SPECIAL ISSUE

NewScientist

WEEKLY March 3 - 9, 2012

THE *deep* FUTURE

A GUIDE TO HUMANITY'S NEXT 100,000 YEARS

Why we'll still be here

What we'll be like · What we'll speak · Where we'll live

What nature will be left · Why our resources won't run out

Which parts of the cosmos we'll explore

What our descendants w

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SPECIAL REPORT

THE DEEP FUTURE

In the 21st century, it can feel as if the future has already arrived. But we're only getting started.

It's fashionable to be pessimistic about our prospects, yet our species may very well endure for at least 100,000 years.

So what's in store for us? We now have the perspective to identify the forces and trends that have shaped humanity and the Earth to date. With this knowledge, we can make intelligent predictions about what is to come. Indeed, many groups are now attempting to extend humanity's horizons far beyond the next century, from the Long Now Foundation to those who say our presence is forging a new geological era.

Over the following pages, *New Scientist* tours the coming epoch, from the language we will speak to what our descendants will make of our trash.

The deep future is only just beginning...

REVENGE IS SWEET

Other worlds

From Michael Dowling

Further to calls to boost the Search for Extra Terrestrial Intelligence (SETI) which looks for artificial radio signals, so it can check exoplanets (11 February, p 28): it is reasonable to assume radio communication will eventually be superseded by a technically superior system.

If sentient alien species do exist, they are likely to be either far ahead of us technologically

or just taming fire – not at exactly the same stage as us. The odds of detecting an artificial radio signal would be slim.

Winnipeg, Manitoba, Canada

The editor writes:

■ SETI's Jill Tarter did describe a targeted search of appropriate exoplanets as a long shot.

Moral maze

From Rod Parker-Rees

You raised the moral puzzle of why most people would be prepared to redirect a runaway tram car onto a branch line where it would hit one person but avoid the five others it would have killed had it continued, but would not be prepared to push one person off a bridge to achieve the same objective (18 February, p 10).

The article doesn't mention one reason – how could we justify pushing someone off the bridge when we could achieve the same end by jumping off ourselves?

Exmouth, Devon, UK

The editor writes:

■ The trolley problem is posed in such a way that jumping does not do any good. You are presumed to be of normal weight, and not heavy enough to stop the tram, but the person you could push is hefty enough to do the job.

Bird brains

From Malcolm Moore

The photographs of bird nests by Sharon Beals raise questions beyond the genes of their builders (11 February, p 26). Weaver birds of Africa build huge condominiums of grass under which our ancestors may have sheltered. Perhaps they watched, fascinated, as other birds built with mud that hardened as it dried.

Did we learn to sew and weave, construct grass and mud huts, thatch and make bricks, from observing industrious birds? Do we owe our textile and ceramics technologies to the descendants of the dinosaurs?

Rotorua, Bay of Plenty, New Zealand

Been there

From Martin Trevelyan-Jones

In his letter (11 February, p 33), Bob Donaghy suggests the last car of a nonstop, high-speed train "breaking off" to become a tram and reach its destination. This is a variation on the "slip carriages" used in the past in the UK. In the 1950s I often had to sit in the last coach, as this was de-linked from the train and stopped at my station by a guard.

Old Colwyn, Conwy, UK

Full circle

From Gerald Legg

David Bowman makes a good case for introducing elephants to control invasive grass in Australia (11 February, p 29), but I presume more dung beetles would be needed to deal with the extra dung. Would additional species have to be introduced? How about some toads to control the beetles?

Hurstpierpoint, West Sussex, UK

Limited hiatus

From Brian Robinson

Jeff Dickens, responding to my letter about a hiatus in the quest for cosmological answers, missed the point (11 February, p 32). The science I question is to do with the massive expense of cosmology and probing for the secrets of the universe.

I did not advocate the removal of the point of science, but a particular point of it. There are more important things – cures for disease, hunger and poverty – than the pursuits of cosmology.

Brentwood, Essex, UK.

Sofa science

From Thomas Faulkner

Reading the discussion of game transfer phenomena (24/31 December 2011, p 76), in which player responses in video games can spill into real life, I must mention what I call the Sky+ effect. (Sky+ is a service in the UK that allows you to instantly rewind live TV using a hard-disc-based personal video recorder.)

One day I saw out of the corner of my eye something move past the window, but I was not quick enough to see what it was. Without thinking, I picked up my Sky+ remote and tried to rewind time.

Llanfair Caereinion, Powys, UK

First flight

From Philip Starr

I am sure your claim that the first uncontrolled steam-powered flight was achieved by Simon Langley in 1896 (4 February, p 3) will be challenged by others, but it was surely predated by John Stringfellow of Chard, UK, who flew a steam-powered aircraft

in a disused lace mill in 1848.

Chard, Somerset

The editor writes:

■ There are numerous claims, but Langley's 1-kilometre flight was the first by a substantially-sized aircraft of that type.

Long way round

From Terry Gibbons

The figures in the sidebar to your article on fuel wasted searching for a parking space (4 February, p 19) imply that the Earth has expanded 1000-fold to a circumference of 40 million kilometres and that the average American car does 24,000 miles to the imperial gallon. Good news!

Far Forest, Worcestershire, UK

The editor writes:

■ Sorry, we were out by a factor of 10^3.

For the record

■ In the story on how prions drive evolution in yeast (18 February, p 14), the mechanism described involves reading RNA in ribosomes, not DNA as stated in the text and the diagram.

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10,000 YEARS AGO
FIRST AGRICULTURE

A LIFE IN TIME

100,000 years is an unfathomably long time. Over the next few pages, discover just how many human lifetimes separate you from your descendants in the far future

80-year lifespan

5500 YEARS AGO
FIRST CITIES & CIVILISATIONS

YEAR 0

YOU ARE HERE

YEAR 3000

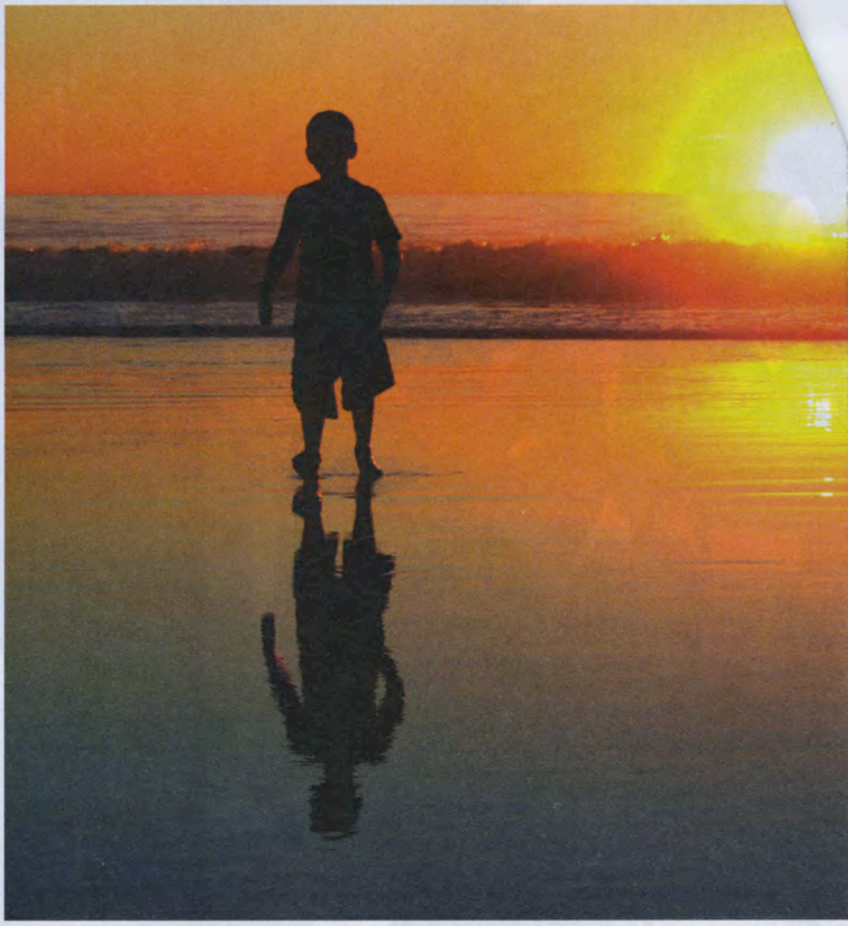
WHY WE'LL STILL BE HERE

WHAT are the odds we will avoid extinction? In 2008, researchers attending the Global Catastrophic Risk Conference in Oxford, UK, took part in an informal survey of what they thought were the risks to humanity. They gave humans only a 19 per cent chance of surviving until 2100. Yet when you look more closely, such extreme pessimism is unfounded. Not only will we survive to 2100, it's overwhelmingly likely that we'll survive for at least the next 100,000 years.

Take calculations by J. Richard Gott, an astrophysicist at Princeton University. Based on 200,000 years of human existence, he estimates we will likely last anywhere from another 5100 to 7.8 million years (*New Scientist*, 5 September 2007, p 51).

Fossil evidence is similarly reassuring. Records in the rocks suggest that the average species survival time for mammals is about a million years, though some species survive 10 times as long. It seems there is plenty of time left on our clock. Plus, if you'll excuse the blowing of our own trumpet, we are the cleverest of the mammals.

Mind you, this could be seen as a problem. Probably the greatest threat to an advanced civilisation is technology that runs out of control; nuclear weapons, bioengineering and nanotechnology have all been cited as bogeymen. But disaster expert Jared Diamond, a geographer at the University of California, Los Angeles, points out that we no longer live in isolated civilisations. Humanity is now a global network of civilisations, with unprecedented access to a diverse, hard-won pool of knowledge already being harnessed for everyone's protection.



ROBERTO CAUDILLO/PLAINPICTURE

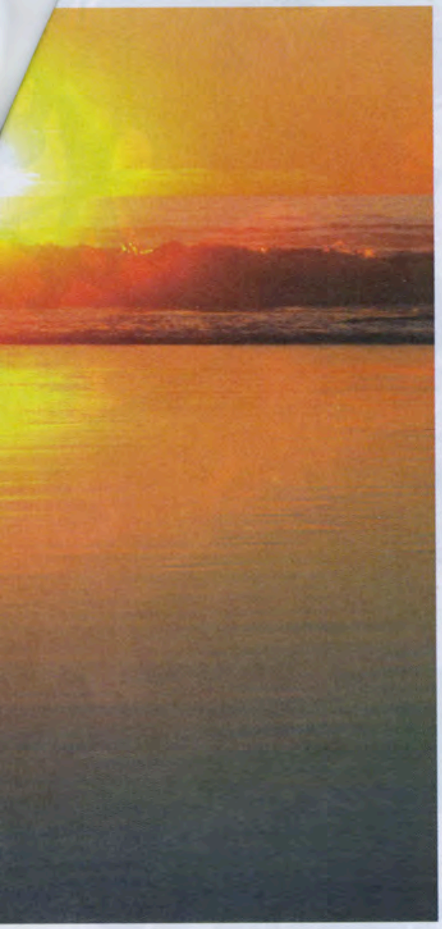
We are also unlikely to be extinguished by a killer virus pandemic. The worst pandemics occur when a new strain of flu virus spreads across the globe. In this scenario people have no immunity, leaving large populations exposed. Four such events have occurred in the last 100 years – the worst, the 1918 flu pandemic, killed less than 6 per cent of the world's population. More will come, but disease-led extinctions of an entire species only occur when the population is confined to a small area, such as an island. A severe outbreak will kill many millions but there is no compelling reason to think any future virus mutations will trigger our total demise.

More scary is the prospect of a supervolcano eruption. Every 50,000 years or so, a supervolcano somewhere erupts and ejects more than 1000 cubic kilometres of ash. Such events have been linked with crashes in human population. Around 74,000 years ago, Toba erupted in Sumatra.

Anthropologists have suggested that the event may have reduced the human population of Earth to just a few thousand (*New Scientist*, 17 April 2010, p 28). But as Bill McGuire, director of the Benfield Hazard Research Centre at University College London, points out, there were many fewer humans then and they were largely confined to the tropics, a geographical concentration that made the eruption's impact much more severe than would be the case with today's widely distributed population. "Wiping out 7 billion people today would be far more difficult," he says.

Judging by their historical frequency,

"A 400-metre asteroid impact would not be enough to destroy civilisation, but certainly an entire country the size of France"



it is estimated that the chance of a super-eruption in the next 100,000 years is between 10 and 20 per cent. With colossal clouds of ash plunging the surface of Earth into darkness for five or six years, global harvests would be badly hit for long enough to cause loss of life on an unprecedented scale. "The likely death toll would be in the billions," McGuire says. But it would have to happen twice in that timescale for a realistic chance of human extinction. That's not impossible, just statistically extremely unlikely.

Deep impact

The biggest extinction threats of all come from space. Solar flares, asteroid strikes and bursts of gamma rays from supernova explosions or collapsing stars are what we really need to get through. "Every 300 million years we would expect a gamma-ray burst or a severe supernova explosion that wipes out most of the ozone layer," says Brian Thomas, an expert on intergalactic hazards based at Washburn University in Topeka, Kansas. The result would be a massive increase in harmful radiation at the Earth's surface and an increased incidence of life-threatening cancers during the decades it would take for the ozone layer to recover. It's impossible to know when such an event might occur.

Yet these things are so rare that the chance of an extinction event in the next 100,000 years is effectively zero. The same can be said for the threat of a solar flare so powerful that it knocks out all critical infrastructure, because it would take flares 1000 times more powerful than the biggest ever seen. "Can our sun, in its present state, produce such a flare very occasionally? We don't know," says Mike Hapgood, a solar physicist based at the Rutherford Appleton Laboratory in Oxford, UK, and project manager for the European Space Agency's Space Weather Programme. But it remains an unlikely disaster scenario. Which leaves the poster child of disaster movies: the asteroid strike.

This one will take some luck to avoid. Space is full of rocky debris that acts as an occasional threat to Earth. It is widely believed that the impact of a 15-kilometre-wide asteroid wiped out the dinosaurs 65 million years ago. In any 100,000 year period we can reasonably expect an impact from a 400-metre asteroid that will cause damage equivalent to 10,000 megatonnes of TNT. "Not enough to do in the whole civilisation, but certainly destroy an entire small country like France," says former astronaut Thomas Jones, who co-chairs NASA's Task Force on Planetary Defence.

Some might argue that without France there is little hope for civilisation anyway, but in reality there is only a 1-in-5 chance of total wipeout. "Global effects come from an impact roughly every 500,000 years, so the odds are about 20 per cent for a catastrophic, civilisation-threatening impact within 100,000 years," Jones says.

We should probably work on some anti-asteroid measures, but really humans concerned about the longevity of our species can relax: the view from here is fine. Michael Brooks ■

YEAR 5000

YEAR 10,000

WHAT WILL WE BE LIKE?

THERE'S a famous thought experiment about kidnapping a Cro-Magnon man, bathing and shaving him, dressing him in a suit and putting him on the New York subway. Would anybody bat an eyelid?

Probably not. Though Cro-Magnons lived about 30,000 years ago, they were to all intents and purposes modern humans. Physically they were perhaps a little more robust, but behaviourally they were indistinguishable from us, give or take the effects of thousands of years of technological progress on our lives.

We have undoubtedly come a long way since then. A Cro-Magnon in 21st-century New York would recognise almost nothing except for other human beings. But his modern human brain would eventually adjust to the startling new surroundings, much as the Tierra del Fuego native who became known as "Jeremy Button" took to Victorian London after he was brought there in 1830 by Robert FitzRoy, captain of the Beagle.

Now turn that thought experiment on its head and project it into the deep future. What if somebody alive today could be transported to the equivalent of New York 30,000 years – or even 100,000 years – from now? Even if suitably attired, would they fit in?

Impossible to say, of course. Just because we've had more than 1000 generations of biological stasis does not mean we can expect thousands more. If you believe some futurists, we will eventually become cyborgs with prostheses in our brains and nanobots racing around our bloodstream.

Extreme as these technological enhancements may sound, they won't produce changes to our bodies and minds that will be heritable and so alter our fundamental biology. Each generation will have to choose whether or not to become cyborgs, just as people can opt for laser ›

YEAR 20,000

eye surgery today. For our descendants to be radically different from us, we would have to engineer our own genome or wait for an event that has happened only rarely in our evolutionary line.

YEAR 30,000

One hypothesis to explain the sudden rise in behaviourally modern humans 30,000 to 40,000 years ago is the random appearance of a beneficial genetic mutation, perhaps involved in language. So beneficial in fact, that the mutation swept through the population. Humans without it would have been unable to compete with their more fortunate fellows, and their less fit genomes would have been consigned to the scrap heap of evolution (*Evolutionary Anthropology*, vol 17, p 267).

The "great leap forward" mutation, if it ever existed, will probably never be identified as it has completely replaced the version of the gene that preceded it. But we can see signs of similar sweeps that are not yet complete. For example, a mutation in a gene called *microcephalin* arose around 14,000 years ago and is now carried by 70 per cent of people. It appears to be involved in brain development, though it is not clear what trait it is being selected for since there is no discernible difference between people who carry it and those who don't.

So it is possible that our descendants could evolve into something similar to *Homo sapiens* today. But radical change seems a long shot.

Of course, we could eventually decide to take evolution into our own hands. In principle, we could engineer ourselves into obsolescence by creating a new breed of human that would outcompete ourselves. The most plausible technology for starting down this road is to genetically engineer sperm or eggs, or early embryos, in order to install changes in their genomes that will

"It is doubtful that we would genetically engineer ourselves on a scale that would alter the course of human evolution"

be passed down the generations. This is just about possible with today's technology, and has been put forward as a way of stamping out genetic diseases such as cystic fibrosis.

Would we go so far as to put desirable traits in rather than just take bad ones out? Even if it were technically possible to do this, it is doubtful that we would collectively agree such changes on a scale that would alter the course of our evolution – unless, of course, engineered humans were so superior that they obliterated the competition.

These possibilities cannot be ruled out. Surely the most likely option is that our time traveller will find himself among friends, a species of human fundamentally the same as us but with cooler technology. Deep down, they will still be human.

Graham Lawton ■

WHAT WILL WE SPEAK?

SHOULD your descendants uncover this page, yellowed and curling, thousands of years from now, many of these words will be incomprehensible – even if they call themselves speakers of English. After all, we struggle to decipher old English texts like *Beowulf*. You might be able to understand the hero's declaration that "Béowulf is mín nama", but a millennium of language evolution has washed away the meaning from "grimma gaést Grendel" – the "ghastly demon Grendel".

If our language has transformed almost beyond recognition in just 1000 years, how might it sound in tens of thousands of years? Languages are largely shaped by the unpredictable whims of their speakers, but by examining the forces facing our language, we can speculate about how our descendants might speak.

The most obvious question is whether they will be using English at all. Although English is the world's lingua franca, its popularity largely hinges on the present economic importance of Anglophone countries. Should another country come to dominate world trade, our descendents may all be learning its language. If so, it's likely that they would begin to incorporate some of its terms into their own language – in the same way that Italians say that they will listen to a "podcast" on their "tablet" at the "weekend". But very popular languages tend to be resilient to invasion, so there's no reason to think that English will disappear entirely.

It's more likely that it will splinter and fragment. We can already see new dialects forming in many of the UK's former colonial territories, such as Singapore and Jamaica. Thanks to immigration, the internet and mass media, words from such dialects often feed back through the English-speaking world – as can be seen in Jamaican variations that are now sweeping through London slang, such as the use of "buff" to mean attractive, and "batty" to mean a person's bottom. Given enough time, these dialects might diverge entirely. If so, English may end up like Latin – dead, but survived by numerous offspring.

Do such grand transformations make it impossible to predict anything specific about future English? Certainly, the language is changing quickly enough as it is; the *Oxford English Dictionary* adds between 2000 and 2500 words each year, says its senior assistant editor Denny Hilton. But there may be thousands of new words that fail to catch the attention of the *OED*'s lexicographers. When Erez Lieberman Aiden and Jean-Baptiste Michel at Harvard University studied Google's corpus of digitised books from the last century, they found around 8500 new words entering the language every year. Many of these are rarely used – words like postcoarctation, reptating and subsectoral.

Use it or lose it

By looking at English's journey since *Beowulf*, we can at least identify trends that might continue. Its future grammar might lack some of the nuances that rule the sentences on this page, for instance. We've already lost many of the rules that governed the language of *Beowulf* – English nouns no longer have different genders, for instance.

Today, this ongoing simplification can be seen in the way we use the past tense. There are lots of irregular verbs whose past tenses do not have the more typical "-ed" ending – we say "left" rather than "leaved", for example. But time is slowly taming these irregular verbs, and the effect depends on how ›

"English is changing quickly. The *Oxford English Dictionary* adds between 2000 and 2500 words each year"

common these verbs are. By studying English texts from the last 1000 years, Lieberman Aiden and Michel noticed that the less a verb is used, the more likely it is to become regular. "If a word is rare, we don't always remember if it is irregular," says Lieberman Aiden – so we assume it follows the pattern of more familiar verbs.

"To wed", which is now used in only very specific contexts, is already in the throes of change. People are beginning to say they are "newly wedded" rather than "newly wed", for example. Others are more stubborn. Having found the way a word's popularity can influence its chances of linguistic change, Lieberman Aiden and Michel started to predict the future lifespan of certain irregular verbs. For instance, given its relative rarity, there is a 50 per cent chance that "slunk" will become "slinked" within 300 years (see diagram, below).

"To be" or "to have", which are used in around 1 in 10 sentences, have "half-lives" of nearly 40,000 years (*Nature*, vol 449, p 713). The researchers speculate that irregular plurals will follow a similar trend – "men" could become "mans", for example – though they haven't tested the idea yet.

In a similar way, we can predict which words will be ousted by new coinages or terms imported from another language. By examining linguistic evolution across the Indo-European languages, Mark Pagel at the University of Reading, UK, has found that this too depends on a word's frequency – the more common it is, the longer it lingers (*Nature*, vol 449, p 717). That's partly because we are less likely to use the wrong term if we hear the right term often enough.

In his forthcoming book, *Wired for Culture*, Pagel also argues that words have evolved to suit their purpose – if they are common and represent important concepts, they will be short and easy to say (see review, page 50). Such words are "highly fit", he says, using a Darwinian analogy. "It's difficult for a new word to dislodge them."

This can be seen in Beowulf's declaration. "Nama" clearly lingers as "name", a very common word then and now. Numbers, question-words and other simple nouns have similar staying power.

So, if your descendants do speak a form of English and happen to be reading this page, there's a chance they may find some meaning in simple sentences like "what is your name?" or "I drink water". There's a slim chance they might even comprehend "Hello from the year 2012". **David Robson** ■

Mind your language

English words often change their spelling and pronunciation over time, but some are replaced by another word that means the same thing. The shortest-lived words are also the least commonly used

YEAR 40,000

WHERE WILL WE LIVE?

ROGER RESSMEYER/GETTY

FISHING boats in the North Sea bring up some strange things in their nets, from the bones of mammoths to ancient stone tools and weapons. Here and in many other places around the world, we are discovering the remains of human settlements on what is now the seabed. As the world changed after the last ice age, many of our ancestors were forced to abandon their homes. And over the next 1000 years, let alone 100,000, the world is going to change dramatically again, forcing billions of people to find a new place to live.

Some places would battle to survive even if sea level remained constant. The ancient Egyptian city of Herakleion disappeared beneath the Mediterranean Sea 2000 years ago as the soft sands of the delta it was built on subsided, and the same is happening to modern cities such as New Orleans and Shanghai. In Miami and elsewhere, seas and rivers are eroding the land that cities are built on.

With a stable climate, it might be possible to save cities like these. But as the world continues to warm, rising sea levels are going to drown many of our coastal cities, along with much farmland. The changing ›

In 100,000 years' time Hawaii will have an extra island

LAND AHOY!

New lands will rise from the sea. It's time to start composing their national anthems

Throughout history, explorers have planted their flags on virgin lands. Today, there's almost nowhere left on Earth where we haven't set foot - but that won't always be the case.

Plate tectonics and volcanism are continually creating new land. For example, future settlers are likely to find Hawaii has an extra island. For more than 80 million years, a "hot spot" of rising magma from deep within the Earth has punched through the floor of the Pacific Ocean to build a series of islands on the crust moving over it. This means Hawaii's Big Island will soon get a baby brother off its south coast, formed by a submerged volcano called Lo'ihi. It is growing fast and should emerge within 100,000 years, depending on sea-level rise. Geologists expect that its peak will eventually tower above all others in the Hawaiian chain.

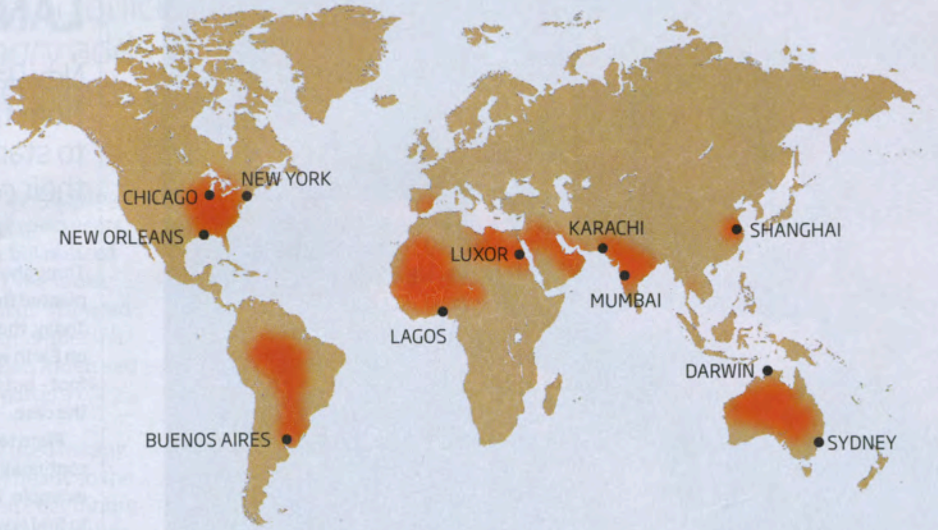
In the much longer term, Europe and Africa could also get swathes of new territory. That's because Africa is moving north-east by about 2.5 centimetres a year, gaining about a centimetre a year on Europe, which is moving in the same direction. In principle, this crunching could shut the Strait of Gibraltar within the next few million years. Without the inflow of Atlantic water, the Mediterranean Sea would eventually evaporate. Countries in southern Europe and on the north African coast would effectively expand across the newly exposed seabed until they join up.

If our descendants are still around millions of years from now, they may have to figure out how to divvy up whole new parts of the world. Jeff Hecht ■

YEAR 50,000

Beyond sweltering

If global temperatures rise 11 °C on average, large regions would experience heat and humidity not seen on Earth today, rendering them essentially uninhabitable



climate will also affect people living well above sea level, making some areas uninhabitable but creating new opportunities elsewhere.

We don't know exactly how much hotter the world will become. But let's suppose events follow the Intergovernmental Panel on Climate Change's "business as usual" scenario, with greenhouse emissions continuing to grow until 2100 and then declining rapidly. Suppose, too, that we do not attempt any kind of geoengineering.

The most likely result is that the average global temperature will rise nearly 4 °C above the pre-industrial level around the year 2100, peaking at 5 °C sometime in the 23rd century (though it might well get a lot hotter than this). It will stay hot, too, as it will take 3000 years or so for the planet to cool just 1 °C.

That might mean that the Greenland ice sheet will be almost gone in 1000 years, with the West Antarctic ice sheet following it into the sea, raising its level by well over 10 metres. That's bad news given that coastal regions are home to much of the world's population, including many rapidly growing megacities. As the sea level rises, billions of people will be displaced.

At least this will likely be a gradual process, though there may be occasional catastrophes when storm surges overcome flood defences. Large areas of Florida, the East and Gulf coasts of the US, the Netherlands and the UK will eventually be inundated. Some island nations will simply cease to exist and many of the world's greatest cities, including London, New York and Tokyo, will be partly or entirely lost beneath the waves.

And as the great ice sheet of East Antarctica slowly melts, the sea will rise even higher. For each 1 °C increase in temperature, sea level could eventually rise by 5 to 20 metres. So in 5000 years' time, the sea could be well over 40 metres higher than today.

Even those living well above sea level may be forced to move. Some regions, including parts of the southern US, may become too dry to support farming or large cities. In other areas, flooding may drive people out.

Any further warming will cause catastrophic problems. A 7 °C global rise will make some tropical regions so hot and humid that humans will not be able to survive without air conditioning. If the world warms by 11 °C, much of the eastern US, China, Australia and South America, and the entire Indian subcontinent, will become uninhabitable (see map, above).

Yet the future will open up alternative places to live. In the far north, what is now barren tundra and taiga could become fertile farmland. New land will also appear as the ice sheets melt.

A rush to exploit the resources in newly exposed bedrock in Antarctica, for instance, could encourage settlement in its coastal regions (see map, left). If it stays hot enough for long enough, Antarctica will once again be a lush green continent covered in forests. Elsewhere, pockets of fresh land will rise out of the ocean in the space of hundreds of thousands of years, perhaps ripe for human settlement (see "Land ahoy!", page 41).

At some point our descendants could take control of the global climate. But it will take thousands of years to restore the ice sheets and get sea levels back down. By the time we are in a position to do so, some people may like life just as it is. The proud citizens of the Republic of Antarctica will fight any measure that would lead to their farms and cities being crushed by ice.

Michael Le Page, Jeff Hecht ■

Polar potential

If the Antarctic ice sheet melts, the large expanse of land beneath could attract settlers from all nations

● Bedrock above sea level today

YEAR 60,000


We could cut our losses with some species and focus instead on creating new ecosystems

KEREN SU/GETTY

WILL THERE BE ANY NATURE LEFT?

ON THE face of it, the future of the natural world looks grim. Humans are causing a mass extinction that will be among the worst in Earth's history. Wilderness is being razed and we are filling the air, water and land with pollution.

The bottom line is that, barring a radical shift in human behaviour, our distant descendants will live in a world severely depleted of nature's wonders.

Biodiversity, in particular, will be hit hard. Assessments of the state of affairs make consistently depressing reading. Almost a fifth of vertebrates are classed as threatened, meaning there is a significant chance that those species will die out within 50 years.

The main cause is habitat destruction, but human-made climate change will be increasingly important. One much-discussed model estimates that between 15 and 37 per cent of species will be "committed to extinction" by 2050 (*Nature*, vol 427, p 145) as a result of warming.

"It will be a new world," says Kate Jones at the Institute of Zoology in London, UK. The ecosystem will become much simpler, dominated by a small number of widespread, populous species. Among animals that are "incompatible" with humans – we may like hunting them or colonising their habitat, for example – few will survive. "I don't have much hope for blue macaws, pandas, rhinos or tigers," Jones says.

Ultimately, though, life will recover: it always has. The mass extinctions of the past offer hints as to how the ecosystem will eventually bounce back, says Mike Benton at the University of Bristol, UK. The two that we know ›

"Animals like pigeons, rats and foxes already flourish alongside humans and may well become the founders of a new ecosystem"

most about are the end-Permian extinction 252 million years ago, which wiped out 80 per cent of species, and the less severe end-Cretaceous extinction 65 million years ago, which famously took out the dinosaurs. The Permian extinction is more relevant because it was caused by massive global warming, but Benton cautions that the world was very different then, so today's mass extinction will not play out in quite the same way.

Recoveries usually have two stages. If ours pans out in the same way, the first 2 to 3 million years will be dominated by fast-reproducing, short-lived "disaster taxa". These will rapidly give rise to new species and bring the world's species count back up (*Proceedings of the Royal Society B*, vol 275, p 759).

YEAR 70,000

But a lot of things will still be missing. Ecosystems will be simple, with similar species doing similar things. Herbivores will be less diverse, and top predators may be absent altogether in many places.

That's where longer-lived, slower-evolving species come in to restore the full complexity of the ecosystem. But this can take up to 10 million years, much longer than even the most optimistic projections of the human future (*Proceedings of the National Academy of Sciences*, vol 105, p 11536).

It doesn't have to be like that. We can take action now to get the recovery going, although we don't know how much we can accelerate it.

Conservation biologists are increasingly thinking the unthinkable, such as relocating species to places where they can thrive while abandoning them to their fate in their native ranges.

That may seem unnatural, but given that human influence has already touched almost every ecosystem on Earth, is "natural" even a useful concept any more?

Even more radically, we might be better off encouraging the formation of new species and ecosystems rather than struggling to save existing species that have no long-term future, like pandas. "There's no way I'd want to get rid of them," says Jones, "but things do change and adapt and die."

Benton says the most important thing is to rebuild biodiversity hotspots such as rainforests and coral reefs. That needn't be a gargantuan task. A recent analysis suggests that damaged wetlands can be restored within two human generations (*PLoS Biology*, vol 10, p e1001248).

Beyond that it may be possible to start "evolutionary engineering". For instance we could divide a species into two separate habitats and leave them to evolve separately, or introduce "founder" species into newly rebuilt ecosystems.

Nature may solve the problem for us by providing founder species from an unexpected source. Animals such as pigeons, rats and foxes are already flourishing alongside humans and may well give rise to new species, becoming the founders of the new ecosystem.

If you are disturbed by the prospect of a world colonised by armies of rapidly evolving rats and pigeons, look away now. **Michael Marshall**

REVENGE IS SWEET

WHERE IN THE COSMOS WILL WE EXPLORE?

IT IS an inescapable fact. The destinations we can visit in outer space will always be limited by the technical challenges of travelling the unimaginable distances involved, especially within a human lifespan. Still, that will not be the only factor shaping where our descendants go. The route that they take into the cosmos will be equally driven by age-old human motivations – and perhaps even a dash of religious fervour.

First, the bad news. Last year, a group of scientists, engineers and futurists assembled in Orlando, Florida, to plot humanity's next era of exploration. The name of the plan was the 100 Year Starship Study. The idea was to begin to work out, over the next century, how to get humans to the nearest stars. You can't fault the idea for ambition, but many of them soon realised that developing the necessary technology was daunting, if not fanciful.

Neal Pellis of the Universities Space Research Association based in Columbia, Maryland, summed up just how far our fastest spacecraft are from achieving interstellar travel. "The nearest star is Alpha Centauri," he told the 100 Year Starship meeting's participants. "At 25,000 miles per hour, it would take 115,000 years to get there. So this is not a plan."

Even if we figure out how to travel at the speeds required to arrive at a star in a human lifetime, the energy required to get there is far beyond our means for the foreseeable future. Mark Millis of the Tau Zero Foundation, a space-travel think tank based in Fairview Park, Ohio, says only a tiny proportion of today's global energy output goes towards space flight. If this state of affairs persists while energy production continues to grow at the rate of recent decades, then interstellar missions are at least two to five centuries away, he calculates (arxiv.org/abs/1101.1066).

For the next few centuries, then, if not thousands of years hence, humanity will be largely confined to the solar system. Even reaching destinations closer to home will remain slow going until we find better propulsion systems than chemical rockets, which are like Columbus's ships in terms of speed and technology, says NASA planetary scientist Chris McKay.

Assuming we achieve the speed boost we need, what routes might we take further into space, and what will drive exploration? Scientists will no doubt continue to send uncrewed probes all over the solar system, but if history is any guide, human exploration and settlement of space will not be driven by scientific curiosity alone.

Roger Launius, NASA's former chief historian, now senior curator at the Smithsonian National Air and Space Museum in Washington DC, says that whenever people have ventured into unexplored corners of Earth, their motivation has tended to be "God, gold or glory" – in other words, a drive to convert indigenous peoples or escape religious persecution, or to extract wealth or earn fame.

In search of glory

Much of human space exploration to date has arguably been motivated by glory. National pride was behind the first crewed space missions and fuelled the colossal investment required to put people on the moon. Political will of the same order will be needed to realise the first Mars walk or human visit to an asteroid.

Further down the track, nations or companies may want to be the first to ›

"Whenever people have ventured into unexplored corners, their motivation has tended to be 'God, gold or glory'" send astronauts to rocky worlds like Saturn's moon Titan, which sports polar lakes of liquid methane. Another tempting expedition would be to Jupiter's moon Europa – especially if the liquid ocean under its surface ice turns out to be home to extreme life forms.

YEAR 80,000

What about God? Could religious motivation play a role in space travel? Future solar-system explorers will have no local aliens to convert, but religion could conceivably be a reason to flee Earth. In the 17th century, for example, English Puritans risked their lives to settle in America for the sake of practising their beliefs. If the private spaceflight industry provides the means, it's not impossible that a religious group might be among the first to populate the moon or a Mars base.

Nevertheless, the dominant drivers of exploration in our history have been economic ones, Launius says. For a space economy, mining asteroids has been proposed, as has space tourism, but neither's time has come yet. "We have yet to find an economic motive to undertake space activities that would involve humans," Launius says. For example, it's impossible to predict what mineral resources will be important to us mere decades from now (see "Will we run out of resources?", right). By the time it becomes viable to mine, say, platinum from asteroids, humanity's demand for that metal may have faded.

Another lesson of history is that exploration has not always been sustained. Instead, it often happens in fits and starts. Consider how the Vikings ventured into North America a thousand years ago, yet permanent European settlement did not follow for another four centuries. Chinese exploration also went on for centuries but ceased by 1500 or thereabouts.

"There's nothing inevitable about space travel," says John Logsdon, a space-policy researcher at George Washington University in Washington DC. He suggests that subsequent generations may take a break from exploring deep space or even venturing beyond Earth.

Indeed, our descendants may well have to come to terms with never having the means or lifespan to reach other stars. For them, the stars will remain tantalising twinkles of light, forever beyond reach.

YEAR 90,000

Then again, there will always be people, like the delegates to the 100 Year Starship meeting, who will work to keep the dream alive. **Anne-Marie Corley** ■

WILL WE RUN OUT OF RESOURCES?

IN 1924, a young mining engineer named Ira Joralemon made an impassioned address to the Commonwealth Club of California. "The age of electricity and of copper will be short," he said. "At the intense rate of production that must come, the copper supply of the world will last hardly a score of years... Our civilisation based on electrical power will dwindle and die."

Copper – and civilisation – are still here. Yet almost a century on from Joralemon's warning, similar wake-up calls can still be heard. The price of copper has surged to a series of all-time highs on the back of increased demand from China. "Peak copper" is upon us, say some; reserves will run out within a couple of decades, say others.

Such prophecies of doom overlook something important. For most of our history, the way technology has developed has been determined by the materials available: think Stone Age, Bronze Age, Iron Age. But while we might label our era the Silicon Age – or perhaps more pertinently, the

IAN TEH/PANOS PICTURES

What we mine for today may cease to be useful in the deep future

Hydrocarbon Age – we are not one-trick ponies any more. These days the rapid pace of technological development is more likely to change the materials we rely on.

The *Engineering and Mining Journal-Press* drove home the point in a prescient editorial response to Joralemon's warning. "We can hardly believe that all our electricity will go back to the clouds where Franklin found it, just because copper is scarce," it said. "Maybe copper won't be required at all for transmission purposes; we may just use the ether." And indeed we do, for long-distance communications that once required large quantities of wire. We also take full advantage of optical fibres, a technology whose widespread use was hardly imagined back in the 1920s.

That makes second-guessing tomorrow's materials landscape foolhardy over timescales of mere decades, let alone millennia. "Within 50 or 60 years we will have made so much progress that it's almost like hitting a big brick wall making any predictions beyond that," says Ian Pearson of Futurizon, a consultancy specialising in future technologies.

The rare-earth metals are a case in point. Shortages of these elements, whose applications range from touchscreens to batteries and energy-efficient light bulbs, are widely predicted within the next decade or so. Much beyond that, though, and it seems implausible to argue that we won't have innovated our way around supply bottlenecks.

"It's fashionable to talk about a shortage of neodymium for magnets in wind turbines, for example," says Pearson, "but the fundamental problem is not neodymium. It is how we extract energy efficiently from wind." No doubt there are as yet undreamed-of ways to do that without building turbines. In the longer term, other innovations may render the whole idea of wind energy passé.

Whatever problems we do face in the deep future, Pearson reckons a shortage of materials is unlikely to be one of them. "Regardless of what humanity is like in 500 or 1000 years' time, we will probably still be filling only 10, maybe 15 metres of air above ground with stuff," he says. "But there's 6000 kilometres of ground with stuff in it beneath us." It's also plausible that it will become technologically and economically viable to mine nearby asteroids for elements we may be running short of.

Recycle the atoms

To ensure the continued survival of our species, it makes sense that we should husband the resources of Earth and its environs, rather than plunder them. Technology could make that easier. Whenever we use stuff, we hardly ever export the constituent atoms and molecules beyond the Earth system; we merely rearrange them chemically, for example converting carbon locked in fossil fuels into carbon dioxide. At present, we are not particularly good at converting our waste products into something useful. But given a few more decades, things could look very different thanks to new methods for nanoscale material manipulation, as well as genetically engineered bacteria that would eat waste up and burp it out in other forms.

By then things will probably be out of our hands anyway, says Ray Hammond, an independent futurology consultant. At some point, we will create computers far more capable than ourselves. "What these machines may be able to suggest to us in the way of resource management or in the construction of synthetic resources is wholly unknowable," he says.

That suggests we should be worrying about other existential threats in the deep future. "The idea that 'things will run out' is to think about the future using today's concepts," Hammond says. **Richard Webb** ■

WHAT WILL OUR DESCENDANTS KNOW ABOUT US?

WHEN humans in the far future are piecing together a picture of the primitive civilisation of 2012, archaeology will surely be the best way to go about it. After all, the best libraries, archives and museums can be undone by a single fire, amply illustrated by the fate of the library of Alexandria.

So what will archaeologists working 100,000 years from now discover about us? Only the luckiest of artefacts will avoid being crushed, scattered, recycled or decomposed. You, personally, will almost certainly leave nothing behind that survives that long. To get a sense of why, just point time's arrow the same distance in the opposite direction. Around 100,000 years ago, anatomically modern humans were just emerging from Africa to populate the world. Most of what we know about them is guesswork, because the only clues that remain are sharp stone tools and a handful of fossils.

You are especially unlikely to leave your bones behind. Fossilisation is an exceedingly rare event, especially for terrestrial animals like us – though with 7 billion people on the planet, at least a few of us will no doubt achieve lasting fame.

Luckiest – and rarest – will be the "instant fossils". These form when people or animals die in calcium-rich seasonal ponds and wetlands, or in caves. In both situations, bones can mineralise quickly enough for fossilisation to win the race against decomposition, says Kay Behrensmeyer, a palaeobiologist with the US National Museum of Natural History in Washington DC. One wildebeest toe-bone in southern Kenya soaked up calcium carbonate so quickly that it began to turn to stone within two years of death.

Future fossil hunters won't be looking for us in graveyards since bodies buried there crumble into dust within a few centuries. Instead, the richest human bonebeds will likely be found in the debris of catastrophic events, such as volcanic ash or the fine sediments left by the recent tsunamis in Asia, Behrensmeyer says. A few bodies might be mummified in peat bogs or high deserts, but they will decay if conditions change, as is likely over a span of 100,000 years.

Those same changes will also lay waste to other important clues to our civilisation: our homes. Climate change and rising sea levels are likely to drown coastal cities such as New Orleans and Amsterdam (see "Where will we live?", page 40). In these cases, waves will probably destroy the parts of buildings above ground, and basements and pilings will soon be buried by sediments. While concrete may dissolve over the millennia, archaeologists will recognise the precise rectangular patterns of sand and gravel that remain as a sign of purposeful design. "There is nothing at all in nature like the patterns we make," says Jan Zalasiewicz, a geologist at the University of Leicester, UK.

Building our own geology

Nowhere will these designs be more unmistakable than in our biggest structures. A few human artefacts, such as open-pit mines, are essentially geological features already, and will last for hundreds of thousands of years as testimony to our earth-moving powers. Our largest dams, such as the Hoover dam in the US and China's Three Gorges dam, contain such an immense volume of concrete that some pieces will certainly survive that long, too, says Alexander Rose, executive director of The Long Now Foundation, based in San Francisco, California. A few structures – most notably the Onkalo nuclear-waste repository in Olkiluoto, Finland – are even being engineered to survive intact for 100,000 years.

We have also been busy building another massive legacy that will be the real bumper crop for future archaeologists: our garbage. The landfill sites where most of our goods eventually end up are almost ideal places for long-term preservation. When full, modern landfills are typically sealed with an impermeable layer of clay, so that the contents quickly become devoid of oxygen, the biggest enemy of preservation. "I think it's fair to say that these sites will remain anaerobic over geological time," says Morton Barlaz at North Carolina State University in Raleigh. Under such conditions, even some organic materials such as natural fabrics and wood are likely to avoid

LOWLY GRAIL

They say diamonds last forever, but you might not expect that alongside those sparkly gems, a future museum may well be showcasing our polystyrene coffee cups.

That's because the petroleum-derived pellets of polystyrene cannot be biodegraded by any known microorganism. This stuff could last a million years.

Having said that, in the wild the cups will likely crumble into unrecognisable lumps. And if recent efforts to engineer fungi that can decompose polystyrene succeed, not even these will survive. But protected in a landfill and undisturbed for millennia, the cups could retain their shape sufficiently to allow future archaeologists to deduce what we used them for.

REVENGE IS SWEET

YEAR 100,000

decomposition – though over the millennia they will gradually transform into something resembling peat or soft coal, says landfill expert Jean Bogner of the University of Illinois at Chicago.

A few materials will be preserved just as they are. We don't make much from stone any more, but a few statues might survive, buried safely away from erosion. Ceramic plates and coffee mugs should last indefinitely, too, just as the potsherds of early human civilisations have. Some metals, such as iron, will corrode quickly, but titanium, stainless steel, gold and others will last much longer. King Tut's gold, after all, looks almost unchanged after 5000 years. "There's no reason to think that wouldn't be the same after 100,000 years," says Rose. Indeed, titanium laptop cases, their insides long since corroded, may end up as one of our civilisation's most lasting artefacts. Who knows – scholars of the future may construct elaborate theories about our religious practices based on these hollow tablets and the apple-shaped figure etched into their surface.

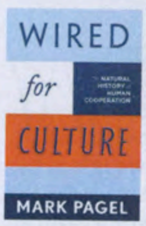
The fact is that no matter how much we may try to preserve a legacy for future generations, we can never know which aspects of our civilisation will interest our descendants. Today, for example, our study of early humans is informed by Darwin's theories, a perspective that was inconceivable only a century ago. Even if the objects in our museums survive, they will only tell future generations what we thought of ourselves. What they will think of us is something no one reading these words today can fathom. **Bob Holmes** ■

"Future scholars may base theories of our religious practices on the odd, hollow tablets with the apple-shaped etchings"

Culture for survival

Nature or nurture? The middle ground between evolution and culture in shaping humanity is bumpy to navigate, finds **David Sloan Wilson**

Wired for Culture by Mark Pagel, Allen Lane/W. W. Norton, £25/$29.95



FOR decades, proponents of the power of culture in human development have been tribal enemies of those who champion the power of evolution. The former have been vilified for portraying humans as blank slates; the latter scorned for embracing genetic determinism. The middle ground was no-man's-land.

Now, at last, the war might be over. A consensus is emerging that humans have an impressive capacity for open-ended change, much as culturalists have claimed, but that this is a result of genetic evolution – and is itself an evolutionary process. Culture can now be approached from an evolutionary perspective, while evolutionists have much to learn from the "natural historians" of cultures.

Marc Pagel, a professor of evolutionary biology at the University of Reading, UK, is well placed to write on these recent developments. In *Wired for Culture* he frames cultural development in the language of Richard Dawkins's selfish gene theory, in which genes are replicators that build individual bodies as vehicles for their own survival. Dawkins famously coined the term "meme" as the cultural analogue of a gene. Pagel's argument goes one step further.

Memes, he says, have built vehicles around themselves made up of groups of people. We live inside "cultural survival vehicles" that allow us to collectively survive and reproduce in any given environment. Pagel argues that there are thousands of such vehicles, each adapted to different environments, exemplified by humanity's wealth of languages. Genetically we remain a single species, but culturally we are worlds apart, comparable to dinosaurs, birds and mammals.

Wired for Culture explores the implications of the emerging consensus across the breadth of human experience, from religion, the arts and economics, through consciousness, deception, conflict and the very idea of truth.

Pagel writes well, and the ideas within the book are engagingly expressed. But in a book which overcomes the traditional separation between evolutionists and culturalists, Pagel has difficulty surmounting tribal boundaries within his own field.

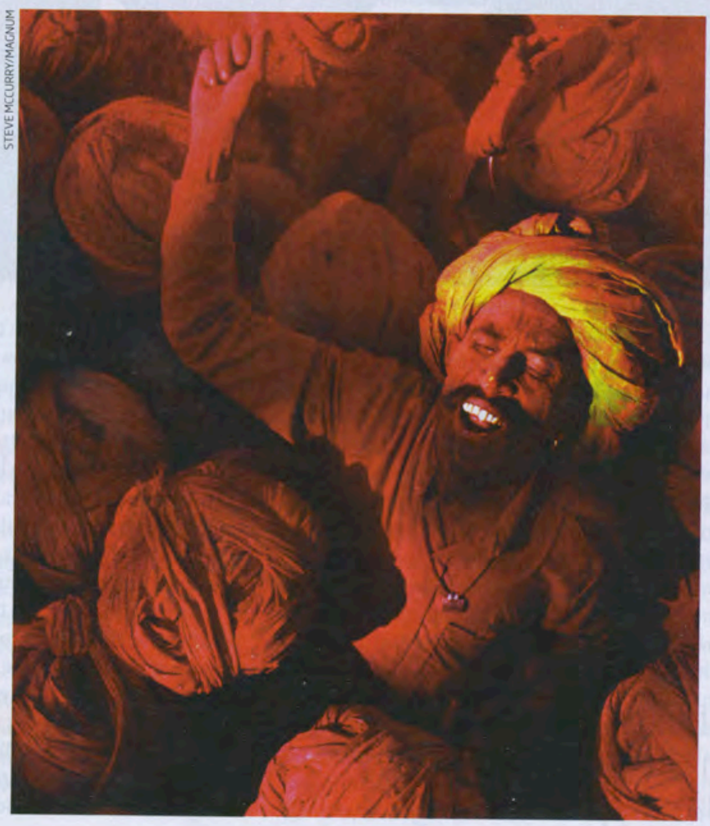
Evolutionary biologists are divided on the subject of group selection – the view that adaptations can evolve "for the good of the group". Acceptance of group selection in the context of selfish gene theory hinges on the question of whether groups can be vehicles of selection. Dawkins and other selfish gene theorists such as Daniel Dennett are sceptical about this possibility, and their scepticism extends to ideas about culture and religion. Indeed, both have famously argued that religious memes are like parasites that are detrimental to their human "hosts".

"Genetically we are a single species, but culturally we are worlds apart, like birds, dinosaurs and mammals"

Pagel departs from Dawkins and Dennett by portraying cultures as group-level survival vehicles, correctly in my opinion, but seems to think that in employing the language of selfish gene theory he is rejecting group selection. This is a failure of translation. When he makes statements such as: "Any group that failed to acquire these cultural forms could find themselves in competition with others that had", he is invoking group selection, pure and simple.

This is an issue for everyone: books like *The Selfish Gene* had a huge impact because they brought issues like group selection into the public realm. Much of the work Pagel cites openly acknowledges the role of group selection in the evolution of human society, and to deny its importance is a disservice to public understanding. It is a pity that Pagel, whose speciality is the evolution of languages, cannot seem to translate among the languages spoken within his own discipline. ■

STEVE MCCURRY/MAGNUM



Do we use religion as a means to survive and reproduce?

David Sloan Wilson is a distinguished professor of biological sciences and anthropology at Binghamton University, New York. His latest book is *The Neighborhood Project: Using evolution to improve my city, one block at a time* (Little, Brown)