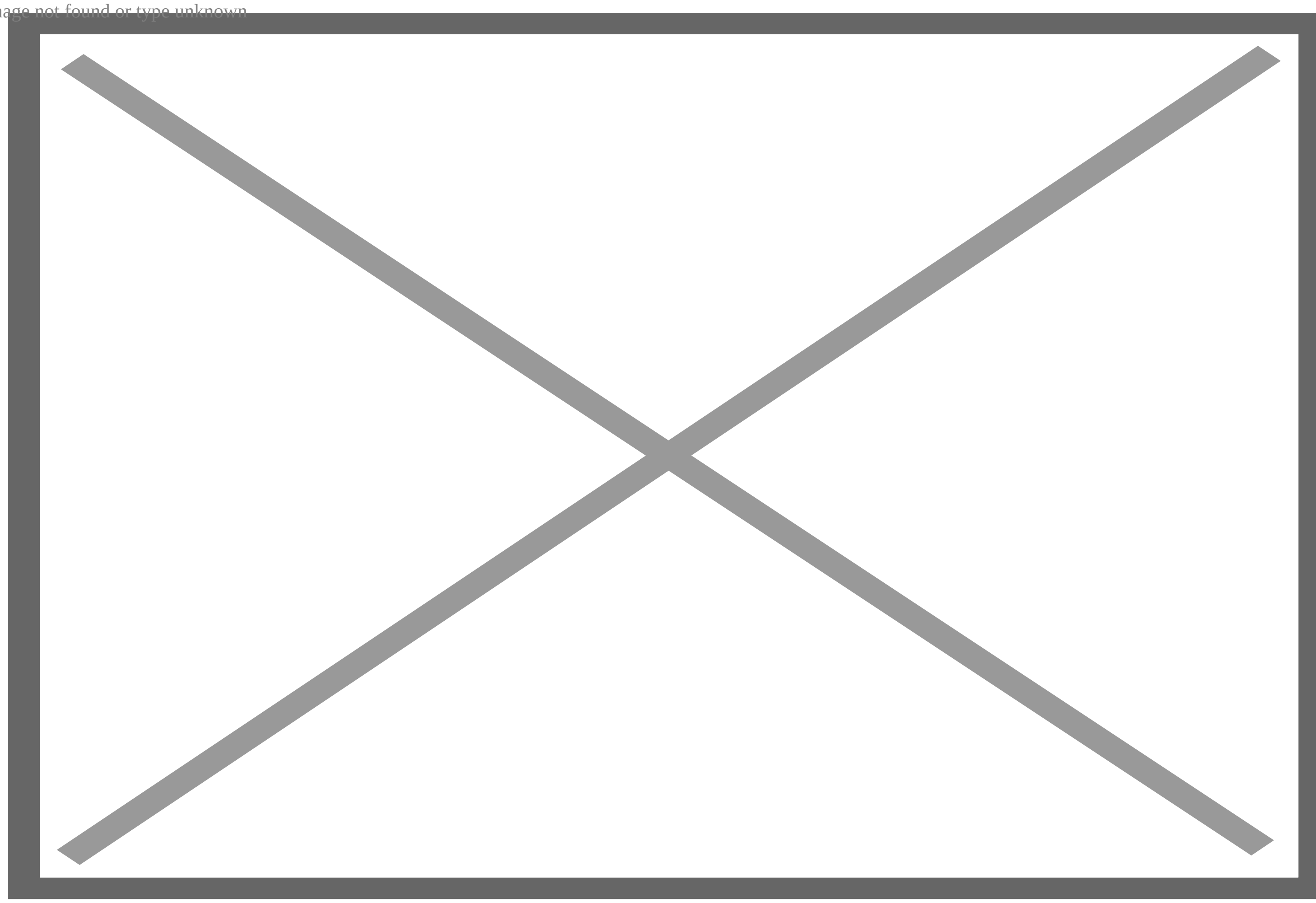
“There has never been another species that has so quickly changed the course of evolution,” says Sarah Otto, an evolutionary biologist at the University of British Columbia. “Darwin would be shocked!”

We can’t always know what causes a particular change, says Otto, whether it’s plasticity in action or the beginning of cladogenesis, where distinct sub-populations form. But there are enough examples where genetic change is involved to know that something deeper is going on.

“Swans that avoid cities have a genetic difference from the ones that are human-tolerant,” she says. And she points to the difference between UK-migrating blackcaps and birds that still migrate to Iberia as being “very clearly genetic”. “The young carry this difference,” she says. Changes like this are the first steps to the emergence of a new species. “The London Underground mosquitoes are an example where we might be forming a new niche and creating new opportunities for speciation,” Otto adds.

I asked her if we are narrowing the opportunities for species to evolve by interacting with their environments – 36% of the planet’s land surface is given over to agriculture, while urban environments around the world increasingly resemble one another. One study found that the mass of plastic is now greater than all living biomass. Biodiversity is haemorrhaging due to human activity, according to many analyses. “We are homogenising the planet in some ways,” she agrees. “On the other hand, we’re making these really extreme environmental shifts. Urban environments are entirely different from our agricultural environments.”

Image not found or type unknown



Migratory birds, such as these snow geese, are shifting routes in responses to urbanization. Credit: Nina Riggio

Highly polluted sites, like mine tailing ponds, represent other kinds of extremes. The common denominator is us. Accelerated evolution won't come close to counter-balancing the extinction crisis. But it will produce a world increasingly defined by those creatures and plants that can live alongside us. "Evolution is this incredible creative process and it's not going to stop," says Otto. "It will continue to produce variants that are better able to tolerate us."

Even microbes are subject to the same human pressures, in some cases fostering innovation, in others inhibiting it. Agricultural fertilisers can carry bacteria to new soil environments just as zebra mussels and other invasive organisms travelled in the ballast water of ships, says Otto. According to microbiologist Michael Gillings, the vast quantities of antibiotics flushed into the environment – up to 500 million copies everyday just from swine and dairy faeces – are akin to an invasive species, accelerating the basal rate of microbial evolution. At the same time, the homogenisation of the mammalian kingdom means more and more microbial biomass is composed of the gut microbes of the limited number of animals we like to either eat or live with.

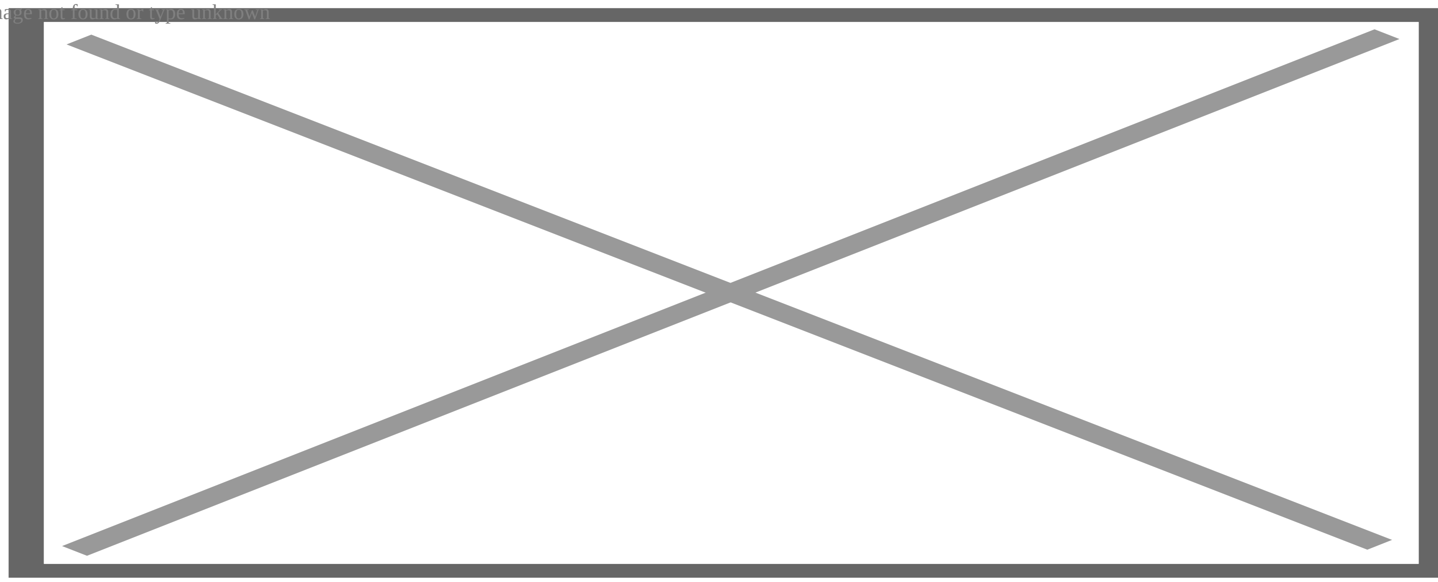
Naturalist and broadcaster Gillian Burke has spent a lifetime observing animal communities around the world. I asked her what kind of changes she's witnessed. "I would say everywhere and everything," Burke says. "Where I grew up in Kenya, I remember a landscape that looked very fluid, where land and water courses moved in tandem. From the air, you can see that's now become squares and straight lines."

Is it fair to say we've transformed the planet into a giant experiment in how species evolve? I asked. "To me, that language is important because it implies that we're running the experiment, but we are part of the experiment," says Burke. "Covid has been great at reminding us of that. We are the selection pressure that is driving the variants – the more it circulates, the more the virus mutates. A vaccine is a new innovation, but then the virus goes, 'OK, I'll just swerve and do something else'. We're in the experiment."

Most people would have noticed changes in animal behaviour during lockdown, she adds. Songbirds in urban areas have learned to sing louder to cope with traffic and other ambient noise. "But the first lockdown was the first time people actually got to experience that," she says. "People said, 'Oh it's quiet, now we can hear the birds'. But the birds can hear each other for the first time too!"

Animal behaviour is culture, according to Burke, and these cultures are evolving in response to human pressure. Elephants pass knowledge and information from generation to generation, including migration routes, she says. But this cultural inheritance is being altered as poachers and conflict zones encroach and climate change makes finding food and water more difficult. Other animal cultures are also in decline. The urban cacophony means some birds can't learn songs properly from their parents. Humpback whales are also vocal learners, with each population sharing a distinct song whose complexity evolves through contact with other pods. But marine noise from shipping is causing some to alter their songs or even fall silent.

Image not found or type unknown



Noise pollution in the oceans has caused many humpback whales to cease vocalization. Credit: NOAA

Culture has played a part in human evolution too. We have accelerated our own evolution by outsourcing it: as Gaia Vince explains in her book Transcendence, technology has allowed us to adopt new capabilities without changing our bodies. Shared culture has given us access to a collective mind, a vast store of information and insight.

Much of this innovation was borrowed from animals or sought to replicate what they could do. Stone tools imitated the cutting teeth of predators. The earliest technologies drew on living tissues such as animal skins and plant ligatures. Human societies have developed by borrowing from and learning to be like animals. Now – ironically, as so many species are forced to adapt to life on a human planet – the world we live in is increasingly modelled on the bodies and behaviours of other creatures.

“We are surrounded by genius,” says biologist Janine Benyus, who popularised the term biomimicry, “a new discipline that tries to learn from those geniuses”. Termite mounds have inspired more efficient air conditioning design. One of the world’s fastest trains achieves speeds of 186mph (299km/h) by mimicking the shape of kingfisher beaks. We have created finer surgical needles based on mosquito proboscis, black box recorders modelled on the shock-absorbing properties of woodpecker’s skulls, better wetsuits after sea otter pelts, and difficult-to-counterfeit banknotes that imitate the iridescence of butterfly wings.

Animal ingenuity also offers new ideas for tackling some of our most pressing environmental problems. Biomimicry can assist the production of renewable energy, from aerodynamic wind turbine blades that mimic the bumpy surfaces of humpback whale fins or the shape of hummingbird wings, to solar arraysthat track the Sun like sunflowers. Alternatives to concrete may imitate how corals build their structures by drawing minerals from seawater, 'growing' the cities of the future while also locking excess carbon in the foundations and fabrics of buildings. Natural filter feeders like oysters can help restore depleted marine habitats.

Even microbes can play a part. One bacteria, *Ideonella sakaiensis*, has evolved to metabolise polyethylene terephthalate (PET), while a common soil microbe, *Methylorubrum extorquens*, produce a protein which can bind americium and curium, two of the most hazardous and long-lived components of nuclear waste.

xenobots

Image not found or type unknown

Xenobots could be used to sustainably clear pollution. Credit: Fox News

Xenobots could also have a positive impact on the planet. The word robot derives from the Czech *robota*, which means forced labour, and subsequent generations of xenobots could be put to work cleaning up some of our mess. Biological robots could remove microplastics from the ocean or contaminants from polluted soil. Xenobots that carry a particular protein glow green under certain wavelengths, but turn red when exposed to others, "remembering" their exposure hours later.

"You could engineer them to sense particular chemicals, almost like a computer programme that says 'if you sense a toxic material, swim towards it, release a chemical that reacts with the toxin',” says Blackiston. The same properties could have medical applications, with xenobots performing non-intrusive treatments or seeking out disease.

In their current form, once the food stored in their cells is used up, the xenobots would simply perish. The prospect of them evolving ways to get energy from their environments is remote. “A skin biopsy can't survive by placing it in water,” Blackiston says. “It needs a very controlled cell culture environment. Likewise, frogs in nature often lose skin cells, and those cells don't go on to propagate or evolve ways to derive energy.”

Blackiston does, though see a future in which evolution takes some surprising turns. “We'll see humans and computers move increasingly towards designing living systems as we make advances in bioengineering, stem cell biology, and computational biology,” he says. It's critical that scientists conduct their research in public: “I'm hoping we'll see ethicists, lawyers, and community members be more involved in the design of the research, and not just comment on the technology once it's out of the lab and into the world.”

The new generation of xenobots bear witness to life's incredible plasticity. But for all their promise, they also remind us how often animals are forced to adapt their bodies to cope with a world dominated by us. It remains to be seen how many species can keep up with a rapidly changing planet. What is certain is that, as our unplanned, planet-wide experiment in the adaptability of living things gathers pace, animal invention is being tested like never before.

David Farrier is a journalist and director based in New Zealand. David can be found on Twitter @David_Farrier

A version of this article was originally posted at BBC and has been reposted here with permission. Find BBC on Twitter @BBC