107 COSMOS THE SCIENCE OF EVERYTHING

COSMOS

THE SCIENCE OF EVERYTHING

ISSUE 107

Resilience

Staying strong, bouncing back

CLIMATE GRIEF
Caring for ourselves and the planet

FUTURE HUMANS
A changing species for a changing planet

AUSTRALIAN AGRIVOLTAICS
Sheep and solar share the paddock

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CSIRO PUBLISHING

Closing one chapter, opening another

A message to our readers about the future of *Cosmos*

After nearly two decades of sharing the wonders of science with you, we've made the difficult decision to cease production of *Cosmos* magazine. This edition will be our final print issue.

While this marks the end of one chapter, our commitment to science storytelling continues. *Cosmos* will remain online at cosmosmagazine.com,

and later this year, our digital content will become part of CSIRO Publishing's new home for trusted science. This platform will bring together peer-reviewed journals, e-books, and fact-based science news — uniting our readers, researchers, and science enthusiasts in one sustainable, forward-looking space. A dedicated news team will continue to cover the latest scientific discoveries and share conversations with the brilliant minds behind them.

To stay connected and informed about what's ahead, we encourage you to sign up for the *Cosmos* newsletters and follow us online.

To our cherished readers, contributors, and staff — thank you. Your curiosity, support, and passion for science have shaped *Cosmos* into something truly special. We're deeply grateful for the journey we've shared and look forward to continuing it with you in new ways.

— The Cosmos Team

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LYNNE JENKINS AND AUSTRALIAN OPAL CENTRE/ XPACIFICA / GETTY IMAGES

The cover of *Cosmos* 1, July 2005.

From the Editor in Chief

***Cosmos Magazine* was founded** 20 years ago this month, and after 107 editions, it's being closed.

It was started by Kylie Ahern and Wilson de Silva with financial support from one of Australia's best known scientists, Professor Alan Finkel, who with his wife Elizabeth, nurtured it for most of its life.

Wilson says they wanted to create a "wise travelling companion and a long conversation." Kylie says they also wanted to shine a light on Australian science: "because while science itself is global, without local coverage of their work – which was at the time sparse – scientist's funding, profile and careers were impacted negatively." Many scientists who are well-known today can trace their public profiles back to coverage in COSMOS.

Alan says: "The vision was to produce an Australian magazine covering the latest science, presented as a feast for the aesthetic and the intellect. And we delivered! A glorious magazine that our subscribers loved and of which all of us were proud. I salute and thank all the editors, journalists, artists and other contributors and staff who made it possible."

Today we put the final magazine to bed.

In 2024 CSIRO, Australia's national science agency, took over the Cosmos brand (print, digital and education) and has worked hard to find sustainable solutions to this financial dilemma. It has decided to support a digital solution.

CSIRO Publishing, an editorially independent unit of CSIRO, best known for publishing books and journals, will support original science news and features on a new website to be unveiled later this year – it will be informed by the proud history of *Cosmos Magazine*.

The long conversation can go on.

IAN MANNIX

ACKNOWLEDGEMENT

Cosmos acknowledges the Traditional Owners of the lands that we live and work on across Australia and pays its respect to Elders past and present. *Cosmos* recognises that Aboriginal and Torres Strait Islander Peoples have made and will continue to make extraordinary contributions to all aspects of Australian life, including culture, economy and science. *Cosmos* is committed to reconciliation and demonstrating respect for Indigenous knowledge and science. The use of Western science in this publication should not be interpreted as diminishing the knowledge of plants, animals and the environment from Indigenous ecological knowledge systems.

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From the Editor

Welcome to our resilience issue!

Resilience is one of those jargon words that means many things to many different people. To a materials scientist, it's how much energy something can take and still bounce back to the same shape. To a psychologist, it's the ability to cope mentally and emotionally to a crisis – to bounce back, as it were.

When I hear the word resilience, I tend to think in terms of systems. Ecosystems, social systems, economic systems, all have a measure of resilience, a way to maintain their character and identity during changing circumstances. But all resilient systems have their limits. There's no way back for an extinct species.

Not all resilience is good. Cycles of poverty and under-privilege are self-sustaining and extremely hard to beat. Viewing these problems through a systemic lens can highlight why they're so hard to break, and give clues on which actions might lead to long-term progress.

And although it's an extremely useful concept, many experts shy away from using the word resilience when communicating their science. When politicians and policy-makers use the term, there's often cuts to be made from a budget. And that connotation makes resilience a thorny concept to communicate.

In these pages you'll discover systems at the edge of their resilience and others that are stubbornly sturdy. You'll learn how environmental scientists build emotional resilience, and tips on defeating the resilient forces opposing climate action.

There are stories about how certain jobs remain resilient through changes in society, and how the human species could remain resilient through an unprecedented climate catastrophe. And how we're building resilience in our health system to combat the rising resilience of bacteria to our antibiotics.

Stay strong, and bend, don't break. I hope you enjoy this last issue of *Cosmos*.

DAVID SHAW

› Science news from around the globe (and beyond)

DIGEST

A fossilised feather preserved in volcanic rock.

EDOARDO TERRANOVA

PALAEONTOLOGY

Fossil feathers found in volcanic rock

The finding reveals a new mode of tissue preservation.

PALAEONTOLOGISTS have discovered that volcanic deposits can turn the microscopic details of animal tissues into minerals – the first time this type of preservation has ever been seen.

"The fossil record is continually surprising us, be it new fossil species, strange new body shapes, or in this case, new styles of fossil preservation," says Maria McNamara from University College Cork in Ireland, who is co-author of the new study in *Geology*.

"We never expected to find delicate tissues such as feathers preserved in a volcanic rock."

The team analysed a fossilised vulture that had been buried in ash-rich volcanic sediment 30,000 years ago, in central Italy. The vulture's body was quickly converted into minerals before the soft parts could decay away.

The specimen was initially unearthed in 1889 by a local landowner, who recognised that it had been exquisitely preserved, including fine details of its eyelids and wing feathers.

Now, the new analysis – led by Valentina Rossi, a palaeobiologist also at the University College Cork – has revealed even finer details.

"When analysing the fossil vulture plumage, we found ourselves in uncharted territory," says Rossi. "These feathers are nothing like what we usually see in other fossils."

Fossil feathers are usually preserved as impressions in lake or marine sediments, or are captured in 3D in amber. They are rarely mineralised. However, Rossi and team found that when the vulture was buried in volcanic material, its feathers were rapidly replaced by a mineral called zeolite – possibly within a few days. The researchers believe that the passage of water through the volcanic ash precipitated the formation of the zeolite nanocrystals. These replicated extremely small details, right down to the microscopic feather pigment structures.

> "We never expected to find delicate tissues such as feathers preserved in a volcanic rock.

"We used to think that volcanic deposits are associated with hot, fast-moving pyroclastic currents that will destroy soft tissues," says co-author Dawid A. Iurino, from the University of Milan. "However, these geological settings are complex and can include low temperature deposits that can preserve soft tissues at the cellular level."

Zeolites are rich in aluminium and silicon, and are commonly formed in volcanic settings. But it is abnormal for them to preserve animal soft tissue.

Palaeontologist John Paterson, who was not involved in the research, says, "There are all kinds of ways that soft tissues can be preserved in fossils, but this is a really unique find."

Discovering this way of preserving soft tissue may now direct palaeontologists towards volcanic deposits.

TECHNOLOGY

World first commercial bio-computer

CORTICAL LABS has launched CL1 – the world's first commercially available computer based on neurons grown from human stem cells.

The technology is based on fusing lab-grown cells with hard silicon. The goal is to create a new form of AI called Synthetic Biological Intelligence (or SBI).

SBI promises to be able to grow, adapt and learn faster than AI based on standard silicon computer chips. It also requires far less energy – a 30-unit rack of CL1 uses 850–1,000 watts of energy. By comparison, it's estimated that training a large language model like GPT-3 uses a little less than 1,300 megawatt hours of electricity – roughly equivalent to the annual usage of 130 US homes.

Hon Weng Chong, founder and CEO of Cortical Labs, says their goal is to make the biological computer accessible to researchers without specialised hardware and software.

"It's the foundation for the next stage of innovation. The real impact and the real implications will come from every researcher," says Chong.

CLIMATE

Forget sand, ancient Arabia was wet

It has implications for climate resilience in the region.

IN THE NOT VERY DISTANT past, the Arabian Peninsula was likely a savannah, with wolves, lions and leopards.

That's the conclusion from new research into ancient rainfall patterns in Arabia going back thousands of years, which reveals the region was much wetter than today.

The findings raise questions about the region's preparedness amid growing urbanisation.

Today, Arabia is mostly covered in very arid desert. But the new paleoclimate analysis, published in *Science Advances*, shows that the past 2,000 years were much wetter, and the region was once a vegetated savannah.

Animals like wolves, lions and leopards were once widespread.

Today, such creatures – as well as others like baboons, oryx and hyenas – are restricted to sanctuaries where freshwater is less scarce. The animals which dominate Arabia today are desert specialists like camels, snakes and small mammals.

Researchers studied Arabia's ancient climate using a remotely operated vehicle to extract sediment cores from deep-sea brine pools nearly 2km beneath the surface in the Gulf of Aqaba in the northern Red Sea.

Chemical signatures in the brine record ancient climate conditions such as CO_2 levels and rainfall.

Sediments extended to 1,600 years ago – a period when the Roman empire ruled northern Arabia and the Levant.

The ancient, vegetated savannah of Arabia persisted until as recently as 200 years ago, when the rainfall was double what it is today.

"This is a key record to fill in the history of Middle Eastern climate," says co-author of the study, Amy Clement from the University of Miami in the US. "The climate, both the average and the extremes, can change dramatically. "

PHYSICS

The sound of two hands clapping

A NEW STUDY has figured out the physical mechanisms and fluid dynamics of clapping hands.

The team used high-speed cameras to track 10 participants who clapped using cupped hands; a more rigid flat handed technique; or the demure fingers to palm.

They assessed the size, shape and texture of the hand, the sound produced, and the force, speed and pressure of the clap.

By sprinkling baby powder onto the hands they could even visualise the airflow produced by clapping them together.

They found that the sound of the clap comes from air being forced through the cavity between the palms and the opening between the thumb and index finger.

The larger the cavity between palms, the lower the frequency of the clap – clapping with cupped palms creates a deeper sound than with flat hands or fingers.

"This is also a fundamental principle of the musical instrument," says Sunny Jung, a professor of biological and environmental engineering at Cornell University in the US and senior author of the paper.

"Depending on the size of the cavity and the length of the neck opening, you create a different sound – we showed that this also applies to hand clapping."

The research opens the intriguing idea that a clap could be used to identify the person clapping.

"The hand clap is actually a very characteristic thing, because we have different sizes of hand, techniques, different skin textures and softness – that all results in different sound performances," says first author Yicong Fu.

"Now that we understand the physics of it, we can use the sound to identify the person."

KAZZAZ PHOTOGRAPHY / MOMENT / GETTY IMAGES PLUS

NATURE

Superb lyrebirds have an unexpected skill

These songbirds are ecosystem engineers with the ability to farm invertebrates.

TRACIELOUISE VIA GETTY IMAGES

Superb lyrebird (*Menura novaehollandiae*).

THE SUPERB LYREBIRD is arguably Australia's most iconic native songbird, known for its ornate tail and incredible mimicry. But new research has found the bird has another, unexpected talent: farming.

In a new paper published in the *Journal of Animal Ecology*, researchers from Australia's La Trobe University have found that lyrebirds arrange litter and soil on the forest floor in ways that promote the growth of more prey.

This ground-dwelling bird creates perfect micro-habitats for its prey – worms, centipedes, and spiders – to live and grow, compensating for the reduction in their numbers through predation.

"Lyrebirds set up the perfect home for their prey, creating conditions with more food resources and effectively fattening them up before eating them," says lead researcher, Dr Alex Maisey.

Superb lyrebirds (*Menura novaehollandiae*) are ecosystem engineers of the moist eucalypt forests in south-eastern Australia, where they live. Each year, they displace 155 tonnes of soil and leaf litter per hectare on average while foraging for their invertebrate prey.

The researchers conclude that lyrebird foraging actively creates conditions that favour the specific invertebrates it preys on. That means there is ongoing replenishment of its food source to compensate for the loss happening through predation.

"Lyrebirds are widespread and active across millions of hectares of forest. Their farming actions play an important role in maintaining forest biodiversity," says Maisey.

Focus: Other humans

1

Fossil footprints show different hominin species coexisted 1.5 million years ago.

2

Modern humans may have descended from at least two ancestral populations.

3

Oldest human face found in Europe adds to question of the path out of Africa. The fossil dates to 1.4 to 1.1 million years ago.

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Interactions between Neanderthals and *Homo sapiens* 100,000 years ago included cultural exchange.

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Were Neanderthals collecting fossils for fun?

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HEALTH

Australia has world's highest breast cancer rate

A RECENT ANALYSIS of global breast cancer rates has found that, while Australia and New Zealand substantially decreased the disease's mortality rate over the past decade, the countries' breast cancer incidence rates were the highest in the world in 2022.

For every 100,000 women living in Australia and New Zealand, 100.3 cases of breast cancer were diagnosed.

"There are various reasons for this," says Nehmat Houssami, the National Breast Cancer Foundation chair in breast cancer prevention and professor of public health at the University of Sydney, who was not involved in the research.

"[They are] related to the population structure (e.g. ageing) and risk factor profile."

According to Houssami, breast cancer risk factors that women may be less aware of include alcohol consumption, low physical activity, and post-menopausal obesity.

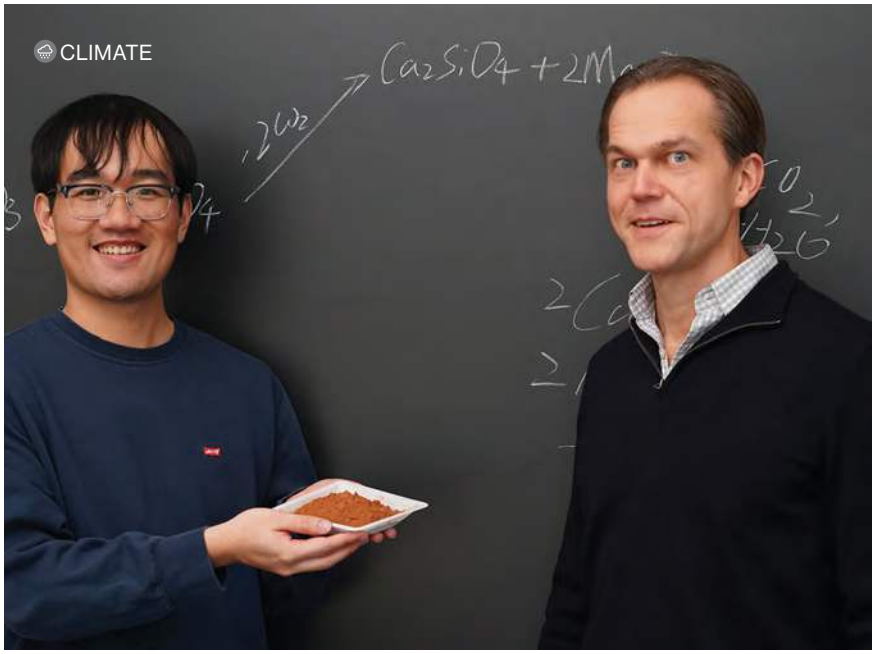
"We need to improve support for women to reduce these potentially modifiable risk factors."

The report found that 1 in 20 women globally are diagnosed with breast cancer and 1 in 70 are likely to die from the disease in their lifetime.

"However, this burden is not spread equally across countries and regions," says Houssami.

"There are large variations in incidence rates and more concerning are the disparities in breast cancer mortality."

CLIMATE



Researchers hold carbon dioxide-trapping material in their lab

New carbon capture method turns up the heat

Team suggests using mining waste to slow global heating.

A CENTURIES-OLD TECHNIQUE for making cement may be the key to large-scale carbon capture, according to US chemists.

The first step in making cement involves converting limestone to calcium oxide, inside a kiln heated to 1,400 degrees Celsius. Calcium oxide is then mixed with sand to produce a vital ingredient for cement.

Inspired by this technique, Stanford University researchers used a conventional kiln to transform common minerals into reactive materials with the ability to pull carbon from the atmosphere – and sequester it permanently.

"The Earth has an inexhaustible supply of minerals that are capable of removing CO_2 from the atmosphere, but they just don't react fast enough on their own to counteract human greenhouse gas emissions," says Matthew Kanan, a professor of chemistry at Stanford and an author of the new study, published in *Nature*.

"Our work solves this problem in a way that we think is uniquely scalable."

It is estimated that 4 billion tons of cement are manufactured each year.

Scaling up a carbonation process to meaningfully slow global heating would require millions – perhaps billions – of tons of magnesium oxide and calcium silicate. The team suggests that they could use mining waste, which contains suitable silicates, as a large source of raw material.

"You can imagine spreading magnesium oxide and calcium silicate over large land areas to remove CO_2 from ambient air," Kanan says.

"One exciting application that we're testing now is adding them to agricultural soil. As they weather, the minerals transform into bicarbonates that can move through the soil and end up permanently stored in the ocean."

CHEMISTRY

The silica skeleton of a Venus' flower basket sea sponge.

Material inspired by a sea sponge's glass skeleton

This material is more sustainable and could dampen vibrations during earthquakes.

A SEA SPONGE skeleton made of glass has engineers wondering how it might improve building materials.

The sponge in question lives at the bottom of the Pacific Ocean, and is known as Venus' flower basket (*Euplectella aspergillum*). It builds its intricate basket-like skeleton out of silica – the main material in sand and glass.

The skeleton's lattice pattern has inspired Australian engineers to develop a new material with incredible compressive strength and stiffness.

It's an "auxetic" material, which means it contracts when compressed.

"While most materials get thinner when stretched or fatter when squashed, like rubber, auxetics do the opposite," says Dr Jiaming Ma of RMIT University, lead author of a study describing the new material in the journal *Composite Structures*.

"Auxetics can absorb and distribute impact energy effectively, making them extremely useful."

The double lattice design forms a uniform square grid further reinforced by 2 sets of diagonal struts.

They tested the design and found the lattice is 13 times stiffer than existing auxetic materials.

It can also absorb 10% more energy while maintaining its auxetic behaviour, compared to existing designs.

The material's remarkable properties could improve architecture and the manufacture of certain products.

They now plan to produce steel versions of the design to test with concrete and rammed earth structures – a construction technique using compacted natural raw materials.

"We're developing a more sustainable building material by using our design's unique combination of outstanding auxeticity, stiffness, and energy absorption to reduce steel and cement usage in construction," says Ma.

"Its auxetic and energy-absorbing features could also help dampen vibrations during earthquakes."

RMIT UNIVERSITY

PHYSICS

Water droplets on car windows build electric charge

WE'VE ALL WATCHED water droplets dance across a car window, stopping and starting, sometimes with a rush.

The droplets are building up an electrical charge, and physicists say it is 10 times greater than previously thought.

The research, published in *Physical Review Letters*, is based on observations of what happens when water droplets get stuck on a tiny bump or rough spot on a surface. They found that a force built up until the droplet "jumped or slipped" past the obstacle. This process leads to an irreversible charge build up which had never been noticed before.

Understanding this "stick-slip" system could be used to enhance surface design with controlled electrification and improve safety in energy-holding systems, such as hydrogen fuel.

"Understanding how and why electric charge is generated during the flow of liquids over surfaces is important as we start to adopt the new renewable flammable fuels required for a transition to net zero," says senior author Joe Berry, a fluid dynamics expert from the University of Melbourne.

ENVIRONMENT

Australia's extinction crisis: 21 species join threatened list

The nation is facing a wildlife wipeout.

Irwin's turtle, one of the species recently added to Australia's threatened species list.

AUSTRALIA ZOO

THE AUSTRALIAN GOVERNMENT has added 21 new species of fauna and flora to the threatened species list, with six more being uplisted to higher threat categories. This decision underscores Australia's worsening extinction crisis as the nation continues to grapple with one of the worst extinction rates in the world.

The newly added species include the vulnerable Irwin's Turtle, Murray Crayfish, and Australian Humpback Dolphin; the endangered Mount Ballow Mountain Frog; and the critically endangered Wadbilliga Ash.

"Species like the Irwin's Turtle, named after famed conservationist Steve Irwin, are now threatened with extinction due to the impacts of disease, habitat destruction and the impacts of invasive species," says James Trezise, the Director of the Biodiversity Council.

"A number of species listed, such as the Western Mud Minnow, are increasingly being impacted by drought and temperature extremes, highlighting the threats that our native wildlife face due to climate change," says Trezise.

In 2023, a record-breaking 144 species were added to the threatened species list – 5 times more than the yearly average. In 2024, 56 more were added. Now, more than 2,000 species are recognised as threatened in Australia.

Under the EPBC Act, any species added to the threatened list becomes a "national matter of environmental significance." In theory, this means that any project or development with the potential to impact these species must receive federal approval. The Threatened Species Scientific Committee also formulates conservation advice and recommends recovery and threat abatement plans. However, these protections often fail in practice.

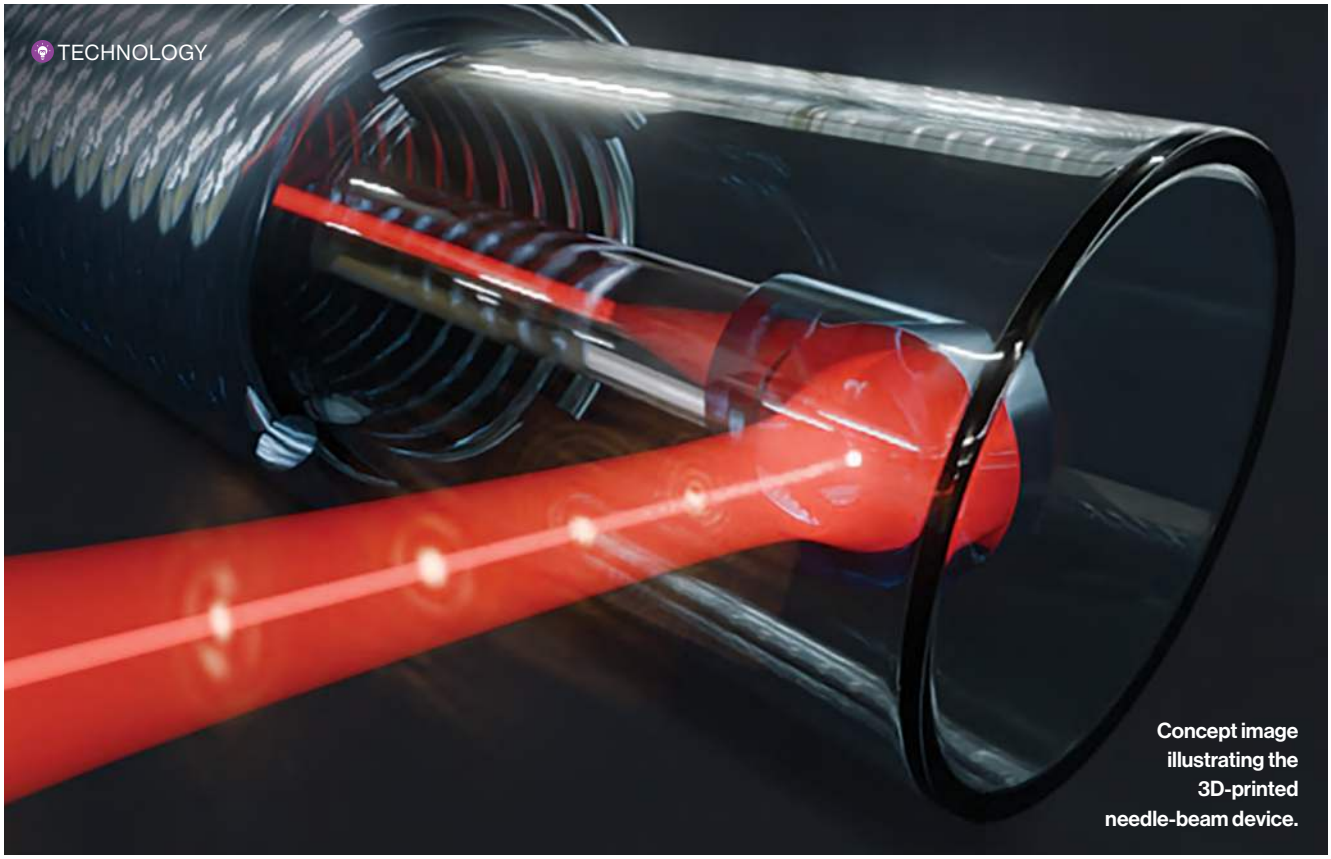
"Unfortunately, in this country, listing species as at risk of extinction does not currently guarantee protection from harm or resources (funding) to support recovery," says Director of the Melbourne Biodiversity Institute and Biodiversity Council Lead Councillor Brendan Wintle.

"Habitats of endangered species continue to be destroyed, and funding to protect and support the recovery of threatened species is pitifully inadequate. Our nature protection laws need an urgent overhaul so they can be effective.

"At the moment, less than 10% of our listed endangered species even have a current recovery plan," Wintle adds. "Successive governments have failed to provide the resources and coordination needed to create and implement recovery plans. Species are hurtling toward extinction, and we're standing by and watching."

While listing species under the EPBC Act is still an important first step toward their recovery, experts warn that much more needs to be done.

"It's estimated we need to invest $2 billion per year in threatened species recovery to prevent the loss of Australian wildlife, but we do not see anywhere near that level of investment from the federal government," says Trezise.



Concept image illustrating the 3D-printed needle-beam device.

FLORIAN STERL

New device designed to prevent heart attacks

It's a 3D-printed micro-lens to see inside blood vessels.

ADELAIDE RESEARCHERS have created a tiny, 3D-printed micro-lens that can peer inside blood vessels and therefore might help prevent heart attacks.

"We 3D-printed this micro-lens, with a diameter of less than 0.26 mm, directly on an optical fibre in a single step," says Jiawen Li, who leads the intravascular imaging program at the Institute of Photonics and Advanced Sensing (IPAS) at the University of Adelaide.

Li recently received an international award for her invention of 3D-printed hair-thin endoscopes that can see inside the human body in a minimally invasive way. These tiny imaging devices were made possible by the development of micro 3D-printing technology, in collaboration with a German company Nanoscribe and the University of Stuttgart.

The devices provide real-time physiological data that has many clinical uses. For example, they can detect and diagnose coronary artery disease. This disease is characterised by the build-up of plaques on the walls of blood vessels, which can lead to life-threatening heart attacks.

While some technology is currently commercially available to detect and image these plaques, they are based on traditional Gaussian beam optics. A Gaussian beam is a projection of light that concentrates energy (for example, most lasers are Gaussian beams). However, the beam is diffracting, which means it spreads out when it hits an object or passes through an aperture, which reduces image resolution and causes blurring. This property leads to limitations when Gaussian beams are used to image blood vessels.

Now, a paper just published in *Advanced Photonics* details the development of an ultra-thin lens that overcomes many of these limitations. Just 0.26 mm thick, the lens has a long focal depth and small focus diameter, and is 3D-printed directly onto an optical fibre for use as an endoscope.

Instead of a Gaussian beam, it uses a 'needle beam', or a Bessel beam. Li explains that this "stays tightly focused over a long distance without spreading much. Thus, its imaging resolution stays great, and the images remain sharp and clear for a longer distance.

"By overcoming the limitations of traditional optics and enabling exceptional image quality, this device could provide greatly improved imaging capability of high-risk plaques that cause heart attacks."

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TECHNOLOGY

Batteries can explode if they overheat

Sensor stops lithium-ion batteries from exploding

The new technology could prevent batteries from overheating.

LITHIUM-ION BATTERIES are widely used because they are efficient and long lasting. But they can be disastrous when something goes wrong, and the battery catches fire or explodes.

A new sensor that could solve the problem of overheating lithium-ion batteries is described in a paper published in the journal ACS Applied Materials & Interfaces.

Damaged or overheating battery cells can release volatile electrolyte vapours.

There were at least 20 fires or explosions of lithium-ion batteries in electric vehicles worldwide in 2021, according to the authors. Though electric vehicle battery explosions are a risk, they are rare.

"Lithium-ion batteries are everywhere," says lead author Liangdan Zhao, a PhD student at Xi'an Jiaotong-Liverpool University, China and the University of Liverpool, UK.

"While they offer high energy density and a long lifespan, they also come with large safety risks. Our research is motivated by this critical safety challenge," Zhao adds.

Ethylene carbonate (EC) is a key component of a battery's electrolyte. The new sensor detects trace amounts of EC, flagging potential battery failures before they become disasters.

The highly sensitive and cost-effective gas sensor was developed using molecular structures called covalent organic frameworks (COFs). These can be engineered to selectively detect different gas molecules.

It's the first time a COF sensor design has been guided by computer simulations to detect EC.

"We screened hundreds of potential materials using computational methods before identifying COF-QA-4 as the best candidate," Zhao says. "It's highly sensitive and selective, targeting the harmful EC gas while ignoring other vapours. The sensor can detect leaks long before they become hazardous."

The sensor can detect EC vapour at concentrations as low as 1.15 parts per million in laboratory tests.

"By incorporating this sensor into existing systems, manufacturers can take proactive measures to avoid dangerous situations," says Zhao. "This could save lives and protect property by detecting potential failures long before they escalate."

TECHNOLOGY

New step to quantum computers

IF QUANTUM COMPUTERS are to fulfill the promise of solving problems faster or those which are too complex for classical supercomputers, then quantum information needs to be communicated between multiple processors.

Modern computers have different interconnected components such as a memory chip, a Central Processing Unit and a General Processing Unit. These need to communicate for a computer to function.

Current attempts to interconnect superconducting quantum processors use "point-to-point" connectivity. This means they require a series of transfers between nodes, compounding errors.

A new device described in a paper published in Nature Physics replaces "point-to-point" connectivity with "all-to-all" in a bid to overcome these issues. The aim is to allow all superconducting quantum processors in a network to communicate directly with each other.

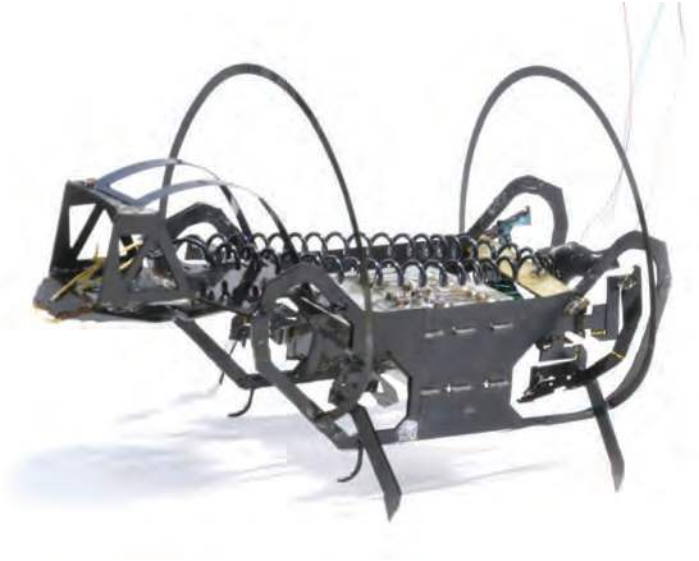
The team demonstrated remote entanglement, enabling a correlation between quantum processors that aren't physically connected.

"Generating remote entanglement is a crucial step toward building a large-scale quantum processor from smaller-scale modules," explains co-author Beatriz Yankelevich. "Even after that photon is gone, we have a correlation between two distant, or 'nonlocal,' qubits. Remote entanglement allows us to take advantage of these correlations and perform parallel operations between 2 qubits, even though they are no longer connected and may be far apart."

Guess the object

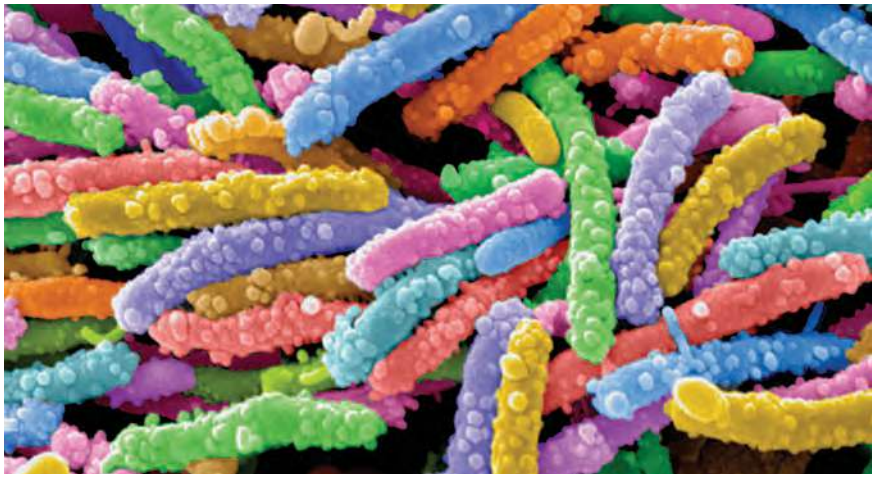
Springs and strings

It's static on the page, but this gadget is designed to move! It's quite the feat of engineering. The agile machine is modelled on one of nature's greatest gymnasts. What is this amazing contraption designed to do? For bonus points, can you name the class of organisms it's modelled on?



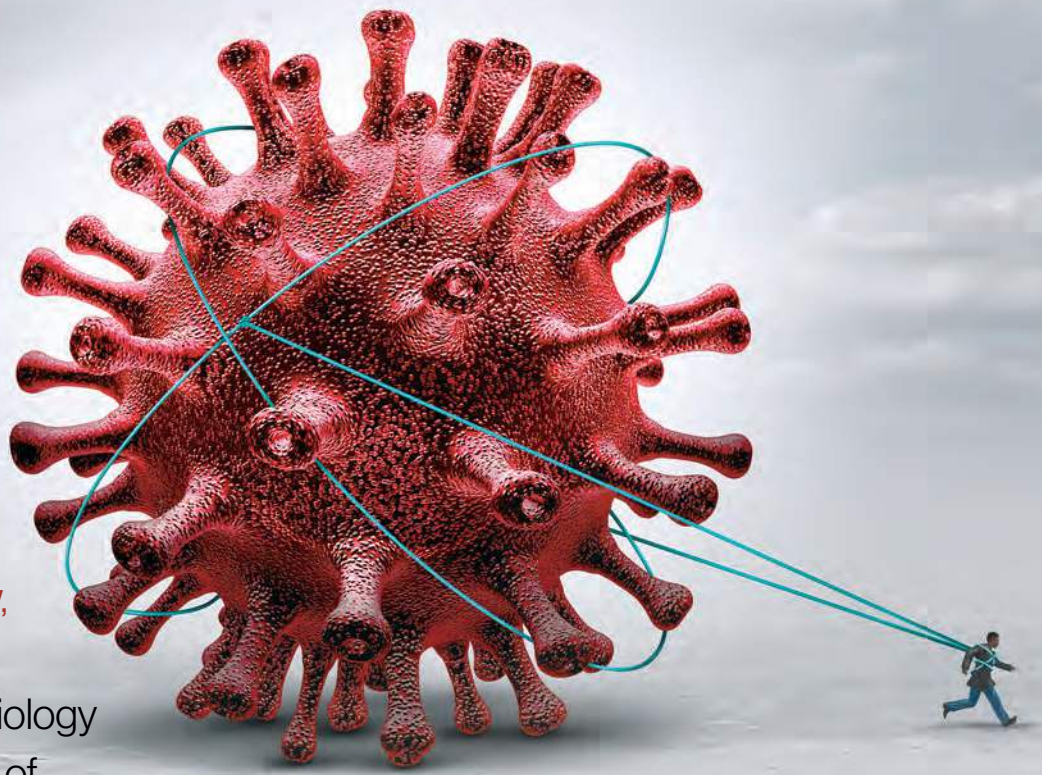
If you'd like to know the answer, you could dig around on our website, cosmosmagazine.com. Or turn to page 110 and find out more about this fabulous contraption.

Multicoloured mystery



The medical mystery from last issue was a collection of *E. coli*.bacteria. You might think of *E. coli* as making us sick, but they can also be used in the medical production of pharmaceuticals. Scientists have given a harmless strain polymer 'Superman capes' to add strength and make them more efficient, so they can carry out reactions faster.

PANDEM1C BY NUMB3R5: MATH3MAT1CAL EQUAT1ONS HELP KE3P US 5AFE



James McCaw, Professor of Mathematical Biology at the University of Melbourne, was on the frontline in Australia's COVID-19 battle. He shares how his 2024 ARC Laureate Fellowship will focus on preparations for the next pandemic.

MATHEMATICAL BIOLOGY is a very broad field. My group works on infectious diseases, studying how viruses and parasites spread within our body, and how they transmit from person to person. We use mathematical models to try and simulate those processes, and we use statistical analysis to understand data that is measuring those processes. We bring our biological knowledge and mathematical analysis together to try and say new things about the biological world itself. We then work in spaces like epidemiology and public health to help support responses to events like COVID-19.

It was on January 16, 2020, that the World Health Organisation first convened a teleconference for people like me, with expertise in pandemic response, on what

WILDPIXEL/GETTY IMAGES

was developing in Wuhan, China. It was clear that a new virus was infecting humans, but it wasn't yet clear how it was spreading.

It took another three days or so before we, as a global community, were almost certain that it was spreading directly from human to human, and that we were facing a global pandemic. But we didn't know how severe it would be.

I was sitting on the emergency response committee at the Commonwealth level, meeting at least once, if not twice a day. For those first few weeks we had very little data. But because of some amazing empirical work, we knew it was a coronavirus: a respiratory virus. We already knew how flu spread, and how the original SARS spread, and because we had those statistics and data, we were able to form a mathematical understanding of what we were potentially facing.

Connecting the dots

When I say a mathematical understanding, I mean a conceptual, theoretical model of how things behave. Just as Newton's laws and Einstein's laws are a mathematical model, we have mathematical models of disease transmission.

This is an important point. I believe science progresses most rapidly and effectively when it has a balance between empirical observation and theoretical considerations – when you think deeply about the processes that are occurring and how they would lead to the data that you see. This balance between theory and experiment has been embraced for centuries in physics, and it serves that science well. And it's starting to happen more and more in fields of biology, which is exciting – like helping society find a way through these pandemics.

With these models, we can reason on what might happen. Where we know that we don't know things, we capture the uncertainty in our models. And that's what we were doing in early February 2020. We were able to say that if this virus spreads very much like flu, it might have these characteristics. But if it spreads more like original SARS, it would have these characteristics, and spread this quickly. We were also able to predict from some very early characteristics that it looked a little bit like both. And as it turns out, that's where it was, in between the two of them.

In this way we were able to make useful predictions about what this new pathogen might do when it got into Australia and began to spread in the population. And it was mathematics that was giving us a qualitative insight, though not a quantitative one. This is another important point: most of the work from mathematics provides you with qualitative understandings of things. It's only when you then bring the mathematics and the data together that you get a quantitative understanding.

James McCaw is Professor of Mathematical Biology at the University of Melbourne.

More than numbers

When someone says maths is about the numbers, that's rarely the case. It's really maths combined with the data – the statistics – that's all about the numbers. The maths is about logical, reasoned thought and understanding the processes that drive transmission.

Most of the mathematics we use is calculus. It's similar to the maths that you're just starting to learn in year 11, and certainly know quite a lot of in year 12. Calculus isn't a familiar word to many people, but it's essentially a study of the rate of change through time.

First, we ask questions and write down equations. For example, the number of people who will become infected tomorrow is related to how many people are currently infected, and how many people are susceptible in the population. If you reason on those sort of logical thought experiments, you can write down equations which very accurately capture what happens when you observe epidemics, and these equations allow you to make accurate predictions about what is likely to happen and how different interventions can change what happens. The models explain why you get epidemic waves, why you get the early exponential growth, then the peaks, the declines, and then the next wave.

My colleagues and I worked very hard to communicate issues of scientific knowledge and scientific uncertainty, then put that into the government decision-making processes, it was then up to our elected representatives and people in the public service to make decisions. They did their job, and we did our job, and Australians did their job by following the advice. But we were aware that there were going to be members of the community who would disagree, and some of these people would express their views in very unpleasant ways. It wasn't easy at times, and I didn't see the worst of it, but many of my colleagues did.

Adding up the impact

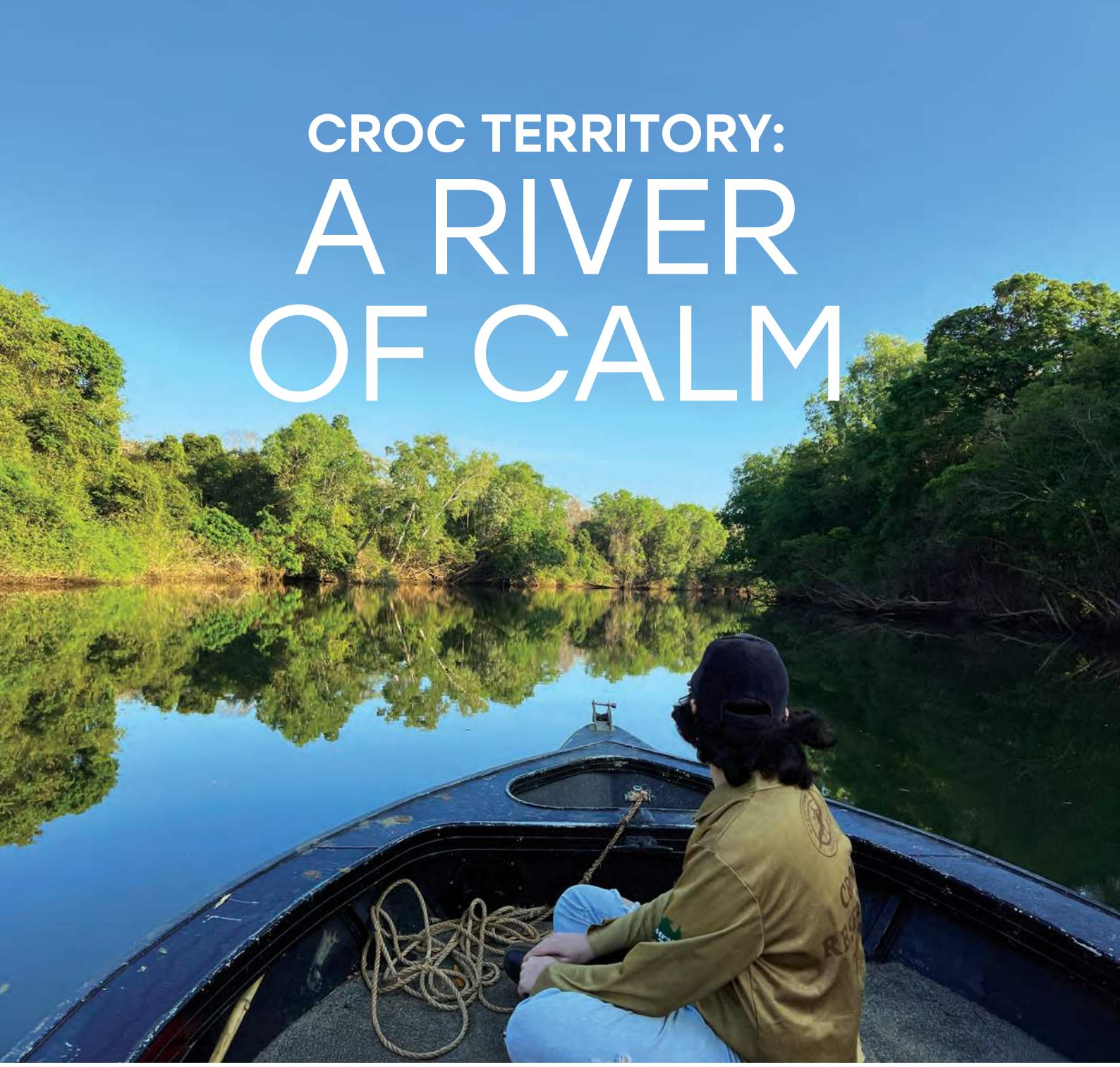
COVID-19 is a nasty pathogen that will continue to impact us negatively for decades to come. For the first few years of the pandemic, we had little immunity, rampant spread at a global scale, and there were severe clinical outcomes. But today most people in the population have been vaccinated and/or infected a few times. We are in a process of bringing COVID-19 into the suite of all the different pathogens and health issues that we manage on a day-to-day basis, and that's necessary because it's going to be with us forever.

We need to manage it efficiently and effectively. Importantly, the solution isn't to say that the flu is fine, so COVID is fine. It's actually to recognise that we can do better against both viruses, reducing the burden of flu and COVID on the community.

Through my ARC fellowship, I'm aiming to train the next generation of mathematicians and data scientists to support government and the community to better understand, and reduce the impact of, infectious diseases.

As told to **Graem Sims**

CROC TERRITORY: A RIVER OF CALM



While many people would find it hard to relax in crocodile infested waters, **Kaitlin Barham** revels in her yearly Croc Trip. But it's not just fun – there's science to be done!

MY FAVOURITE PLACE IS A RIVER.

It's a couple of plane trips, a long drive, and a perilous water crossing away from anywhere. You can feel it sink deep into you, the further you go.

One plane in, and things become noticeably lusher, more humid. The second plane is much smaller than the first, and we're elbow-to-elbow with FIFO workers as we look down on red dirt and green-grey trees. Then the drive, on roads that become less and less friendly to our vehicles, but smell more and more like bush smoke and melaleuca.

The very first time we drove across the river, I was scared. There's no bridge, no road – just some precarious-looking rock ledges. By my fifth trip, it feels like coming home. I look down at the shallow water and say hello to the river, and I wonder if Drew is watching us.

Drew is our neighbour, and he's a crocodile. This crossing is in the middle of his turf, and he swims over it each day on the high tide. Last time we measured him, he was 4.39 m long – and still growing.

That was back in 2018. So this time, Drew's the crocodile we're hoping to catch the most.

CRAIG FRANKLIN

Home away from home

Croc Trip is a fixture on the calendar now. Each August, crocodile researchers from the University of Queensland and Australia Zoo make the trek up to Wenlock River in far north Queensland. We're here to study crocodiles – their behaviour, their health and their diet. It's an involved process, so our team of 20-plus has a range of expertise in animal handling, boating, and (perhaps most importantly) cooking.

For this one month, we live in tents and are woken by dawn birdsong. But over the last 15 years, the campsite has slowly become filled with the comforts of home. This year, our main base has Starlink, air conditioning, hot showers and a giant fridge of cold drinks. This close to the equator, these aren't just luxuries – they help keep the team focused and alert after long days spent out in the heat.

Once we arrive, we fall easily into well-established routines. A few days are spent constructing traps, which are arrayed along 50km of the river in spots that we hope look inviting – if you're a crocodile. Sometimes, if there's a certain croc we really want to check up on, we'll put the trap in their favourite spot, and bait it with their favourite food. (Drew, for instance, is a fish guy.)

Each morning after that is spent on the boat, checking traps. Camp is lovely, but being out on the river is my real favourite place. We leave early enough that the air is cool and the water still. Then for an hour or two we're skimming across the surface, pointing out wildlife and trying not to swallow wind-blown sand. In 5 years, I've gone from being very bad at spotting crocs in the water to comfortably average.

Croc tracking

Of course, the crocs we're really hoping to see are the ones that have entered the traps. Sometimes, we're not so lucky. Crocs are picky. For all our attempts to figure out the perfect combination of temperature, moonlight, and bait decomposition that will lure them in, they do what they want.

The occasional day off isn't so bad, anyway. With our new internet connection, everyone has emails to check and reports to write – even out here.

But the rest of the time, the energy becomes electric. Anyone who's not on trap shift is crowding around the camp phone with anticipation turned all the way up to 100 – whether it's day 1 or day 31. Any croc is a good croc, but on the day we catch Drew, people are yelling and jumping and hugging each other. And I'm no exception!

Kaitlin Barham poses with her supervisor, Professor Craig Franklin from the University of Queensland.

The team install a GPS tracker to a large crocodile.

CRAIG FRANKLIN / KAITLIN BARHAM

The Australia Zoo team are experts at crocodile handling, and it's always awe-inspiring to watch them work. In no time, they can get an animal almost 3 times as long as I am tall out of the trap and safely restrained. When I'm especially lucky – that is, when the crocodile is bigger than we thought it was – I get to help. Drew has grown a lot, so I'm on tail duty today.

Then the UQ science team get to do what we came all this way to do.

To learn about the behaviour of crocodiles, we attach trackers that can tell us about their movements, body temperature and diving habits for years to come. To learn about their physiology, we take samples of blood and scale to analyse in the lab when we get back home. Measurements can tell us how much they've grown since we last captured them.

This time when we measure Drew's total length, everyone happily agrees that he's "put a bit on". He's grown by 13 cm, which translates to something like 50 kg. It's no wonder, too. The data we get from his tracker over the next few days shows us that he's made a push to expand his territory, and it's clearly working for him. I feel a little proud. We've tracked 250-something crocodiles in the last 15 years, but Drew's the old friend next door.

In a while, crocodile

When we release Drew, we know it's not goodbye. His new acoustic tracker will continue to pick up his movements for the next 10 years, teaching us new things about crocodiles and their relationship with the environment around them.

Croc Trip is about crocodiles, obviously. But to me, it's also about cool mornings, dinners by the fire, and sharing our research with the only other people we know who get as excited about it as we do. It's about the way the setting sun shines through eucalyptus leaves, sketching wild things in the bush, and it's about the river.

Leaving the river always feels like even more of a goodbye. It's a mercy, really, that we have to cross it again as we leave. I can look down at the water, running a little faster, because of recent unseasonal rain, and I can say, see you next year.

Kaitlin Barham is a PhD candidate at the University of Queensland.

Safeguarding our planet

Building resilient scientists

Defeating undesirable resilience

The future of humans

OF SKATES AND SALMON

Can the threatened Maugean skate coexist with Tasmania's salmon industry? **Lauren Fuge** talks to the experts on the ground – and on the water.

In the tannin-stained waters of a remote Tasmanian harbour, a prehistoric creature prowls the darkness. This ray-like predator has hunted the shallow harbour for tens of thousands of years, yet it was unknown to science until 1988. Now, there's a risk that it could soon become the first marine fish in modern times to go extinct due to human activity.

The only place the endangered Maugean skate (*Zearaja maugeana*) calls home is Macquarie Harbour, which has been shaped and scarred by human hands since European colonisation. In recent decades, the vast circular pens of salmon farms have begun to dot the harbour, producing Atlantic salmon as well as producing controversy about how the salmon industry affects the unique and delicate ecosystem of Macquarie Harbour.

Some wonder if this means the end for the skate. The Tasmanian government says that the salmon farming industry and the skate can co-exist. But does this claim stack up with the science?

MARK PRIEST IMAS

IMAS researcher David Moreno releases a tagged skate.

A unique harbour

Macquarie Harbour is an enormous estuary in western Tasmania, covering 315 square kilometres.

"It's about six times the size of Sydney harbour," says David Moreno, a researcher at the Institute for Marine and Antarctic Studies (IMAS) at the University of Tasmania. "It's a beautiful area. The bottom half of the harbour is a World Heritage Area, and it's surrounded by some pretty ancient forests. It's on the west coast of Tasmania, so it's exposed to the Roaring 40s – really big weather, lots of rain."

Moreno explains that both the King and Gordon rivers flow into the harbour, creating stratified water columns: "You basically will always, year-round, have a freshwater layer on top, and then a brackish layer in the middle, and then a full marine layer down on the bottom." And there's very little mixing between layers.

The freshwater is dark because it's full of tannins, making it difficult for light to get through. Even though the harbour is relatively shallow (up to 50 metres in depth), its bottom layers are more like a deep-sea environment with little light or plant life.

The mouth of the harbour is also narrow and shallow, so that the amount of freshwater pouring out of the rivers determines how much ocean water can get in through the mouth. This exchange of oceanic water is one of the few ways oxygen can get to the depths of the harbour.

"Because of those oxygen conditions and the light and the low productivity, it's naturally low in life," Moreno says. "Quite a simplistic food chain lives there. The animals there are pretty unique."

One of the most remarkable species in the harbour is the Maugean skate.

Skates are part of the ancient lineage of cartilaginous fishes, along with sharks and rays. Skates resemble stingrays, but have short, thick and fleshy tails without stingers. They are also egg-laying creatures, while rays give birth to live young. Maugean skates spend their time hunting crustaceans on the sea floor.

The Maugean skate was first discovered in 1988, in the brackish waters of Bathurst Harbour further south. In 1994, CSIRO technician Mark Lewis collected five specimens in Macquarie Harbour. Since 1992 the skate has not been spotted outside Macquarie Harbour, and scientists believe it holds the species' sole remaining viable population.

Given their apparently small population and geographic range, Maugean skates have been listed as endangered since 2000. And human activity in the harbour isn't helping their survival.

Hogarth Falls feeds into Macquarie Harbour.

Hell's Gates is the deepest channel leading into Macquarie Harbour.

LEFT TOP: GETTY IMAGES / ARTHERNG / LEFT BOTTOM: SCOTT DAVIS

Aquaculture nets on Macquarie Harbour.

GETTY IMAGES / DAVE G. HOUSER

Landscape shapers

Macquarie Harbour has a long history of human industrial impact, dating back to the start of European colonisation.

A stone wall was built in the 19th century to keep the channel open, which affected the transfer of water – and oxygen – in and out. Mining wastewater used to flow down the rivers and contaminate the sediment with heavy metals. Hydroelectric dam projects upriver changed the natural patterns of freshwater flows.

Then salmon aquaculture kicked off in the 1980s, producing Atlantic salmon in netted pens on the surface. The industry began a massive expansion in 2009 after an environmental impact study that suggested the harbour could support 29,500 tonnes of salmon production per year, more than double what they had previously been producing.

Huon Aquaculture, Tassal and Petuna – the three aquaculture companies that operate in the harbour – signed an agreement in 2012 to "avoid significant impacts" on the World Heritage Area and the Maugean skate.

But a 2014 monitoring report led by CSIRO and IMAS found that the dissolved oxygen levels in the harbour's depths had steeply declined since 2009. Timewise, this corresponds to the expansion of the salmon industry.

However, experts say that this isn't the whole picture.

Salmon vs skate

IMAS senior researcher Jeff Ross says the oxygen levels in the harbour are dynamic, and this decline in oxygen was linked to several different factors.

"We've seen temperatures go up by a couple of degrees, and warm water holds less oxygen," he says. "We also know that in Macquarie Harbour, the rivers play a really important role in determining how much oxygen can come in from the ocean."

And then there's salmon farming.

"There are a number of ways that salmon aquaculture can affect the environment," says Ross. "One is their dissolved waste. So when the fish eat, they excrete urea and it becomes ammonia ... The other major source is solid waste, so that's any feed that the salmon don't eat, and also their faeces."

This waste will float down to the sediments of the seafloor to be processed by worms and bacteria, which consume oxygen. More waste means more seafloor life, to a point. If the oxygen runs out, it can be catastrophic.

"One of the most important things to acknowledge with Macquarie Harbour is that it is a naturally low-oxygen environment," says Ross. "We've seen before farming that the oxygen levels were low, and that's what we'd expect in a system like that, but what we saw in about 2009 is the oxygen levels declining even further, and 2014, '15 and '16 ... there were periods of time in the bottom waters where there was very little oxygen at all."

These levels are linked to the health of the environment on the sea floor. In 2016, sediment samples showed that the microfauna living on the sea floor had dramatically decreased in abundance.

These oxygen levels also affect species like the Maugean skate.

"This animal has evolved in this very unique ecosystem for a very long time, and therefore it has a very close relationship to the conditions," Moreno says.

Over time, it has developed mechanisms to cope with the challenge of a low-oxygen ecosystem.

"But it also means that if you push them beyond that, there is a pretty steep tipping point."

Population mystery

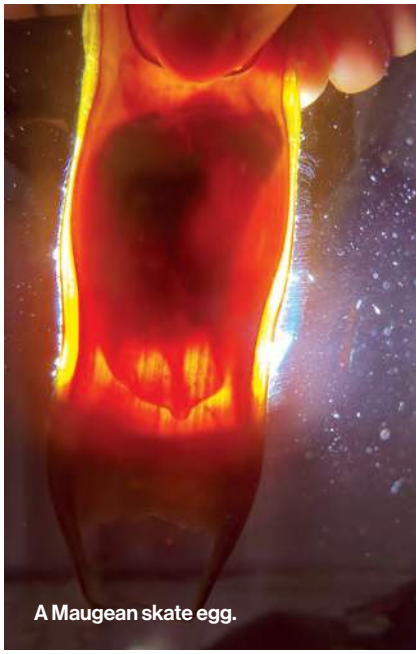
A recent estimate from Moreno's team at IMAS indicates that the skate population may be bouncing back after a steep decline. But it's extremely difficult to know how many of these elusive skates are in the dark, deep harbour.

Moreno says they know with certainty there aren't tens of thousands of animals, and there also aren't just a few hundred. "Beyond that, we're still working on it," he says.

The team made the first population estimate of the skate in 2014, which was around 3,000 animals – plus or minus 1,500.

They continued to monitor the animals, both via catching them and via electronic tags. The year 2019 saw two widespread mortality events, resulting in a 2021 report estimating a 47% population drop since 2014. Both of these die-offs were attributed to a drop in oxygen levels in the water, as shown by environmental sensors mounted in tracking tags. But this was not necessarily linked to salmon aquaculture.

Moreno says the first event was caused by a layer of freshwater preventing new, oxygen-rich oceanic water coming in.



A Maugean skate egg.

The other was likely the result of a huge westerly storm that pushed low-oxygen water from the deep ocean up to skate habitat.

After these mortality events, IMAS's most recent monitoring report in 2024 suggested an upward tick in the population trend. It found "a significant increase in relative abundance from 2022, with current estimates now not significantly different to 2014". This means that the number of animals caught in comparable amounts of fishing effort was the same.

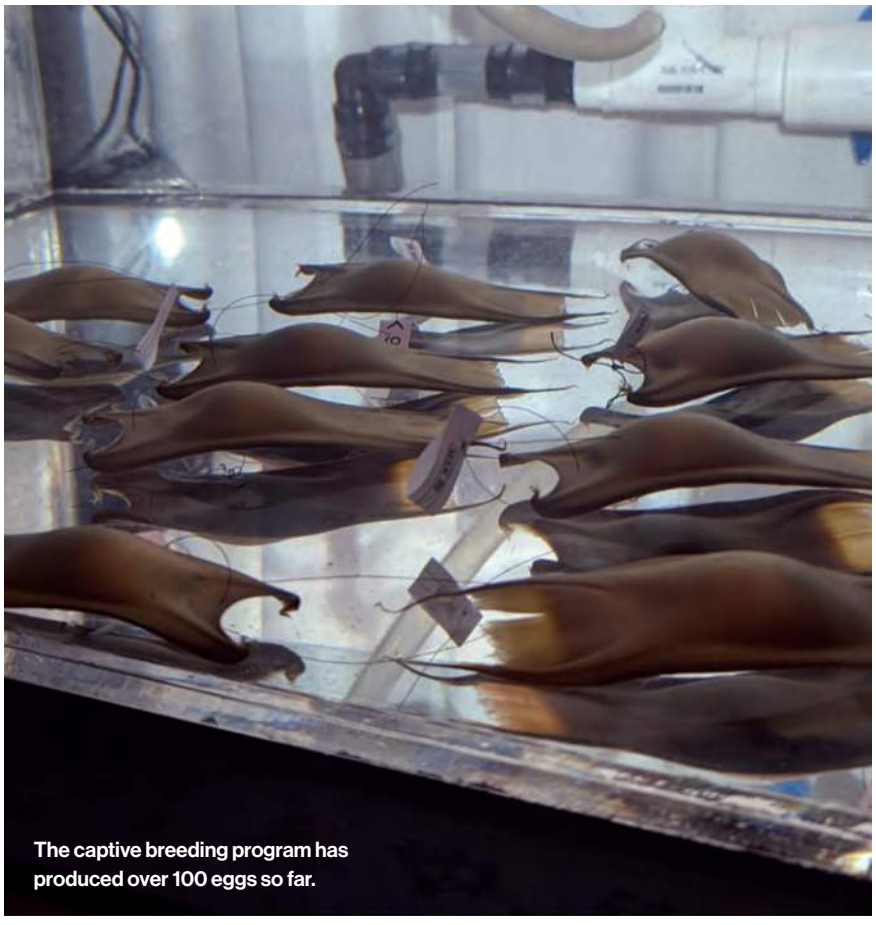
"That's not to say that there was a proportional increase in the population," Moreno clarifies. "Several things can affect an animal's catchability, so we are not yet fully in a position where we can understand how that translates to the actual population ...

"It's important to know that we don't know that the population has bounced back."

The other challenge is that the skate – although ancient – is new to science.

"Unfortunately, there isn't very good historical data to compare to, so the estimates that we have for historical trends begin after the environmental impacts had already begun," Moreno says.

"Long story short, we don't fully know how many animals are in the population at the moment."



The captive breeding program has produced over 100 eggs so far.

Counting cleverly

IMAS and CSIRO teams have been developing experimental techniques to more accurately estimate the total population, because conventional approaches haven't worked.

At first, they looked at the skates' genetic data. For many animals, this can give a good estimate of population size. But the naturally low genetic diversity of the skates poses a problem.

"There are just too many untested assumptions to use that technique effectively," Moreno says. "That was one of the first things that we attempted and realised that it was not going to yield very useful results."

Instead, skate researchers at IMAS are trying genomic approaches, looking at bigger chunks of the skate's genes to have a better chance of finding variability.

Meanwhile, a CSIRO team led by Toby Patterson is also working on applying a genetic analysis technique called close-kin mark recapture (CKMR) to the skate. The technique involves taking a small sample from each animal caught, building its genetic profile, and comparing it to every other animal caught to see if and how they are related.

The goal is to count the close relationships (like parent-offsprings, or half-sibling

LEFT TOP: DAVID MORENO IMAS/ LEFT BOTTOM: JAYSON SEMMENS IMAS

pairs). If the population is low, then it's more likely to find close relationships between the survivors.

Moreno and colleagues are also developing acoustic imaging technology to spot skates in the water. This is akin to ultrasounds, which use ultra-high-frequency sound (around 3 Megahertz) to generate an image.

"You don't need light," Moreno says. "In very ... turbid, mixed water environments like Macquarie Harbour, you can generate a very nice result."

But because the technology uses such a high frequency of sound, it can't travel far. The imaging device – which looks like a handheld video camera – must be underwater and close to the subject.

The team is working on cost-effective ways to survey larger parts of the harbour, to provide the statistical power to estimate the skate population with more certainty.

Breeding for the future

The federal government has committed $5.7 million to help protect the skate, with the Tasmanian government contributing $4 million. This included $2.1 million to initiate a captive breeding program in Hobart – one of only three captive breeding programs for skates and rays in the world.

Led by IMAS Professor Jayson Semmens, the program began in the summer of 2023, when a large marine heatwave was predicted to hit Tasmania – creating similar conditions to 2019, which saw multiple die-offs.

"Deep water temperatures in Macquarie Harbour have warmed in the last 30 years at the same rate as the surface temperatures in the outside, so by 1.5 to 2.5 degrees Celsius," Moreno says.

This heat affects the water's capacity to hold oxygen. "There was a genuine fear that if we got unlucky, [the heatwave] could spell out natural extinction for this species," explains Moreno, who works on the program with Semmens.

So they moved fast to set up a captive population.

In December 2023, they collected four carefully selected adult animals, as well as 50 eggs, 26 of which soon hatched. One of the adults was pregnant, and has since laid more than 100 eggs in captivity. In December 2024, the first captive-hatched skate celebrated its first birthday – a huge milestone.

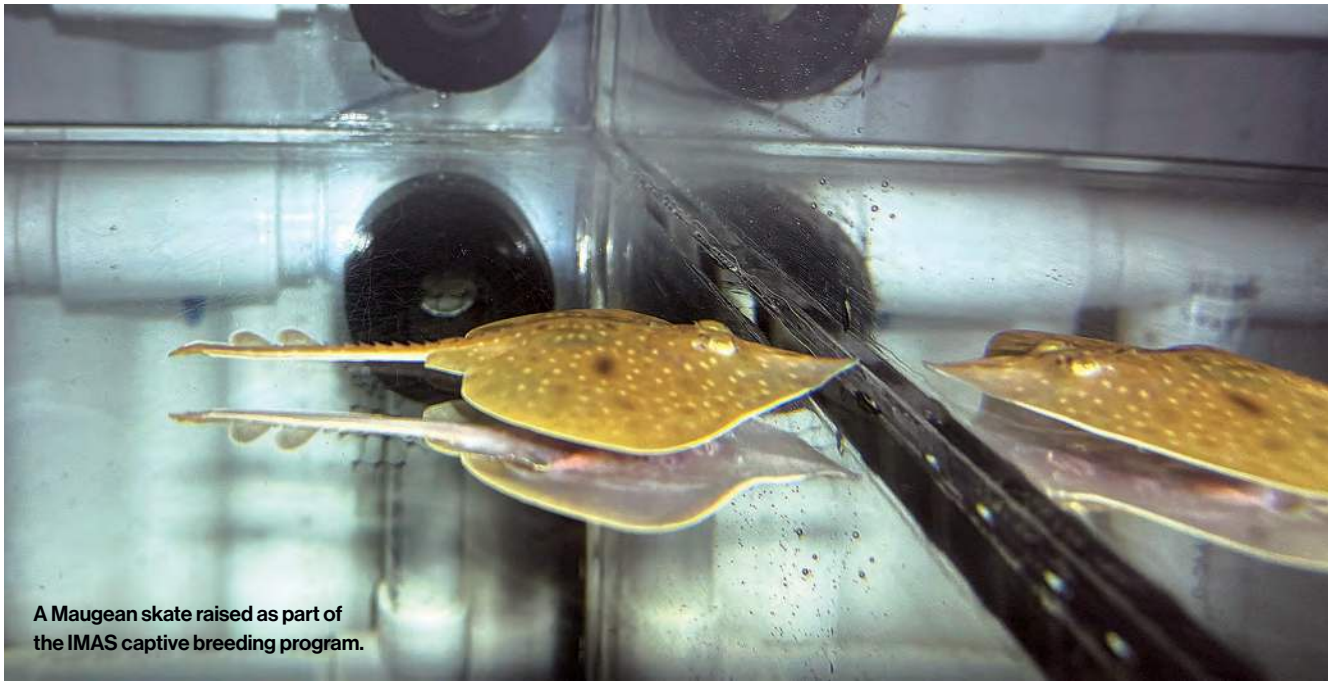
"This species had never been kept in captivity for more than two weeks, so there were a lot of uncertainties about whether it was even possible," Moreno says.

The program has enabled field biologists to study the captive animals in depth, building on their understanding of the species.

The next step is to supplement the recovery of the wild population.

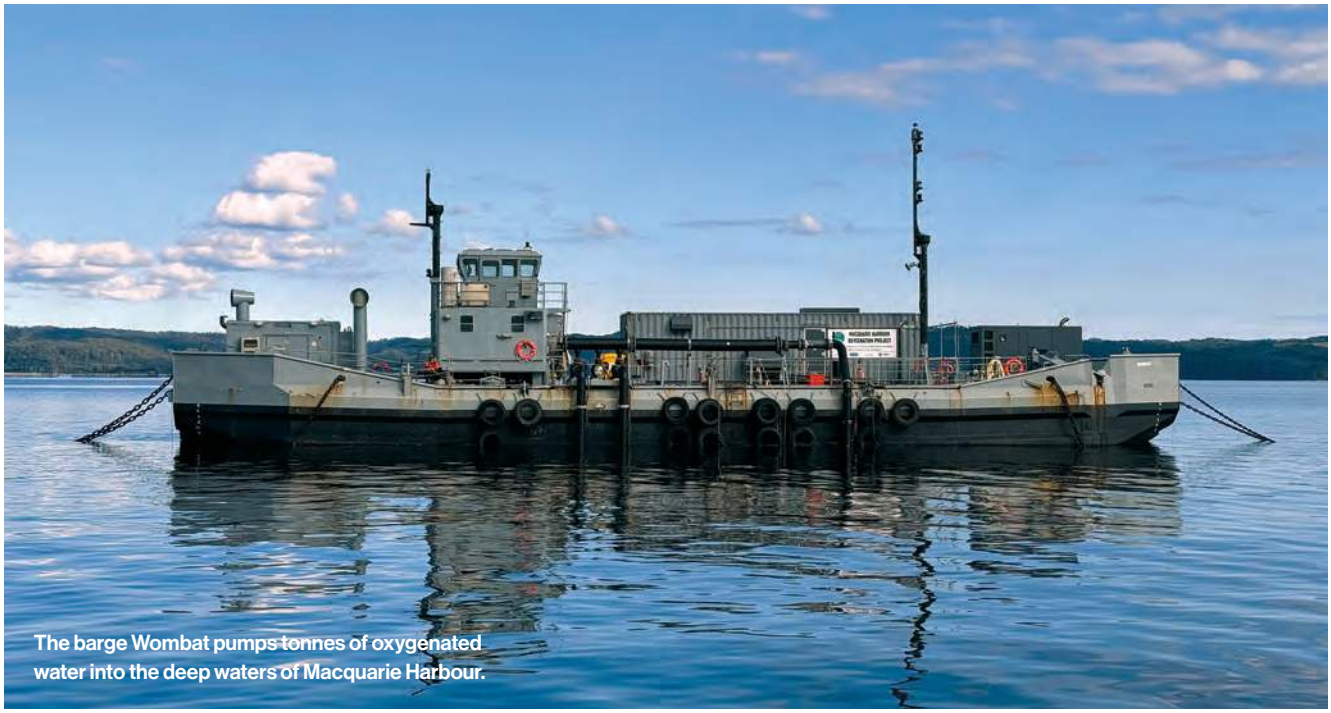
"The best captive breeding program is the one you don't need anymore," Moreno says.

However, the captive animals have been held in tanks in pristine conditions, with water high in oxygen, so it is unclear how they will fare in the wild. That is, unless oxygen levels improve.



DAVID MORENO IMAS

A Maugean skate raised as part of the IMAS captive breeding program.



The barge Wombat pumps tonnes of oxygenated water into the deep waters of Macquarie Harbour.

Re-oxygenating Macquarie Harbour

In 2024, researchers began a pilot study that used a modified barge to pump reoxygenated water into the harbour.

"We essentially were bringing water up from 30 metres [below the surface], where it's low in oxygen but it's saline, and then we had a system that pumped that water full of oxygen, and then we took that saturated water and we put it back down at depth," says Ross, who heads the project.

"Then we monitored all around that point. So we've got real time sensors of oxygen, currents, heavy metals, fauna..."

When tests showed that the oxygen was staying down at depth and spreading out as required, the team started scaling the operation. They are now injecting four tonnes of dissolved oxygen per day into the harbour, with further increases to come.

Ross believes this is a promising tool to promote oxygen levels in the harbour. Data shows that levels are improving, but only partly due to the reoxygenation project. The recovery also comes from a reduction in salmon farming (down to 9,500 tonnes in 2024) and a few years of low river flows, meaning ocean water can more readily enter the harbour.

However, the system requires ongoing monitoring to know whether it is rebalancing.

"In the next few years, we can become more confident as to whether that's a genuine recovery, because we know that oxygen can come up and down," Ross says.

The Wombat sits in Maquarie Harbour.

LEFT TOP AND BOTTOM: IMAS

Looking to the future

So, can the skates and the salmon industry co-exist?

"We've got good signs in terms of oxygen levels, and some encouraging signs seen with skate numbers," Ross says. "That would tend to suggest it's possible."

But, he adds, we need to see if these conditions are sustained, and whether the system can be in balance with the salmon biomass.

"It's not an opportunity to take our hands off the wheel," he says.

Moreno agrees that the conditions of the harbour are vital to skate survival.

"What needs to happen for the remediation of the species is the remediation of the habitat," he says. "One doesn't exist without the other.

"One thing that the science definitely shows with certainty is that if conditions are improved, every characteristic – genetic, physiological, biological, reproductive – of the species suggests that they have the capacity for recovery. So if you give them an inch, they'll take it and go a mile."

However, Moreno also notes that the skate will likely remain endangered – "it's reliant on this one place, so it's always going to be vulnerable," he says.

"Micro-endemics are rare. Large, vertebrate, carnivorous micro-endemics are incredibly rare all around the world. In Tasmania, we are very lucky to have had three: the Tasmanian devil, the Maugean skate and the thylacine.

"One of them, of course, is a textbook example of what can happen when a conservation intervention doesn't happen on time."

But the research is going full steam ahead, and there are reasons to be optimistic.

"We're monitoring in the field," Moreno says. "We're trying new technologies. We're working hard on novel molecular and genetic analysis to try to understand the history of the population.

"We're looking into assisted reproduction technologies for artificial insemination – anything that can help with the captive breeding.

"We're trying everything."

But the scientists are only one part of the equation that determines the skate's fate, which also includes federal and state politicians, the salmon industry, conservation organisations, grassroots movements, local businesses and more.

"Our job is to produce the best possible quality science to inform everything that's happening – all the management actions and population recovery and action plan," Moreno says. "And that's what we try to do, regardless of what's happening outside of that."

What happens with the skate will be a litmus test for the future of other species, too.

"The reality is that changing environmental conditions are going to affect the vast majority of marine species in coastal habitats in the next 30 years, and what we're seeing here is sort of a microcosm of what's coming for a lot of species," Moreno says.

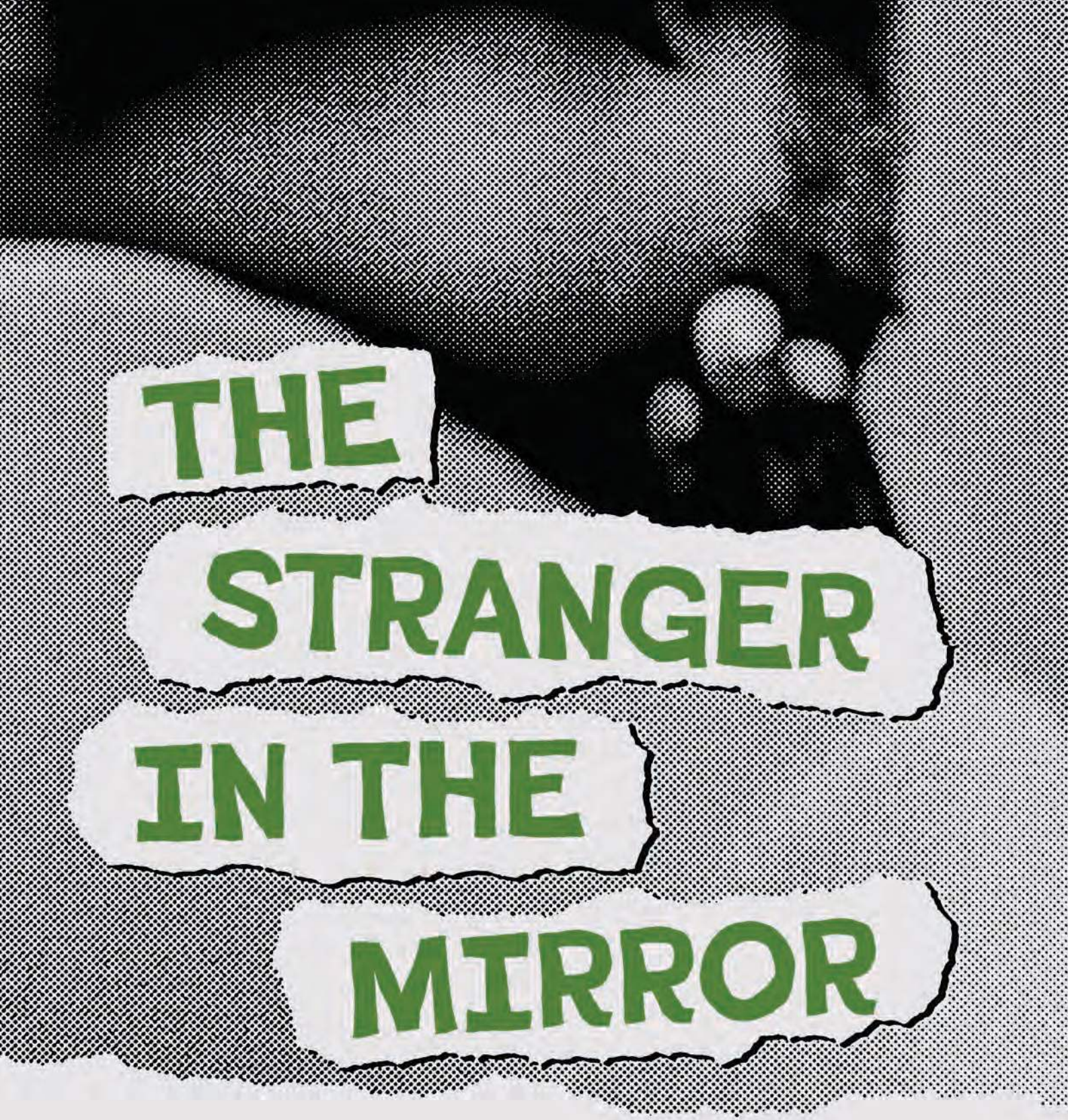
The skate will serve as a model for understanding how other species will react – and a model for what the research and management processes might look like to successfully help a species recover.

It'll be a challenge, Moreno adds: "This is a remote, not very abundant, cryptic, endangered animal, so it's a hard problem. But that's our job – to find solutions to hard problems."

Lauren Fuge is a former editor of *Cosmos*. She is a winner of the UNSW Bragg Prize for Science Writing and an AAAS Kavli Award for her work in *Cosmos*.

A scientist sifts through a sample from the harbour floor, looking for macrofauna.

IMAS



THE STRANGER IN THE MIRROR

Small, slender and short-lived, with broad noses, big, dark-adapted eyes, living underground, and in the shadows of a shattered, steamy, chaotic world. **Richard Musgrove** asks: will this be us in 10,000 years?

Climate change is the greatest challenge in human history – current trends could have us eventually approaching extremes not seen on our planet for 15 million years. Will a destabilised global climate wreak economic havoc, leading to societal collapse, mass mortalities, even extinction? Or will we pull ourselves out of this spectacular self-imposed nose-dive?

Which raises the question – what if we don't? How will humanity change on a much hotter Earth?

Mesopithecus pentelicus thrived in the rainforests of the late Miocene, 7 million years ago.

MAURICIO ANTÓN

Numbers matter

Uncharted territory approaches as we nudge the Paris Agreement's 1.5°C above preindustrial levels, on track for a potentially catastrophic 2.7°C by 2100. What about 2200, or 3200?

Globally, days above 50°C have doubled since the 1980s – in Australia, Pakistan, India and the Persian Gulf – with the 'feels-like' temperature often higher. Even immediately reduced carbon emissions will still mean lingering planet-wide heating and associated effects for many thousands of years.

Our adaptability has led us this far, but what does evolution have in store for our species if we don't rise to face our greatest challenge?

The answer is unlikely to be in the mirror.

Nothing sweats like us

To understand where we are going, we need to examine how we got here and the drivers that made us what we are: the most successful mammal on the planet.

Let's step back 7 million years. Imagine the leafy-green chaos of a closed canopy rainforest. Noisy, drippingly-humid, multilayered and hugely biodiverse, and humming with life. Apes, which may have been bipedal and would be hauntingly familiar to us, hang out in trees and forage on the forest floor. There's plenty of food and water. Life is good.

"We are the most superb tropical animals," says Emeritus Professor Duncan Mitchell, of the School of Physiology at the University of Witwatersrand, South Africa.

"Nobody copes with heat better than humans do, and that's because of our immense capacity to sweat.

"Problem was, we evolved that sweating capacity in canopy forest where temperatures were 20°C to 32°C, no wind, no solar radiation penetrating through the forest." We could comfortably sweat buckets because there was always more water nearby to drink. And we didn't have to exercise much to survive, says Mitchell, because food was plentiful.

Duncan Mitchell is Emeritus Professor of the School of Physiology at the University of Witwatersrand, South Africa.

But climates change. Rainforests dry, gaps appear, and savannah grasslands spread. We were left to manage with the sweaty physiological tools inherited from our rainforest ancestors. Evolution does that – working with what's at hand. Staying alive now meant more exercise, and more sweating. So, staying close to, or carrying, water was now a matter of survival, says Mitchell. And our developing noses (we are the only ape with such endowment) allowed us to carry the jungle with us, in a sense, warming and moistening each breath.

Fast forward 4.6 million years – the Pleistocene Ice Age is well underway. This 2.6-million-year epoch of extremes spawned continent-spanning ice sheets and massive grinding glaciers. Blistering cold has pushed average global temperatures down to around 8°C.

You might see our earliest ancestor in the genus *Homo* – *H. habilis* – around 2.3 million years ago [mya]. *H. ergaster* (also known as African *H. erectus*) would appear around 1.8mya. It was the first of our line with human-like proportions – with long legs and relatively short arms, tall and slender and possibly mostly hairless.

H. heidelbergensis follows, giving rise to Neanderthals (*H. neanderthalensis*), whose compact and sturdy build kept heat around internal organs, says Michelle Langley, Associate Professor of Archaeology, at Griffith University. Their probable cousins, the Denisovans, were high altitude specialists. Then there's us – the 'generalist specialist', *H. sapiens*.

Now, we stand alone. No cousin-species remain, although Neanderthal and Denisovan DNA in our genome suggests there was a little genetic mixing along the way.

Cultural and behavioural innovation and adaptability allowed this rainforest-evolved ape to withstand the harshest conditions the planet could throw at us, as we spread across the globe, adapting to most conditions anatomically, behaviourally and culturally.

Arctic cold favoured greater body volume to surface area, allowing those with relatively bigger bodies and rounder heads to survive better and pass on their genes more often. Paler skins made more essential Vitamin D production possible. Contrasting hot climates favoured tall, lanky bodies allowing more efficient heat loss, says Langley, and darker skins provided better protection from damaging UV rays and perhaps tropical diseases.

Be cool or be dead

We are still that naked tropical ape under our clothes and inside our air conditioned spaces.

Heat balance is the key, says Mitchell. "We have to be able to make sure we can dissipate the heat we generate by exercise into the environment, so that we can achieve heat balance even with heat load." The alternative is heat exhaustion and eventual death.

And sweat is the key to losing that waste heat. Sweat evaporates, cooling our skin,

Michelle C. Langley is an Associate Professor in the Australian Research Centre for Human Evolution at Griffith University.

making use of the "water vapour pressure gradient", says Mitchell.

Water vapour pressure (WVP) is the amount (the 'partial pressure') of water vapour in wet air, Mitchell says. Called 'partial' pressure because air has other components which also exert pressure, atmospheric water vapour pressure varies with temperature and relates to how much water vapour is in the air (absolute humidity), not how much moisture the air can hold (relative humidity).

Our skins continually respond to temperature, sun and wind as we move through our individual microclimates. Evaporative cooling – sweating from the skin and loss of moisture from the mouth and upper respiratory tract (i.e. nose and nasal cavity, mouth, throat and voice box) windpipe, cools us down. But this evaporative cooling only happens if the WVP of the air touching our bodies is lower than that of the warm sweat on our skin. This works even at 100% relative humidity, although there, your skin must be at a higher temperature than the air, says Mitchell.

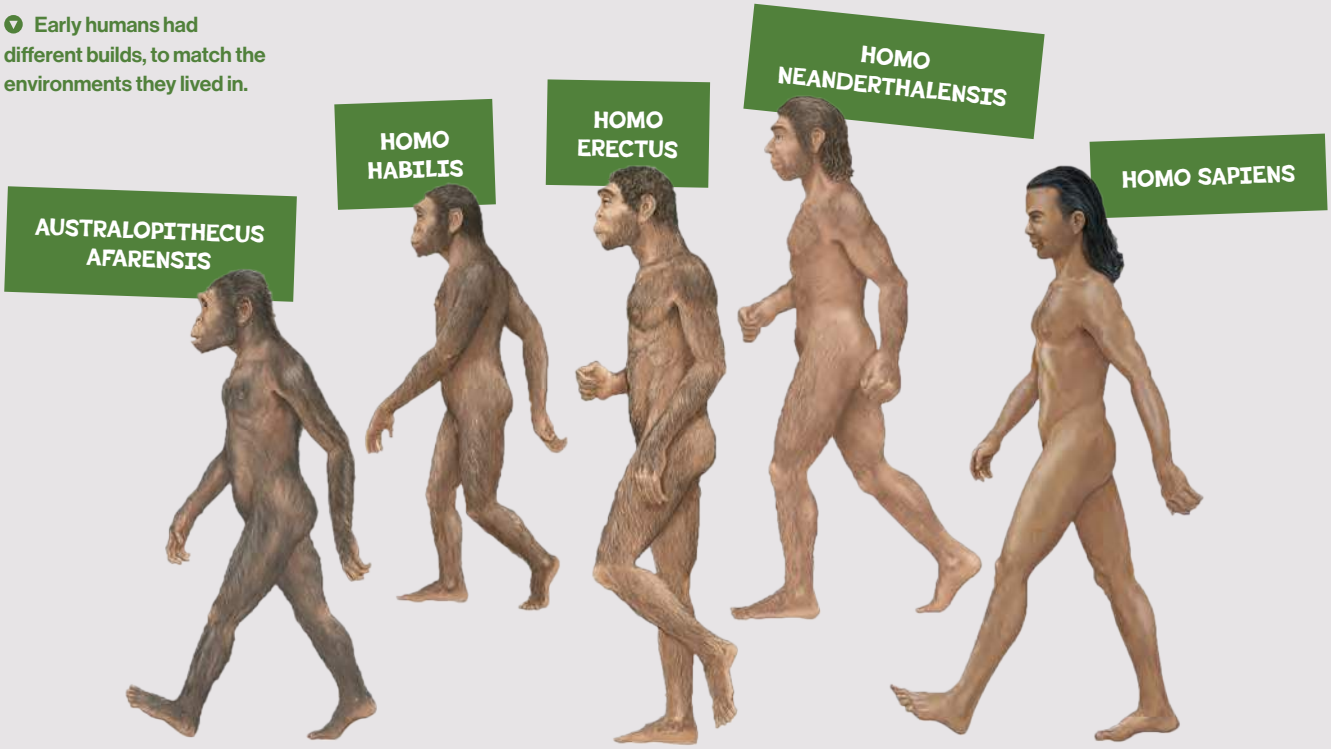
But there are limits. And here's where global warming comes in. As Mitchell says, "we can evaporate sweat if environmental water vapour pressure is below 60 hectopascals [hPa], though it gets harder and harder to evaporate enough as the WVP approaches 60hPa".

So, what does that mean in the real world? Look at the Bureau of Meteorology WVP map for the week ending January 25, 2025. Water vapour pressure tops out at about 36hPa, around Australia's far north-west, for now. But water vapour pressure is rising about 7% for every degree of global warming.

Global temperatures have increased 1.3°C since the Industrial Revolution, and we are nudging 1.5°C, on track for around 2.7°C of warming by 2100, call it somewhere between 2.2°C and 3.4°C. This could mean 3.9°C to 5.6°C of warming by 2200-2300.

Around 3°C of warming means 50°C days in Sydney and Melbourne become

Early humans had different builds, to match the environments they lived in.



GETTY IMAGES / ENCYCLOPAEDIA BRITANNICA

common, per *The Conversation*. Double that warming by 2300, and the consequences are unthinkable.

Rising temperatures might push up the 36hPa WVP to around 41hPa by 2100 (at 7% per degree of warming), and to more than 52hPa by 2300 or sooner. Meanwhile, the WVPs in more temperate regions will also increase in concert.

"Assuming water vapour continues to rise, those WVPs are highly likely," says climate change specialist, Stephen Turton. The last time CO_2 levels were this high (400-600 ppm) was the Miocene Climatic Optimum, 16.9-14.7 million years ago.

There goes Northern Australia – no sweat! And Australia won't be alone.

We can't live in such environments if we can't sweat. "Such 'deadly heat' might mean that some areas are just abandoned," says Dr Michael Grose, Senior Climate Researcher at CSIRO.

Higher WVP also means more extremes – droughts and bushfires, rain, storms, floods, and rising sea levels – a destabilised climate wreaking havoc with our economies.

As Grose told *Cosmos*: "We've already locked in ongoing sea level rise for hundreds of years that's going to just continue inexorably to rise."

And projected economic impacts include 12% reduction in GDP per 1°C of warming, meaning (assuming now as '0'), a 12% reduction by 2100, and perhaps a 48% reduction by 2300 or sooner. As climate change accelerates, effects will multiply, and disruptions will reverberate through supply chains, making everything less efficient and reliable. Those disruptions will affect the very infrastructure we're building to fight against further warming, and to mitigate against its effects.

People better start thinking about 2200, says Mitchell.

Stephen Turton is Adjunct Professor of Environmental Geography at Central Queensland University.

Dr Michael Grose is a Senior Climate Researcher at CSIRO.

Climate wars

Climate change will become very real when the air conditioning fails.

Will we adapt? Of course we will – to a point. We are the world's most successful mammal after all. But we have no evolutionary experience of the predicted extremes. Yes, there were Miocene mammals, but not us.

There will be conflict, as Mitchell says, "the most catastrophic and probably the most predictable consequence of climate change is war". Turton agrees: "There would be depopulation because of climate change and possibly political instability. There will be wars fought around climate resources, particularly water; places where you can grow food, and where you can't because it'll be too hot."

The worst possible scenario may be a slow whittling away of capacity, capability and global co-operation. Playing out like a post-apocalyptic movie. Decades of decline amid accelerating climate chaos.

As Professor Emeritus Michael Gillings, of Macquarie University, puts it: "If we don't get our emissions under control we're heading for a future where everything becomes less predictable, food supply, energy supply, housing. Everything degrades, and we'll go back through an agrarian stage to isolated villages and gradually devolve back to being hunter gatherers again."

Who are the survivors?

If you want to prepare for the worst, it might get a bit uncomfortable. "The only way that you can prepare yourself physiologically for work in the heat is to work in the heat. As soon as you switch on an air conditioner, you're blocking your ability to cope with climate change," says Mitchell. But, what about the elderly, the very young, the pregnant, the poor and poorly nourished, the sick?

It's hard to not envisage a scenario out of the dystopian movie, *Mad-Max*. Although some form of the moisture-conserving 'stillsuit' featured in Frank Herberts's book, *Dune*, could become a thing.

Physical work, including farming, and general activity would become nocturnal or crepuscular (dawn and dusk), says

1.5L of sweat evaporating per hour can produce 1000W of cooling.

ISTOCK / GETTY IMAGES PLUS / HUNG CHIN LIU

Mitchell. Major sporting events are already starting late, including 2023's Rugby World Cup in Paris, and this may set the pattern, he adds. Farming in warmer areas will become trickier as plants don't have a choice to hide in the shade – Gillings suggests a focus on hydroponics.

Nocturnalism, of a sort, is not new for us, unlike the sleep-all-night-routine. Before the Industrial Revolution biphasic sleep (early to bed, up at midnight for a few hours activity followed by a second sleep) was common. And many warm climate cultures already integrate a siesta after lunch.

Living underground may also become more attractive. This is a very ancient practice, but we can look to the modern example of Coober Pedy to see how it might turn out. Food again becomes an issue – it would depend on the food sources that could survive the changing climate, says Langley. Mushroom quiche anyone?

"Surviving populations are going to be those which can engineer their way out of it – smaller populations in the right place with the right solutions," says Langley. "Success could depend on their sociality and willingness to collaborate and work together for the greater good. Whether we go underground or under the water, life is going to be very, very different."

Human evolution?

It's impossible to know what exactly would happen to humanity after many thousands of years living on a vastly warmer world. On that timescale, evolutionary pressures might start to change our very makeup.

Perhaps nocturnalism would favour those of us with particularly good night vision. We could end up with more light-sensitive rod cells and larger eyes. Conversely, genes for colour-blindness and short-sightedness may not survive the slide back to hunting and gathering. What colour were those poisonous berries again?

Smaller size could be an advantage, particularly in droughts. Smaller people have comparatively larger surface areas, so they can lose more heat through skin blood flow rather than through sweating. Although this only works while the air temperature is below the 37°C our bodies maintain.

And lankier heat-shedding builds and perhaps broad noses could be favoured. Dry, cold air appears to favour narrower noses – a thinner air-stream being easier to warm and moisten, whereas warm, humid air presents no such challenges.

Lifespans will change. "Lifespan evolution is inversely proportional to mortality rate," says Gillings. "A slide back to hunting and gathering would mean selection for shorter lifespans, less height, more aggression." Because that's what would keep our species alive.

Climate change also means "rapid evolution of pathogens, including vector-borne diseases", says Mitchell, and as children are more prone to these diseases, there'll be selection for better immune systems. Mosquitos carrying Zika, Japanese encephalitis and malaria are likely to spread as it warms.

Michael Gillings is Emeritus Professor at Macquarie University.

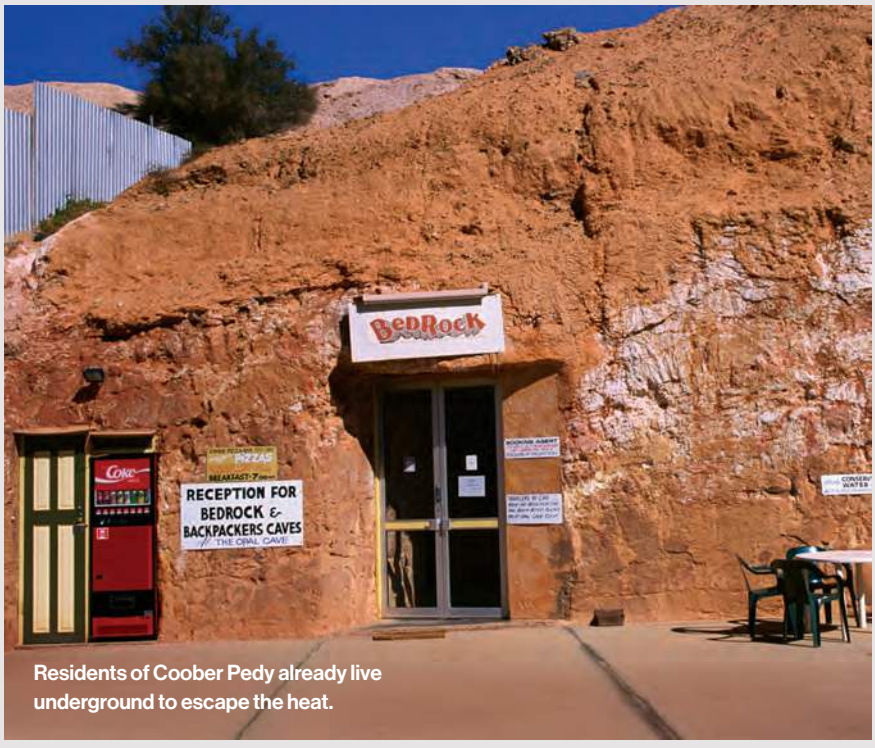
Aedes aegypti is a vector for many tropical diseases including dengue, Zika and yellow fever.

We will survive – in some form

"Climate change is not an existential risk," says Grose. "Unlike nuclear war, it will not wipe humans out. We will survive in this in one form or another, but there's a long way between doing great and being extinct, it just depends – what we do will determine how far [we go] down that road."

Will our distant descendants recognise us as human? Who is that stranger in the mirror?

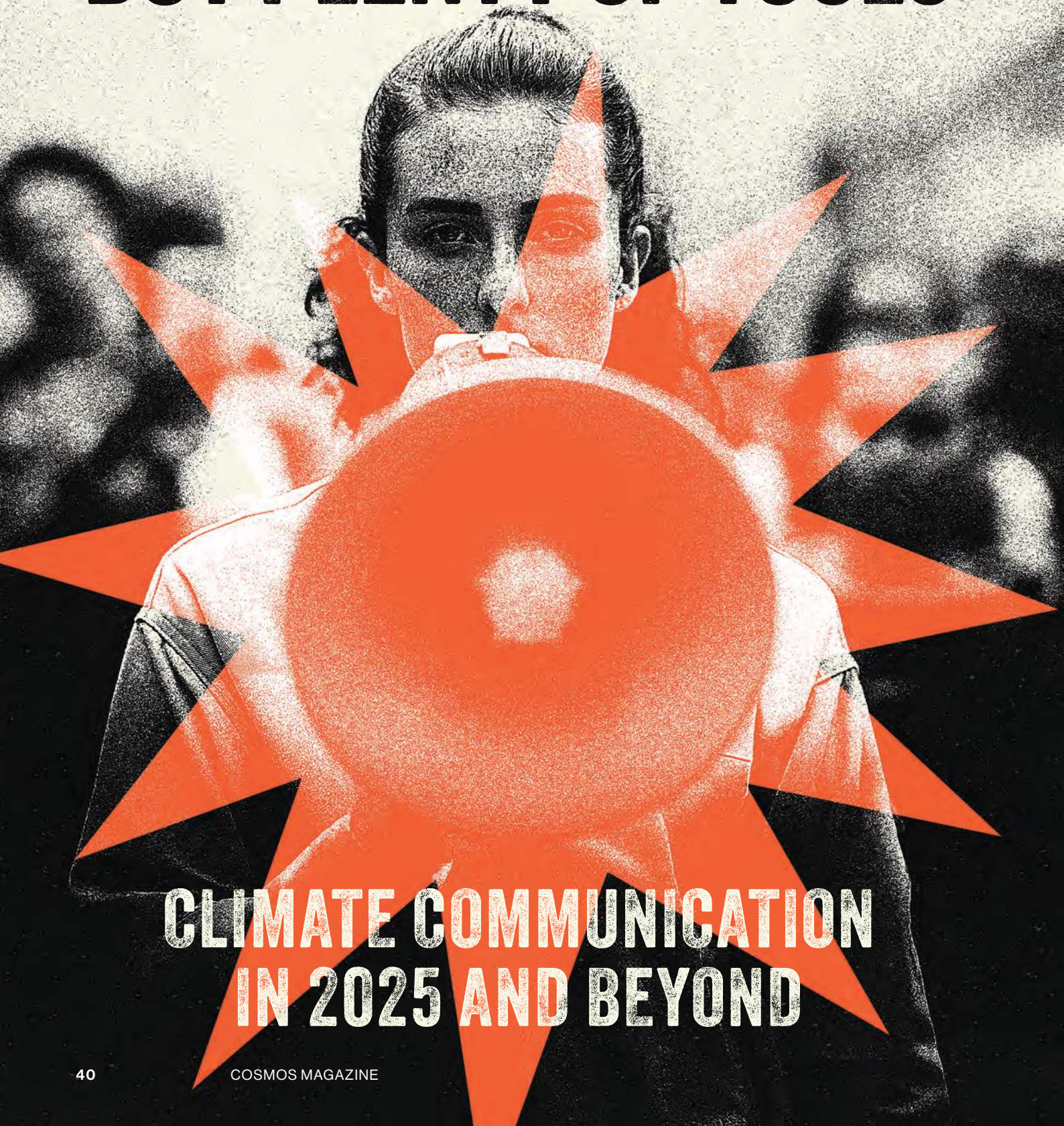
Richard Musgrove is a science journalist focusing on the environment, technology and health. His article on bioplastic art appeared in Cosmos 105.



Residents of Coober Pedy already live underground to escape the heat.

FROM THE TOP: GETTY IMAGES / JOAO PAULO BURINI / JOHN W. BANAGAN

NO SILVER BULLETS BUT PLENTY OF TOOLS



CLIMATE COMMUNICATION IN 2025 AND BEYOND

We've known about the causes and effects of climate change for decades, so why aren't we acting on it? **Lee Constable** finds the best ways to win hearts and cause real change.

Libby Lester is a Professor and Director of the Monash Climate Change Communications Hub.

As a climate communicator I am often asked by frustrated climate-concerned members of the public: "How do we get them to just listen to the science?" The 'them' in question varies from political leaders and corporations to family members and even complete strangers on the internet. The science in question is climate science.

Have we failed?

Libby Lester is Professor (Research) and Director of the Monash Climate Change Communications Hub.

"I was at a party recently and someone asked what I do. I said I work in climate communications. And they said, 'how's that going for you?' What could I say? 'Not well, we've failed,'" Lester told them.

Lester started communicating about climate change in the 1980s, first as a journalist, including as environmental reporter for the *Sunday Age* before moving into academia where she has spent the past 25 years focused on environmental and climate communication.

"There's been a massive change in awareness and understanding of climate change," Lester says, but adds "that hasn't led to the type or level of meaningful action we need."

Where are we now?

Dr Rebecca Huntley is a social researcher and author of *How to Talk About Climate Change in a Way That Makes a Difference*, a work that explores the importance of feelings over facts (or at least in conjunction with them) for having impactful climate conversations.

Dr Rebecca Huntley is Director of Research at 89 Degrees East.

Huntley and her colleagues have been tracking Australia's attitudes and action relating to climate change, publishing The Sunrise Project's Climate Compass.

Their data points to Australians falling into one of seven groups that reflect their attitudes and beliefs relating to climate change ranging from 'Alarmed' (the most concerned) to 'Dismissive' (climate deniers who may not just lack concern about climate change but be actively trying to prevent and delay climate action).

While over a quarter of us (26%) fall into the 'Alarmed' category, understanding that the climate crisis is both human-caused and impacting us now, it's important to note how many people sit somewhere in the middle between 'Alarm' and 'Denial'.

'Concerned' and 'Cautious' people made up a combined 40% of Australians in this survey, with both categories far outweighing the 10% who are outright climate deniers.

The climate is changing and so are our attitudes

The Climate Compass report demonstrates a change in attitude from 2020 to 2022 in several areas with another report due to be released in 2026.

In the most recent study, the majority of Australians identified as feeling more concerned about the climate than they were just two years before with weather, floods and bushfires cited as the top three causes for increased concern.

Extreme events like flood and fire may have a galvanising effect, however that isn't the case for everyone.

Hardcore climate denialists are a problem, especially those with a large platform, but, as Huntley says, "they're really only a small percentage of Australia, the larger problem is that within all of us is a level of denial".

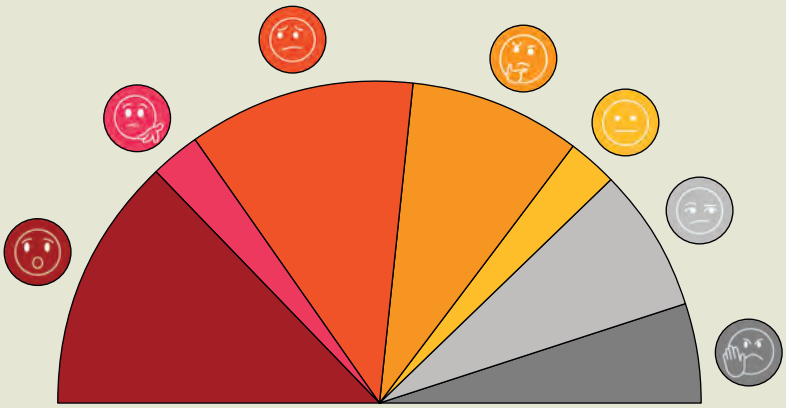
"Even people who are science literate and even people who say that they trust the CSIRO and want to hear from experts experience this level of denial or minima. At the core of it is the need to be innocent," Huntley explains.

This need for innocence drives some people further from reckoning with the climate reality as they want to believe this isn't something they could have seen coming, acted on earlier and could have done anything to prevent.

"And that happens in the face of the combination of truth and powerlessness. And all the science education in the world can't combat this kind of deep psychological social response to devastating effects."

THE CLIMATE COMPASS

Climate Compass divides Australians into one of seven groups based on their climate change attitudes and beliefs.



ALARMED

At 26% of the Australian population, the alarmed have the highest levels of concern about climate change. They believe humans are fully responsible for climate change and believe that climate change impacts will affect current and future generations.

ALERT

With 5% of the Australian population, the alert are highly concerned about climate change but think that other issues are more important. They also struggle to believe that any action they take will have an impact and some even believe that it is too late to take action on climate change at all.

CONCERNED

Comprising 23% of the Australian population, the concerned have slightly lower levels of worry about climate change but still see it as an important issue. They agree with the science of climate change but think it will be more of a problem for future generations so they have less urgency for action.

CAUTIOUS

At 17% of the Australian population, the cautious express some worry about climate change but overall feel it's an issue for the future and that other things are more important right now. Some of them don't fully believe that humans are responsible for climate change and they are concerned about the risks of phasing out fossil fuels.

DISENGAGED

Representing 5% of the Australian population, the disengaged are not engaged in climate change or any political issues. They are uncertain on the science of climate change and think if it is real that it is a problem for future generations and won't affect them.

DOUBTFUL

Making up 15% of the Australian population, the doubtful are not convinced on the science of climate change and don't believe that humans are the cause so they don't agree that it will affect them or future generations or see any need for urgent action. They believe that moving away from fossil fuels will damage the economy or have other negative impacts.

DISMISSIVE

And at 10% of the Australian population, the dismissive are climate deniers, they either don't believe climate change is happening at all or think it is a natural process not influenced by humans. They may be actively taking action to try and delay or stop action on climate change.

"WITHIN ALL OF US IS A LEVEL OF DENIAL"

Who should we be talking to?

A common refrain of communications is "know your audience". Communicators are encouraged to familiarise themselves with the demographic details, media consumption behaviours, daily habits and political views of their target audience in order to better craft their communications strategy and messages.

When it comes to climate change, the societal impacts are ubiquitous. The potential audiences for climate communication are many and varied. It can be hard to know where to start.

Another common concern of climate communicators is that they not spend their time and energy "preaching to the converted", in this case, the 'Alarmed'. Rather than focusing on shifting the perspectives of the 'Disengaged' and 'Doubtful', experts like Huntley encourage climate communicators to consider engaging with audiences in the middle ground who may be more open to shifting their attitudes (and even their actions) toward higher levels of concern.

Preaching to the choir isn't all bad

Climate protests are important platforms for community movements to gain media attention and apply political pressure around the issues of climate crisis, but Dr Hannah Feldman, from the Australian National University, suggests an added function for participants. The School of Cybernetics and Institute for Water Futures researcher has investigated how teenagers engage with climate change including through 'School Strike 4 Climate'.

"Does climate protest help? Well, yeah, on an individual level, it does. It really does empower individuals," Feldman states.

This is just one way that we can see how connecting with fellow climate-concerned community members (whether at community events or in protest) to share knowledge can be powerful, even if it just provides a sense of belonging and support for the psychologically and emotionally taxing work that is climate advocacy.

Climate protest can also function as an important forum for climate communications even amongst the converted.

"In the work that I was doing with teenagers, one of the things that came up over and over again is that as a community they use School Strike as an opportunity to learn," Feldman says.

"And people will bring along friends who aren't that interested or don't really know what's going on and will use it as a moment to do some of that communication. To learn about an issue, and to learn about politics as well because it is highly politicised."

Who should do the talking?

An important question climate communicators need to ask is: "Am I the right person to communicate this?"

The often deplorable treatment that experts suffered during the pandemic may suggest that scientists are a poor candidate as climate spokespeople today. However, recent research published in *Nature Human Behaviour* finds public trust in scientists is robust in most of the 68 countries surveyed. Of course, climate scientists aren't the only possible messenger.

Relatability and personal story are common factors in determining who is listened to on the topic of climate crisis. At a recent Bushfire Survivors for Climate Action event I attended, one survivor noted that, while she had always cared about and been outspoken about the need for climate action, it wasn't until she experienced the first-hand threat and tragedy of losing her home in the Black Summer bushfires that media and other opportunities to speak exploded.

One group of climate messengers with a uniquely strong voice are children. "It's really hard to argue with the safety of kids. It's like a powerful rhetorical device," Feldman says. "No one's going to be like 'who cares about the kids?'"

Sydney students attend the School Strike 4 Climate in 2023.

JENNY EVANS / GETTY IMAGES

Just as any messenger will have strengths and weaknesses (perceived or otherwise) when it comes to communicating with a chosen audience, child climate communicators face challenge too.

"What we see with youth protests is that people refute them in different ways," says Feldman, noting that the authority and knowledge of children who communicate about climate is often called into question.

What are we aiming for?

A common issue of science and climate communications is that communicators identify the audience they want to communicate with (the who) and the topic (the what) but neglect to ask themselves arguably the most crucial question – why?

What would successful climate communication look like? And what would the world look like for Professor Libby Lester to proudly proclaim "We've succeeded!" when someone asks her about the field of climate communications?

While climate action calls for climate mitigation (for example lowering greenhouse gas emissions) and adaptation (for example extreme weather preparedness and response measures that allow us to survive through climate change already in motion), climate justice puts equity and human rights at the centre of the climate conversation.

The United Nations' Sustainable Development Goals were created with the implicit understanding that climate change (and indeed all aspects of environmental sustainability) is a human rights issue and its impacts are not felt equally across society on a local or global scale.

Hannah Feldman is the Institute for Water Futures Research Fellow at the Australian National University.

The Paris Agreement adopted at the UN Climate Change Conference (COP21) focuses not only on climate mitigation to limit global warming but also includes provisions for climate justice by providing a framework for increasing the financial, technical and capacity building support for developing countries. This recognises that developing countries shoulder the highest burden and vulnerability when it comes to climate risks and the challenges of energy transition while being responsible for a much smaller proportion of the emissions responsible for the climate crisis compared to developed countries.

With this in mind we are seeing climate communicators and communications researchers focus their efforts toward the overarching goal of climate justice.

Just transition requires two-way communication

One of the most frustrating things in science communication is that telling people facts doesn't necessarily lead to a change in their beliefs or behaviours to align with those facts.

The most impactful climate communication need not focus on the science itself, instead communicating about the social or

Huntley talks at an event organised by Surfers for Climate.

SUPPLIED BY REBECCA HUNTLEY

political elements of the climate crisis. And using a climate justice lens can help identify key elements to make your message resonate with your audience.

In farming communities the conversation around just transition explores the impacts of climate change most felt by farmers compared to others. Farmers are unequally impacted by climate change events like flood, fire and drought. A just transition ensures the path to net zero and beyond doesn't disproportionately burden independent 'ma and pa' farms, allowing farming operations of all scales to transition and adapt to climate crisis.

But if you want to engage a community in a climate discussion, there's one thing that's non-negotiable – listening.

Lester's research on social licence and the energy transition explores this in Australia and across Asia in industries including forestry, dairy, fish farming, mining and energy. Many communities are facing significant changes both from climate change adaptation and the transition to clean energy. Facilitating that transition means talking with community members as the local industry and economy changes, but it also means communicating their experiences and concerns to politicians and policymakers.

Listening and patience is particularly important for engaging with Indigenous communities. Caring for Country has been central to Aboriginal and Torres Strait Islander cultures for millennia while colonisation has gone hand-in-hand with environmental degradation and oppression of Indigenous peoples.

▲ Around 750 workers lost their jobs when Hazelwood power station closed. A just approach means supporting those impacted by climate action as well as climate change.

▼ Dried grapes hang from a vine. Worldwide, grape harvests have advanced 2-3 weeks over the past 40 years. The resulting changes to grapes also affect wine quality and style.

The transition away from fossil fuels is an opportunity to create a world that is not just more sustainable in an environmental sense but in a social sense too, where the benefits and opportunities of the transition are shared equitably rather than at the cost of former coal mining communities, First Nations people and the most vulnerable in our society. This is an opportunity recognised by organisations such as the First Nations Clean Energy Network that aims to "ensure First Nations people play a central role and harness the opportunities from Australia's renewables boom".

No silver bullets but plenty of tools

Knowing your goals and listening to your audience are keys to success. However, Lester cautions that "ultimately, there is no silver bullet – reaching people requires strategy, flexibility and a lot of persistence".

Lee Constable is a science communicator, author and presenter, who focuses on science, sustainability and society, and where they collide.

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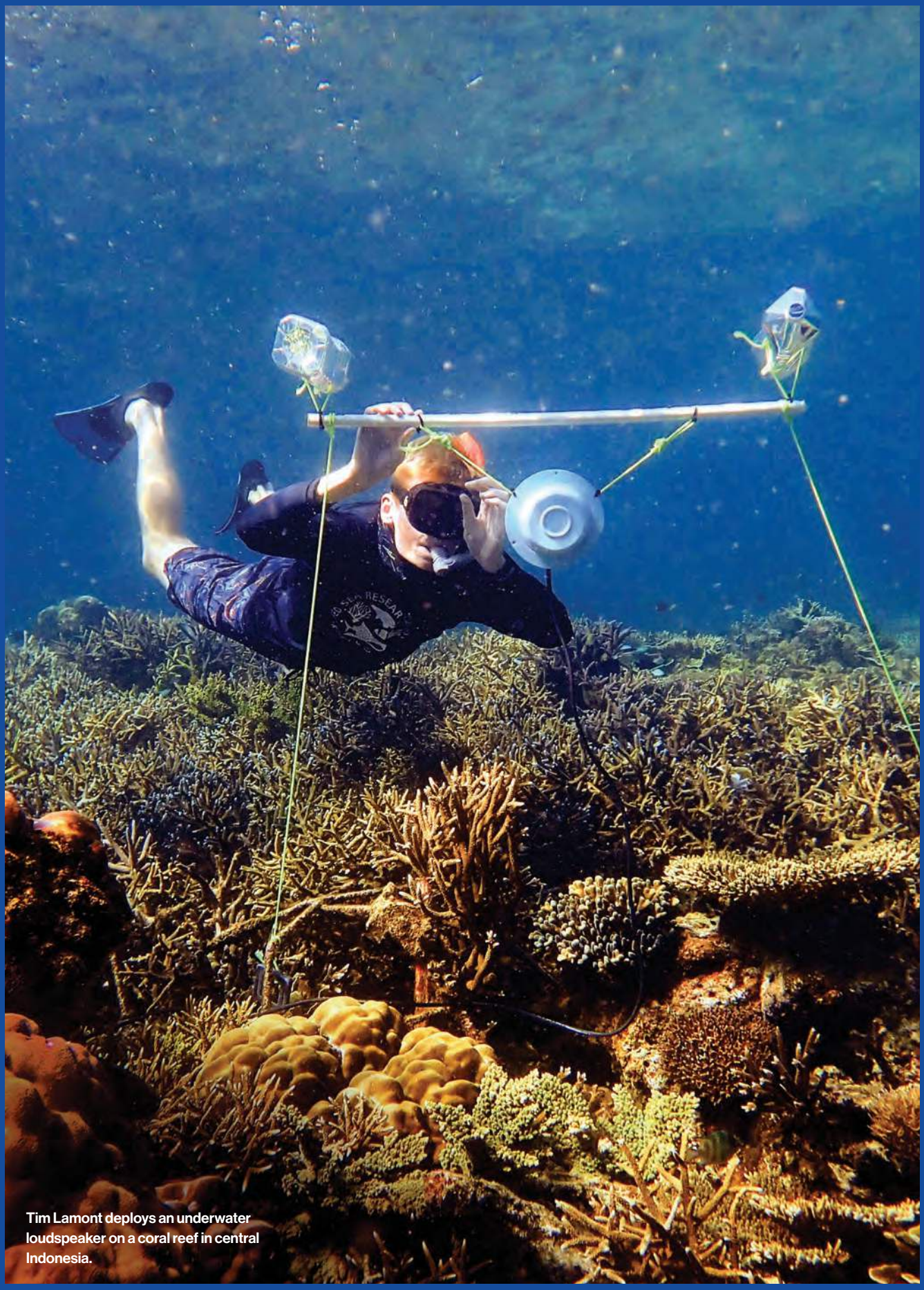


Tim Lamont deploys an underwater loudspeaker on a coral reef in central Indonesia.

HARRY HARDING

GREAT BARRIER GRIEF

It's well recognised that climate change is causing a mental health crisis. How are scientists on the frontline coping? **Denise Cullen** reports.

Tim Lamont was surveying the coral reefs off Lizard Island in Far North Queensland as part of his PhD in coral reef ecology when he first felt his mood start to take a downhill slide.

Wild weather and successive mass bleaching events had taken their toll on the Great Barrier Reef. And painstakingly documenting its degradation, day after day, week after week, was a grim and demoralising task.

"A lot of us on that research station were finding it quite emotionally draining to be doing these surveys of reefs that were just battered," says Lamont, who is now a research fellow in marine ecology and ecosystem restoration at the Lancaster Environment Centre in the UK.

"I was losing sleep over it, and even weeks and months later, I was still having flashbacks."

Lamont (then Gordon) and his colleagues wrote a short letter that was published in *Science* in 2019. They made the point that "environmental scientists must be allowed to cry".

Lamont says they didn't know if anyone would even read it, let alone reply. But the response was immediate and overwhelming – mostly from other scientists who expressed relief that they weren't the only ones struggling to put on a game face as inwardly, their hearts were breaking.

The conversation continues, as others write books, host events and launch various projects designed to explore their own and others' experiences with troubling climate-related emotions.

"We said our 300 words and we didn't have much more to add," says Lamont. "And then we watched in awe as all sorts of other people said brilliant stuff off the back of it."

TIP NO.1 FROM SCIENTISTS ON COPING WITH CLIMATE DISTRESS

Hope can be both a noun and a verb, Tim Lamont points out. Using hope as a noun suggests reliance on external circumstances and a lack of control. But when used as a verb, hope becomes a conscious choice. "It's a way of life and a decision," he says.

▲ Bushfires rage in the Blue Mountains in 2019.

The rising tide of climate distress

Many Australians have already faced the physical consequences of climate change.

A poll of more than 2,000 people undertaken by the Climate Council of Australia found that 4 in 5 respondents had experienced some form of extreme weather disaster, such as flood or bushfire, since 2019. Of these people, 1 in 5 say the event had a "major or moderate" impact on their mental health.

But the mental health effects of climate change aren't confined only to those who, say, watched their home burn to the ground or fill with floodwaters.

Research published in 2022 in the *Australian & New Zealand Journal of Psychiatry* indicated that 9.4% of respondents had significant eco-anxiety – a chronic fear of environmental doom. Of those who had a direct experience with a climate-change event, 25.6% met the screening criteria for post-traumatic stress disorder. And of those who did not have direct experience, or who were unsure, 15.7% met the criteria for pre-traumatic stress, a "before-the-fact version of classic PTSD ... [arising from] anticipations of a catastrophic future".

In 2022, for the first time, the Intergovernmental Panel on Climate Change also assessed that exposure to climate change, even vicariously, was imposing widespread and cumulative effects on mental health globally.

"Anxiety about the potential risks of climate change and awareness of climate change itself can affect mental health even in the absence of direct impacts," the panel noted.

▼ A dead fish sits on the dried bed of Wivenhoe Dam near Brisbane in 2007.

TIP NO.2 FROM SCIENTISTS ON COPING WITH CLIMATE DISTRESS

Occasionally narrowing your focus can quell overwhelm, says Gretta Pecl. She's observed that young researchers tend to do better if they're working on a small, well-defined problem – such as physiology in lobsters. "The broader the problem they work on, as in big picture climate change (issues), the more quickly they get depressed, because they realise that we're not going to solve this problem anytime soon, or at all," she says.

GETTY IMAGES NEWS / DAVID GRAY / STRINGER / GETTY IMAGES NEWS / JONATHAN WOOD / STRINGER

Researchers in the trenches

It seems no-one is immune from the mental health effects of climate change. Yet a 2023 paper published in the *Yale Journal of Biology and Medicine* highlighted that researchers in climate-related careers represent one group of people who were more vulnerable than others. Others include young people, indigenous communities, and climate activists.

One factor underpinning scientists' vulnerability is their proximity to the problem.

When you're involved in tasks like monitoring the state of coral reefs amid rising sea temperatures and ocean acidification, or tracking populations of endangered species to identify extinction risks, or measuring the retreat of glaciers due to global warming, the evidence is in your face – every day.

As Lamont pointed out in his letter to *Science*, there's also the "dangerously misguided" belief that scientists must be dispassionate observers.

This resonates strongly with Olly Dove, Climate Research Officer within the National Environmental Science Program Climate Systems Hub. Dove participated in a climate distress panel as part of last year's Australian Marine Sciences Association annual meeting combined with the New Zealand Marine Sciences Society.

"The recurring themes that were coming [were] that people felt they'd had to repress their emotions in the past to be seen as objective and qualified and professional," she says.

And this repression could have serious consequences.

"It could cause burnout, or people being apathetic at work, or losing passion ... and leaving the climate change sector," she says. "But you need those passionate people who do feel it to stay working in that field, because they're the ones who'll have the extra drive to make things better."

As an added pressure, the role of environmental scientists also puts them in regular conflict with climate change deniers. However, Neville Nicholls, an Emeritus Professor within Monash University's School of Earth Atmosphere and Environment, says this creates a lot less wear and tear than it used to.

Nicholls recalls that in the 1990s, scientists who sounded the alarm about global warming were often ridiculed, silenced, verbally abused and threatened.

He almost lost a colleague to suicide during 'Climategate' in 2009. This scandal involved the release of hacked emails belonging to climate change scientists, which wrongly suggested that they were fudging the data to bolster the case for human-caused global warming.

This "derailed" public trust and momentum in global climate change mitigation efforts. "That was both depressing for individual scientists and it was bad for the world," Nicholls adds.

While pockets of scepticism remain, Nicholls takes some heart from the fact that climate change is widely accepted today by governments, businesses and members of the public.

"It's been a big change from just a few scientists hitting their heads against brick walls," he says.

TIP NO.3 FROM SCIENTISTS ON COPING WITH CLIMATE DISTRESS

Working on solutions can provide a balm. Many scientists deliver talks to raise awareness, while others provide media commentary. While not climate-change specific, Olly Dove hosts the That's What I Call Science podcast. David Karoly, Emeritus Professor at the University of Melbourne and Councillor on the Climate Council (of Australia), serves as a pro bono expert witness in climate change-related litigation. "The first case that I was involved in was back in 1996–1997," he says. "I have always thought that getting involved in court cases is a little bit like getting involved in public communication. It's just communication to judges, but it has much higher potential impact."

German tourists wear masks due to bushfire smoke in 2019.

Brisbane homes underwater during the 2011 floods.

GETTY IMAGES NEWS / JENNY EVANS / STRINGER / ISTOCK / GETTY IMAGES PLUS / ON-AIR

How climate change affects mental health

In 2008, psychiatrists diagnosed what they believed to be the first case of "climate change delusion".

During Australia's severe drought, a teenage boy had stopped drinking in the belief that his water consumption would deplete supplies and thus kill millions of others. It's an extreme example, but it also raises the question: How do we maintain mental health on an ailing planet?

A flurry of research into the effects of climate change on mental health is now emerging.

The psychiatric bibles DSM-5 and ICD-10 offer no specific references to mental disorders related to climate change, meaning that new terms capturing different gradations of experiences have to be created.

Gretta Pecl is a professor in marine ecology at the University of Tasmania. She is "genuinely frightened about the future" and challenges the use of terms such as eco or climate-anxiety.

"Anxiety is a pathologised description of someone's behaviour ... a reaction that is beyond what is considered normal," she explains. "But feeling distressed about the world the way that it is at the moment and the challenges we're facing is a completely rational, logical response."

Amid the arguments about nomenclature, psychology is grappling with an increasing number of new validated psychometric tests to measure the different dimensions of eco-emotions.

These currently range from the 32-item Inventory of Climate Emotions, which probes anger, enthusiasm, anxiety and sorrow, to the 81-item Environmental Distress Scale, which measures 6 environmental distress components, including the concept of solastalgia. Coined in 2007, this term describes the emotional distress caused by environmental change, particularly when it affects the place people call home.

Gretta Pecl is a professor in marine ecology at the University of Tasmania.

Neville Nicholls (second from right) presents at the Tropical Ocean Global Atmosphere conference in 1995.

NEVILLENICHOLLS

Bringing coping skills to the forefront

Lamont says scientists can learn a lot from other professions in which distressing circumstances are part of the everyday, such as health care, disaster relief, law enforcement and the military.

"[People have learned] how not to take that home ... or allow it to cloud their judgment in moments where professional precision is important," he says.

He suggests that improved psychosocial working environments for scientists might include systematic training, early intervention debriefing after disturbing events, formalised social support from colleagues and managers, and therapeutic counselling.

But coping with climate change concerns as an individual requires a different set of tools from what is usually prescribed for those with mood or anxiety disorders, Pecl adds.

"The standard advice often includes getting out into natural spaces – but a lot of the time, it's a trigger," she says.

Last year, for instance, members of Pecl's ocean swimming group revelled in the warmth of the water in April, whereas she felt nothing but dread.

Another reminder came when she took her children to visit the Great Barrier Reef.

"Everyone was saying, 'Oh look at all the amazing coral', and I was swimming around thinking, 'My God, this has declined since the last time I was here'," she says.

TIP NO.4 FROM SCIENTISTS ON COPING WITH CLIMATE DISTRESS

Though climate change issues feel urgent, it's important to take breaks to avoid burnout. "When you're personally drained and exhausted, you pull back, and you look after yourself," says Pecl. "And when you've got energy, you push out into those spaces where you're probably not going to make a difference, but you want to give it a go anyway."

TIP NO.5 FROM SCIENTISTS ON COPING WITH CLIMATE DISTRESS

Engaging in one-on-one treatment with a climate-aware therapist can help people address climate-related trauma, or process stress, fear and anxiety about the future. Group training sessions are also emerging. For example, Pecl organised Karen Grant Outdoor Counselling to run a 1-day workshop for people working at her Centre for Marine Socioecology. The 'How do we live our best life, knowing what we know?' workshop was targeted at researchers working on challenging issues like climate change and biodiversity loss.

Tim Lamont is a marine biologist at Lancaster University.

Focus on feelings, rather than facts

For decades, by virtue of their training, climate scientists have focused on the facts. But the shift towards a greater emphasis on emotions may hold the keys both to maintaining personal mental health, and mobilising the masses towards greater climate change mitigation efforts.

A deep vein of psychological research suggests that identifying and naming so-called 'negative' emotions (also called affect labelling) can reduce subjective feelings of distress.

It also draws a distinction between psychological stress that leads to positive outcomes, such as pro-environmental behaviour, or that which leads to negative outcomes, like throwing in the towel.

Nicholls acknowledges many legitimate reasons to be angry and anxious about the future. "But your anxiety shouldn't be so strong as to stop you working," he says.

The changes he's seen over the course of his career allow him to describe himself as "cautiously optimistic" about the future. "I'm probably more optimistic now than I've been at any time in the last 30 years," he adds.

Pecl agrees that maintaining "active hope" is important.

"I actively choose hope," she says. "Not the wistful, whimsical version of hope, but the 'We've just got to roll up our sleeves and keep going anyway' kind, because I'm not prepared to give up at this point.

"I remind myself ... that every fraction of a degree of warming that we avoid is pain and suffering averted, and it's worth it."

Gretta Pecl shares her knowledge with young scientists at Squidfest in 2022.

GRETTA PECL

TIP NO.6 FROM SCIENTISTS ON COPING WITH CLIMATE DISTRESS

Start a personal project. Jonica Newby documented her own experiences by writing the book *Beyond Climate Grief* (NewSouth Publishing 2021). Joe Duggan, then a science communication student, launched the Is This How You Feel? project – an exhibition of letters from climate scientists that encouraged honest and heartfelt reflection.

Denise Cullen is a freelance journalist and forensic psychologist based in Brisbane. Her last story for Cosmos looked at how research using organoids may one day help cure genetic diseases.

JOHN JAMES AUDUBON

The eastern chipmunk (*Tamias striatus*), illustrated by John James Audubon.

CHANGING TIMES FOR SCIENTIFIC ILLUSTRATION

In modern times, there's a camera on almost everything, from drones to phones. But as **Bonnie Koopmans** reports, there's still demand for scientific illustrations.

Human understanding of natural history has always been passed on through art. From rock paintings to digital 3D models, illustration allows us to share knowledge and experiences of our environment. But if you ask about scientific illustration, people will most likely turn to scientific illustration works from the 18th to 20th centuries – by artists like John and Elizabeth Gould, or John James Audubon – who popularised the art of science as a way of advancing and communicating Western discoveries and methods of categorising nature.

The art of observation, which stands hand-in-hand with the careful brushstrokes of a scientific illustrator has, for centuries, not only assisted in the scientific descriptions of species, but has revealed the stunning colours of birds from distant lands, the seemingly-impossible life cycles of insects, and newly described plant species to a wider audience.

Before photography, careful observation and the ability to draw and paint accurately was the primary method of visual documentation. What many people don't realise is that scientific illustration is a field that, even today, continues to flourish. It has evolved to embrace modern technology, but still adheres to key values of accuracy, careful observation and science communication.

An inauspicious start

Whilst I was studying the Bachelor of Natural History Illustration at the University of Newcastle (sadly now-defunct), most people seemed to grasp the idea when I referred to it as 'scientific illustration', but there was often a certain confusion that this was 'still' a job.

"What do you hope that might lead to?" is a question feared by any student, especially one visual arts-related, and in my final year in 2019, I had the opportunity to meet a number of people in the field – many of whom had been working as scientific illustrators for decades. Upon hearing I was specifically interested in entomological illustration, I was met with the comment that 'Entomological illustration is basically dead, now that photo stacking exists'.

This was incredibly disheartening to hear as a near-graduate not even out in the field! Whilst not entirely true, I understand what they meant to a certain extent: photography has overtaken illustration in practicality, accuracy and speed for some subjects – and insect specimens, being small, intricate and immobile subjects, are a perfect example of something that can be photographed very well, especially with the correct equipment and processing software.

The focus of scientific illustration outcomes have, somewhat, shifted to what can't be photographed well. That includes anything extremely small, such as nanoparticles, or anything extinct, with dinosaurs being a fan favourite. Internal structures, also, can be challenging to photograph, and the reason why medical illustration is particularly in demand. Even for subjects that can be reasonably easily photographed, the use of illustrations is preferable if it will ensure consistency between subjects and emphasise important elements.

Take bird field guides, for example: photographic guides exist, but an illustrated guide can clearly emphasise small differences between species by drawing the birds in similar postures and with consistent and even lighting, and removing the complicating factors photographs contend with, such as distortion and visual clutter from background elements like leaves.

Back to the 80s

Scientific illustration may have been around for hundreds of years, but that doesn't mean that it's the same job it once was. Like so much of science, new innovations have driven scientific illustrators to new heights.

Diversifying from pencil, pen and paint to the digital realm, the wide adoption of computers in the '80s greatly expanded the ways in which illustration could be undertaken. Anne Hastings, former scientific illustrator of the Australian National Insect Collection, experienced the change firsthand.

In her early days in the role, she found producing meticulous pen-and-ink insect illustrations both satisfying and challenging, however, as time passed, the opportunity to try new digital techniques became ever more appealing. As these things often happen, I first met Hastings through something like six degrees of separation, as a string of people figured a freshly-graduated illustrator like myself would benefit from the experience of one who had once walked the same path.

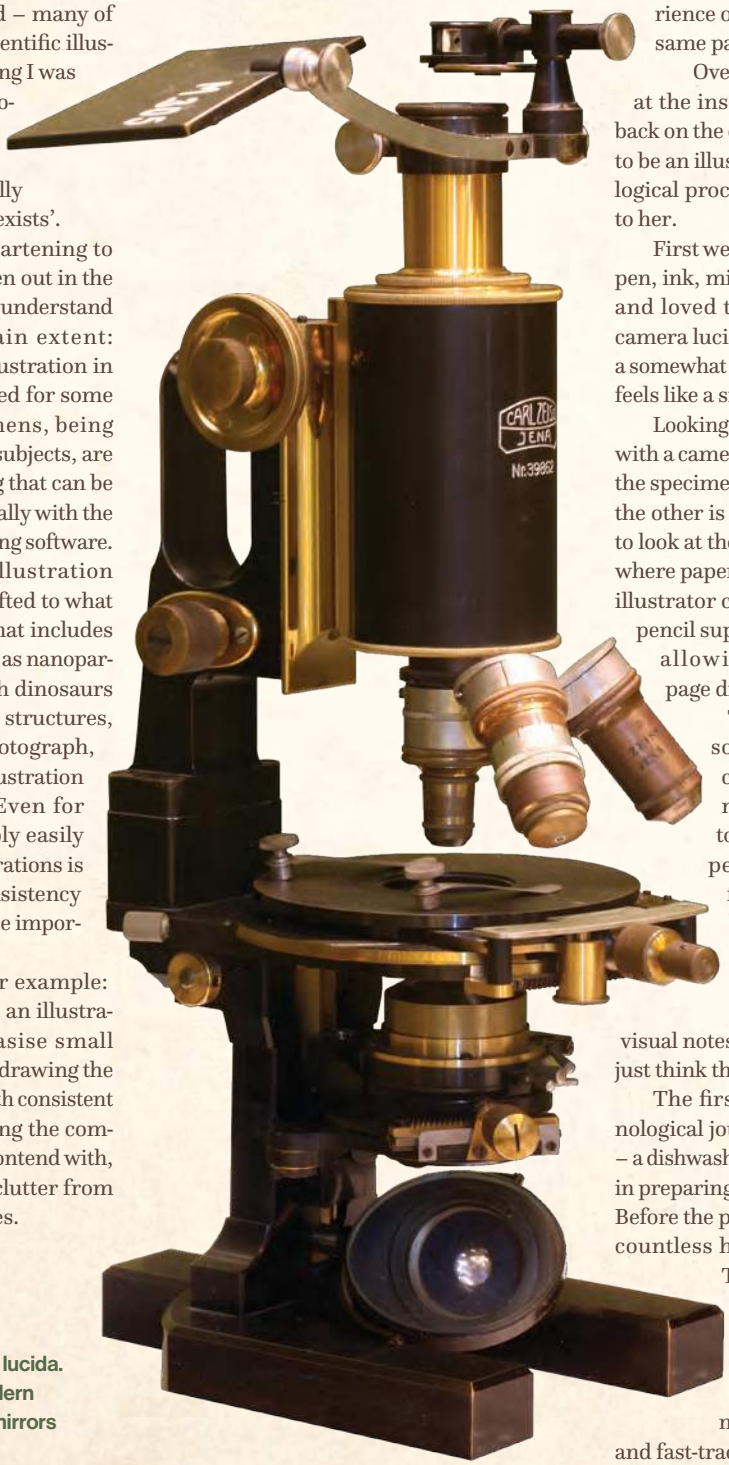
Over the span of her 35-year career at the insect collection, Hastings looks back on the experience as "an exciting time to be an illustrator". She recalls the technological procession of equipment available to her.

First were the traditional tools: Rotring pen, ink, microscope – all still widely used and loved today! Hastings often used a camera lucida attached to the microscope: a somewhat niche piece of equipment which feels like a small form of magic.

Looking through a binocular microscope with a camera lucida attached, one eye sees the specimen on the microscope stage, and the other is directed by a series of mirrors to look at the space next to the microscope, where paper can be placed. In this way, the illustrator can see their ghostly hand and pencil superimposed over the specimen, allowing it to be traced onto the page directly.

The camera lucida has been somewhat superseded by small camera units attached to the microscope, allowing images to be captured and for multiple people to observe and discuss features through a screen. That being said, I still jump at any chance to use a camera lucida – they're wonderfully handy for taking quick sketches and visual notes of specimens, and, honestly, I just think they're fun.

The first new tool of Hastings' technological journey was the process camera – a dishwasher-sized camera that specialised in preparing images for print reproduction. Before the process camera, Hastings spent countless hours meticulously stippling. The miraculous camera used a screen to convert a tonal graphite drawing into a halftone image – speckled gradient patterns, like what's used in newspaper printing – emulating and fast-tracking the stippled style.



A nineteenth century camera lucida. Contemporary versions use modern microscopes but the system of mirrors remains essentially the same.

WIKIMEDIA COMMONS / RAMA CC BY-SA 3.0 FRANCE

A digital revolution

One of the most exciting advancements for Hastings was the introduction of digital illustration, allowing her to move beyond the standardised black and white inkwork of taxonomic illustration. Plates of line drawings intended for publication – often painstakingly cut out and arranged by hand – could instead be created and arranged digitally, with the first version of what we now know as Adobe Photoshop released in 1987.

Around the same time, vector illustration also became possible. In this new file format, pictures are not made from a grid of coloured square pixels. Instead, mathematical formulas define the curves of lines to create infinitely scalable illustrations. Thrillingly, this new digital format also introduced colour into Hastings' work, as experimentation could be rapidly undertaken – a diagram of a beetle rendered in bright purple could easily be recoloured if it was deemed too bold.

Personally, decades on, I sometimes encounter a perception that digital art is somehow easier than traditional mediums, as the computer 'does it for you'. Whilst working digitally makes some specific techniques easier or faster, I can assure you, the illustrator is still making all the brushstrokes!

Whilst this method of drawing began with a mouse, the introduction of the pressure-sensitive drawing tablet and stylus allowed a more natural method of drawing digitally, especially with the inclusion of pressure sensitivity (often linked to digital brush size or opacity) and tilt (linked to brush shape). These are typically attached to a computer, but as computing devices have become smaller and more lightweight, portable tablets now mean digital illustration can be done anywhere, including in the field.

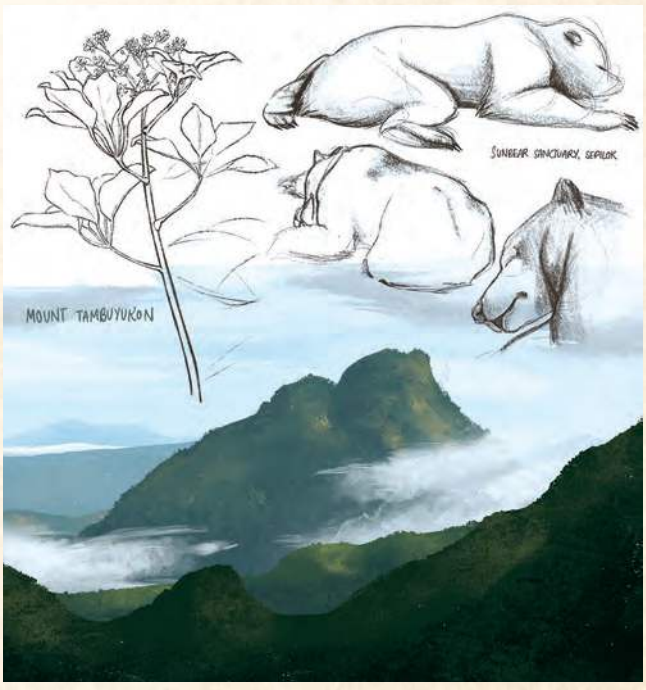
Art created digitally is becoming a widely accepted medium in scientific illustration. Notably, acceptance is growing in botanical art, which has long placed special emphasis on adhering to and upholding traditional painting methods. Just in the last few years I have noticed an increase in prestigious botanical art awards accepting digitally created entries.

Much like the widespread adoption of the Gutenberg moveable-type printing press allowed an explosion of information exchange across Europe in the 1400s, the internet provided a new format for the exchange of information on a scale like never before.

In the early 2000s, Hastings turned her hand to HTML coding and learned how to use Macromedia Flash for interactive material – building and maintaining websites to encourage identification of species or to understand the anatomy of flies. The rapid advance of technology in the span of one person's career is remarkable, and seemingly a trend that shows no sign of slowing down. "It was an opportunity to keep learning, which is what makes anything interesting," Hastings says. "I don't think I would have lasted in the job if it hadn't changed."

Koopmans making a digital field sketch in Sabah.

A moth illustration drawn using a camera lucida.



Digital field sketches from Sabah by Bonnie Koopmans. Procreate on iPad Pro.

BONNIE KOOPMANS

Into the third dimension

The extension of digital art into 3D modelling and animation in the scientific illustration field is a natural progression, especially considering the increased popularity and accessibility of 3D modelling and printing software. Award-winning Australian illustrator and fellow Natural History Illustration graduate Rachel Klyve has been pioneering 3D modelling to create highly-accurate digital versions of plant and animal species, primarily those of significance to Australia's biosecurity.

Weeds, especially ones not yet in Australia or a particular part of the country, can be difficult to access for study as they pose a high risk to Australian agriculture and native landscapes. Klyve creates models of key weed species to provide resources for improved identification, as well as increase broader awareness of these weeds.

"The models are created to scale," she explains. "They're interactive, so viewers can rotate the plant to look at it from all angles and zoom in to diagnostic features."

Beyond biosecurity concerns, access to specimens for study can be impacted by factors such as scarcity, or, simply, it being the wrong season to observe the species. By interacting with a 3D model, those learning about the species can inspect minute details in a way that is second only to holding a specimen itself.

"Because of advances in digital 3D software and online viewers I have a career that wasn't possible a few years ago when I trained in scientific illustration," Klyve says. "I am proud that my work is used daily by biosecurity professionals who report it helps them do their job well. It's art and science joining for practical outcomes."

In the shadow of AI

In the past couple of years, the next technological threshold for illustrators has made itself abundantly clear. Artificial Intelligence (AI) has become an overwhelming presence online, in the news, and in the scientific community.

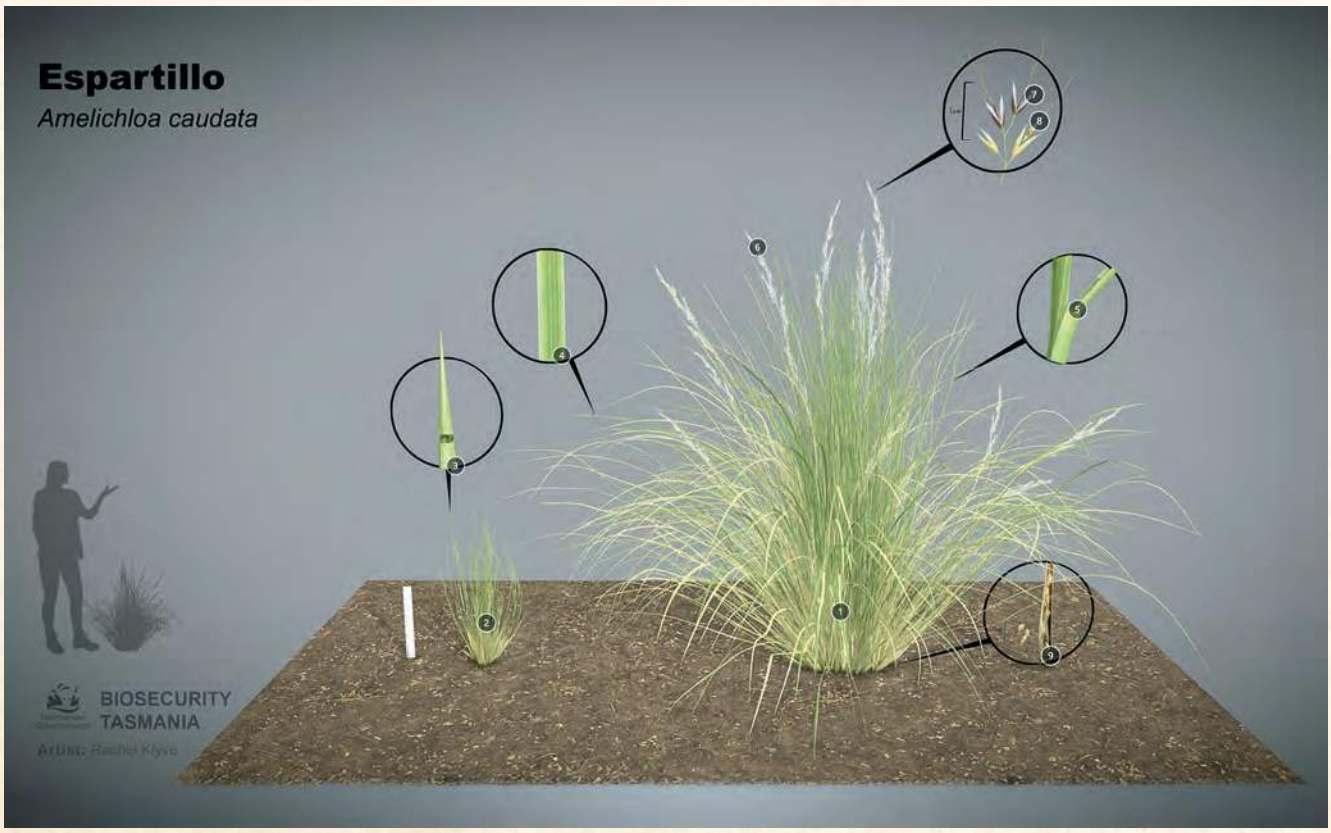
Whilst the capabilities of AI holds incredible potential – especially for processing complex calculations such as the prediction of novel protein structures – the application of AI to image making has been contentious and keenly felt amongst artists, from character designers to, of course, natural history illustrators trying to encourage scientific literacy in those around us.

Copyright infringement has always been a risk to artists, especially online, usually in the form of theft of a particular artwork to sell on merchandise. Now, swathes of artistic content on the internet can be scraped for data to train AI models – which, in Australia at least, is an infringement through reproducing an artwork digitally without consent, with no current legal exceptions for using images for machine learning.

Even with my comparatively small online presence, I have no doubt my art is already in training sets somewhere, but I continue to use social media and the internet to promote my work because I don't yet have the industry reach or clientele base to do without – and many others are in the same situation. In a globally connected world, artists rely on the internet for opportunities and marketing: benefits which must now be balanced with the risk of wide scale infringement.

For the moment, scientific illustration careers are relatively safe from the impact of generative AI, even though it can produce images in mere seconds at little to no cost. The key value of scientific illustration lies in its accuracy, and the lengths to which we go to ensure this – consulting with scientists and undertaking careful research so that what we depict is factually correct, and easy to understand.

Therein lies the other major moral dilemma in the use of AI, which is already seeing ramifications – its ability to create compelling disinformation. This is often pretty inoffensive, like social media accounts



RACHEL KLYVE FOR BIOSECURITY TASMANIA, HIGHLY INVASIVE GRASSES PROJECT © BIOSECURITY TASMANIA

getting thousands of likes for pictures of bird species that don't exist.

But it can also have life-threatening consequences. Recently, serious concerns have been raised about AI generated mushroom field guides. Reportedly, people have been poisoned eating mushrooms they believed, based on these books, to be safe. An AI is not a trained mycologist, but it can create content that looks and sounds very convincing.

Many illustrators, including myself, are somewhat anxious about this technological advance and where it may lead – even though it also holds incredible potential. As with the digital and internet revolutions Hastings experienced in her career, I do wonder how great and lasting an impact AI will have on mine – only time will tell how it will change the niche and availability of work.

The most critical aspect of scientific illustration is that it continues to be informed by real science, and along the way it will naturally be influenced by new research outcomes and scientific methods, formats for outreach, or media for the production of work. Ultimately, we, the illustrators, uphold a commitment to accuracy, champion the need for careful observation and delight in outreach and the communication of scientific information – these will always be necessary skills, the technologies involved might just change a little.

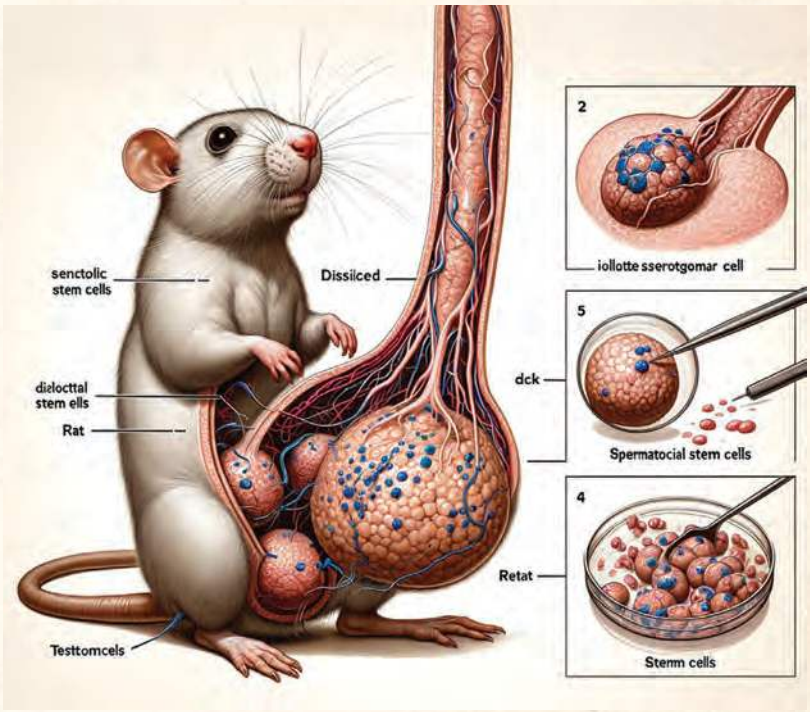
Bonnie Koopmans is a freelance scientific illustrator and natural history artist. Her story on subantarctic birds appeared in Cosmos 105

Magnified detail of Rachel Klyve's digital 3D model of Espartillo (*Amelichloa caudata*).

A screenshot of Rachel Klyve's digital 3D model of Espartillo (*Amelichloa caudata*).

FROM THE TOP: FRONTIERS / RACHEL KLYVE FOR BIOSECURITY TASMANIA. HIGHLY INVASIVE GRASSES PROJECT © BIOSECURITY TASMANIA

THE Ai RAT



This AI generated image created a furore when it appeared in a paper published in *Frontiers in Cell and Developmental Biology*.

"The figure in the retracted article is so comically bad that its publication does not contribute to the important debate on the more widespread and subtle use of AI in publishing," says Dr Frederick Fenter, Chief Executive Editor for *Frontiers*. "The figure was published due to a control error in the final production stages, after the authors added this image to the manuscript following completed peer review. Needless to say, it was rapidly retracted."

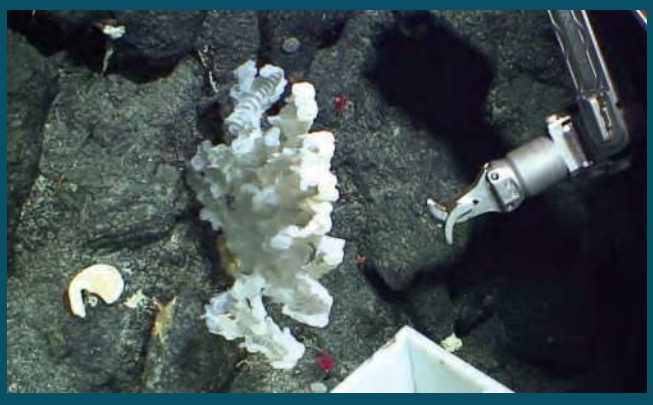
This incident paints an uncertain future for scientific illustration. Obviously, at least some researchers are happy to include highly inaccurate diagrams, and some publishers will fail to catch them before publication. But equally, many researchers strongly value the rigour and clarity that scientific illustration provides.

Artificial intelligence and image generators, now that they have so quickly come to the forefront of technology and the public eye, are certainly not something that can be put back in the box. The speed with which it has been adopted by search engines, social media platforms, and operating systems is making it increasingly difficult to avoid, and the more it's used and training models are refined, the more difficult it will become to assess whether an image or video is accurate, or true. Some kind of equilibrium will need to be struck with the technology to improve environmental impact and address the legalities of copyrighted images in training sets, and until then, responsible use is in the hands of the users.

DRUGS FROM THE DEEP

The drugs don't work as well these days. As diseases such as tuberculosis and golden staph become resistant to our treatments, **Amalyah Hart** dives deep in the search for new antibiotics.

▼ A remotely operated submarine collects samples from a fan sponge.



SUPPLIED: PAUL RACE

In October 2013, a British research vessel carrying a team of scientists set sail from Santa Cruz, on the island of Tenerife, Spain. Its destination was the Caribbean island of Trinidad, by way of a deep scar in the seafloor known as the Mid-Atlantic Ridge.

On board was biogeochemist Kate Hendry, then a professor at the University of Bristol, UK. Hendry was interested in the chemistry of seawater – how nutrients and other important compounds circle the world's oceans, and how changes in temperature and chemistry can disrupt this finely tuned system.

Over the course of the 7-week cruise, Hendry would spend hours sitting in the control room, watching as highly trained technicians navigated remotely operated vehicles across the seabed, gathering samples as they went.

Hendry was looking for marine sponges living in clefts in the seabed and on the slopes of seamounts. She wanted samples both alive and dead, so she could trace the availability of nutrients in the oceans of the past and present.

She had also promised to save some pieces for a friend. Hendry had agreed to share some of her samples with microbiologist Paul Race, another professor at Bristol.

Race was hunting for new drugs to counter the emergence of antimicrobial resistance (AMR) – a problem the World Health Organization (WHO) identifies as one of humanity's greatest existential threats. He hoped these sponges might contain compounds that could help him.

A lab worker sprays penicillin mould into growing medium in 1943.

"IT WOULD GO ON TO SAVE MORE THAN 500 MILLION PEOPLE AROUND THE WORLD FROM FATAL INFECTION."

FROM TOP: IMPERIAL WAR MUSEUM / KATHERINE DUNCAN

A history of antibiotics

It's one of science's most famous flukes. In 1928, Scottish physician and microbiologist Dr Alexander Fleming returned from a holiday to find that a petri dish containing *Staphylococcus aureus* – a common bacteria found on human skin and in mucus that can be particularly dangerous if it enters the bloodstream – had been contaminated with a fungus.

Startlingly, the bacteria were conspicuously absent in the area around the fungus. What Fleming had discovered was a substance he named penicillin, and it was produced naturally by the mould to fight off bacteria.

It took nearly 2 decades to come to market in the UK, but penicillin was the first antibiotic. It would go on to save more than 500 million people around the world from fatal infection.

This remarkable accident kicked off what's known in microbiology as the Golden Age of antibiotic discovery.

The period between the 1940s and 1960s saw the discovery and commercialisation of most of the antibiotics we use today. Many of these came from microbes themselves.

In particular, it's estimated that about 64% of the antibiotics in use today were developed from compounds produced by the abundant phylum of bacteria known as Actinomycetota. Variants of these bacteria live in almost every corner of Earth, from the waters of the Arctic to the soil of the Amazon.

"They're these incredibly talented producers of chemistry," explains Katherine Duncan, an expert in marine microbial antibiotics at Newcastle University, UK. "They've got large genomes, lots of biosynthetic gene clusters that code for antibiotics, and they also reside in a lot of different environments."

Golden Ages are generally defined only after their decline and collapse – and antibiotic discovery was no different. Since the 1960s, the discovery of new drugs has slowed dramatically.

"What's happened over time is people have routinely returned to the same types of environments to try to find microbial life, and that's created a replication problem," explains Race.

Katherine Duncan is a Senior Lecturer in microbial metabolomics & antibiotic discovery at Newcastle University.

Paul Race is a Professor of Biotechnology at Newcastle University.

Actinomycetota are the source of over half of the antibiotics in use today.

SUPPLIED: PAUL RACE

The race against resistance

Today, AMR – the development of immunity to antibiotics by pathogenic (disease-causing) bacteria and microbes – is globally recognised as a major and imminent threat to human life.

In 2019, an estimated 1.2 million deaths globally were attributed directly to AMR. Tragically, one in 5 deaths due to AMR occurred in children under 5 years old. And this problem is still growing. Nearly 40 million people are predicted to die from antibiotic-resistant infections between now and 2050.

Resistance is compounded by the over-prescription of antibiotics by doctors, and the over-use of antibiotics in agriculture, where they're added to livestock feed to improve growth rates in healthy animals.

And unfortunately, our efforts to prevent AMR also stymie investment into new antibiotics. When a new drug is developed, it's kept as a last resort – which means low sales and low profit potential.

But resistance is ultimately an inevitable counterpoint to the existence of antibiotics, as Race points out. The trick is to stay ahead in the evolutionary arms race.

"Bacteria are very crafty beings, and they acquire mechanisms to circumvent the effects of the antibiotics we use," he says. "There's this misconception that it's feasible to come up with a single solution – a silver bullet that fixes the problem."

"You're never actually going to be able to do that, so what you need to do is stay one step ahead of the curve. This means you need a constant pipeline of new antibiotics, which kill bacteria in new and different ways."

"The general public probably think there is a bit of an endless supply," adds Duncan. "But every company has different brand names for the same drug."

In fact, there are roughly 9 major classes of antibiotics – though opinions on classification can vary – and a few additional, specialised classes exist. There haven't been any new major classes of antibiotics developed since 1987.

Antibiotics in the same class typically fight pathogens in the same way. And that can have implications for AMR.

"Antibiotic resistance is obviously a wider problem about misuse and education, but one thing is pretty clear," says Duncan. "We need new chemistry."

A distant search

Back on land, Hendry handed over some of her samples to Race, who set to work delving into each sponge sample's microbiome – the complex community of micro-organisms that inhabit every living thing.

According to Race, solving the problem of replication requires looking in new places, where species have adapted novel internal mechanisms to manage different environmental pressures.

Scientists estimate that only a tiny fraction of the natural products on Earth with therapeutical potential have already been discovered, so we don't lack options. But the best places to look for these products are not always the easiest to get to.

As well as the deep sea, scientists have hunted for new natural products in the frigid waters of the Arctic Ocean, and at the fringes of hydrothermal vents. Microbiologists select these environments as places to search precisely because they are so extreme.

The reasoning is that bacteria and other microbes – already among the planet's most resourceful organisms – are more resourceful, and diversify more quickly, when exposed to intense evolutionary pressures.

Bacteria are such good sources of antibiotic products in part because they have highly dynamic genomes.

"Bacteria acquire genes vertically, passed down from their ancestors, but also horizontally, acquiring them from their environment," explains Duncan. "So, they're constantly trying out genes to see if they'll be useful."

Horizontal gene transfer is the mechanism by which bacteria snip out genes from other bacteria and stitch them into their own genomes. It's the reason bacteria are so good at acquiring resistance to antibiotics in the first place, but it also makes them helpful chemists.

Sometimes, a bacterium will acquire a gene that produces a useful chemical. It could help the bacteria survive in a threatening environment, or outcompete its peers. And some of these useful chemicals, known as secondary metabolites, can form the scaffold for building new antibiotics.

"The reason we really like sponges is because they are the second-earliest form of multicellular life to emerge on the planet," says Race. "So, they have [one of] the longest, most highly evolved microbiomes, and that amplifies the diversity and number of micro-organisms rather than if you just scooped a bunch of sand from the bottom of the ocean."

In 2021, researchers from Flinders University reported that 12 sponge samples from the waters around South Australia were found to contain 70 different bacteria that were active against at least one of 11 human pathogens.

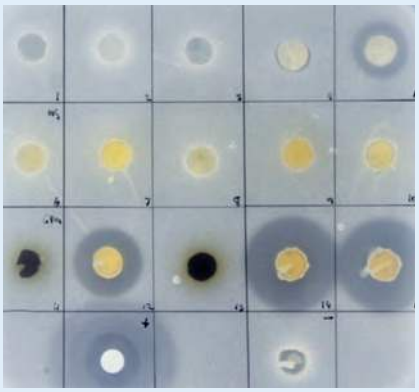
Remarkably, 37% of the tested bacteria showed activity against *Staphylococcus aureus*. Since the advent of penicillin, this bacteria has been steadily developing resistance to the various antibiotics thrown its way.

The most famous multi-drug-resistant strain of *S. aureus* is methicillin-resistant Staphylococcus aureus, known more commonly as MRSA. It was responsible for more than 100,000 deaths worldwide in 2019.

Most teams of researchers looking at sponges source them from shallower, coastal seas. But the benefit of a deep ocean trench, says Race, is its extremity.

"The micro-organisms that live there are placed under unique and extreme evolutionary pressures – there's high pressure, there's salinity, low temperature, low UV exposure and so on," he explains.

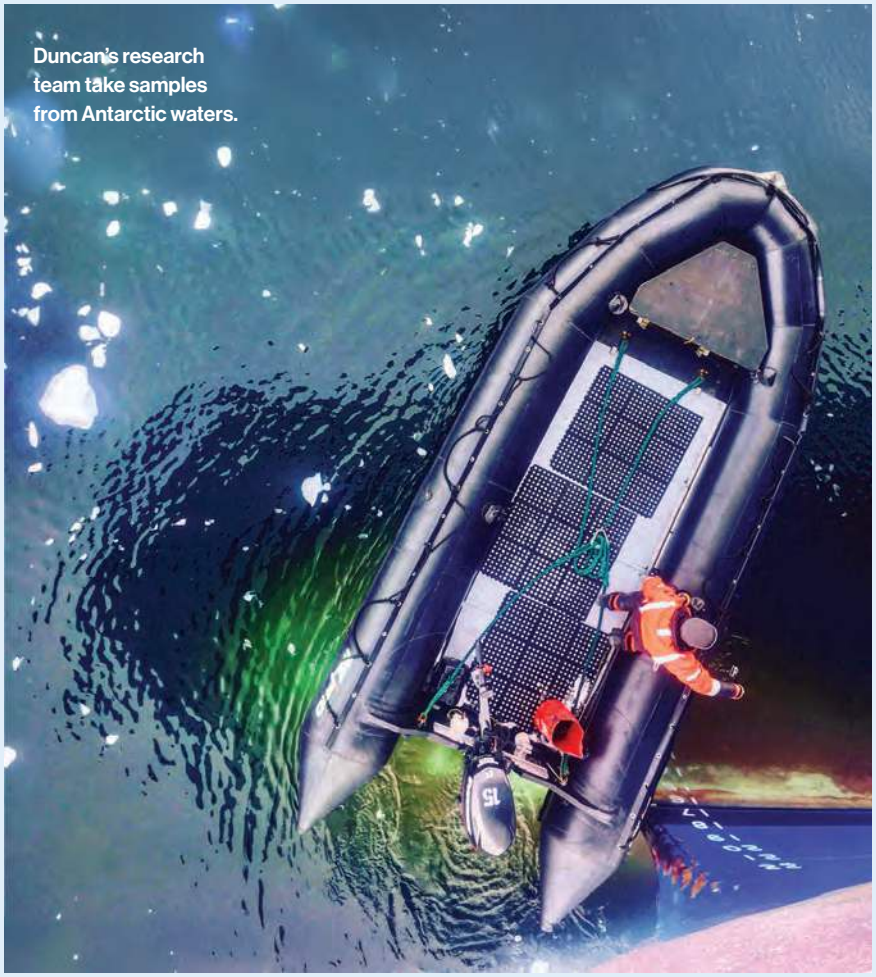
"And so, by looking there, it will increase the probability that we find new antimicrobial natural products that don't look like molecules that have been discovered previously."



A bioassay testing the efficacy of several different compounds.

Purified compounds extracted from sponge samples.

KATHERINE DUNCAN



Duncan's research team take samples from Antarctic waters.

KATHERINEDUNCAN

Reasons to hope

In August this year, a team of researchers from Finland and Norway reported 2 previously unknown compounds, produced by 2 new strains of Actinomycetota discovered in the microbiomes of invertebrates living in the Arctic Sea off Svalbard, Norway.

These compounds were able to fight against a particularly vicious strain of enteropathogenic *Escherichia coli (E. coli)* that causes severe and sometimes deadly diarrhoea in children under 5, particularly in developing countries.

The findings were particularly exciting, because one of the compounds was antivirulent. This means it stopped the bacteria from causing deadly symptoms, but without stopping the bacteria from reproducing.

It did so by preventing the formation of 'actin pedestals', which are tiny raised structures that allow the pathogen to attach to the host's gut lining.

Reducing a bacterium's virulence without inhibiting its growth means the bacterium is much less likely to develop resistance, because it simply doesn't need to – there is nothing impeding its core evolutionary purpose, which is to reproduce.

Duncan's research lab at Newcastle University looks at Actinomycetota sourced from environments that are similarly extreme, including the deep ocean as well as the seas around Antarctica.

She's particularly interested in understanding how environmental factors affect which products a microbe can – or will – produce.

Microbial genome sequencing can show which genes code for which molecules, providing a kind of blueprint for the types of chemistry an organism can produce. This window into the gene pool has shown that lab studies of various microbes don't always exhibit the full potential of their genome.

"For example, if a bacteria had 15 biosynthetic genes, we may see the product of 3 of them [in the lab]," Duncan says.

Hunting for the full suite of potential products, then, requires understanding the unique environments these microbes grow in.

Now, Duncan's lab records the geographic coordinates, temperature, pressure, salinity and other factors, like time of year, for all samples. Reproducing these conditions in the lab when they culture newly discovered microbes will hopefully help them tease out nuggets of pharmaceutical gold.

Duncan's lab routinely screens their newly discovered compounds against the so-called ESKAPE pathogens – 6 superbugs on the WHO's highest priority hitlist. First defined in 2008, the ESKAPE pathogens *(Enterococcus faecium, Staphylococcus aureus, Klebsiella pneumoniae, Acinetobacter baumannii, Pseudomonas aeruginosa and Enterobacter spp.)* remain some of the most challenging pathogens to treat.

They are notoriously consummate escape artists, and they have been known to 'share' their resistance innovations through horizontal gene transfer.

While the future can seem bleak under the growing cloud of AMR, Duncan finds ample reason for optimism.

"I think the [COVID-19] pandemic showed that we can accelerate drug discovery if there's motivation, so that's quite encouraging," she says.

Global benefit-sharing agreements mean that researchers around the world can access data and samples more easily and equitably. Such agreements include the 2010 Nagoya Protocol, which ratifies in law the sharing of benefits from genetic resources, and the UN's BBNJ Agreement, which requires signatories to use and share biodiversity from the high seas sustainably.

And antimicrobial resistance isn't the only problem being tackled through marine and extreme-environment drug discovery.

A natural product known as *Salinosporamide A*, derived from the actinomycete *Salinospora tropica*, a bacteria found in marine sediments, is emerging as a potential anti-cancer agent.

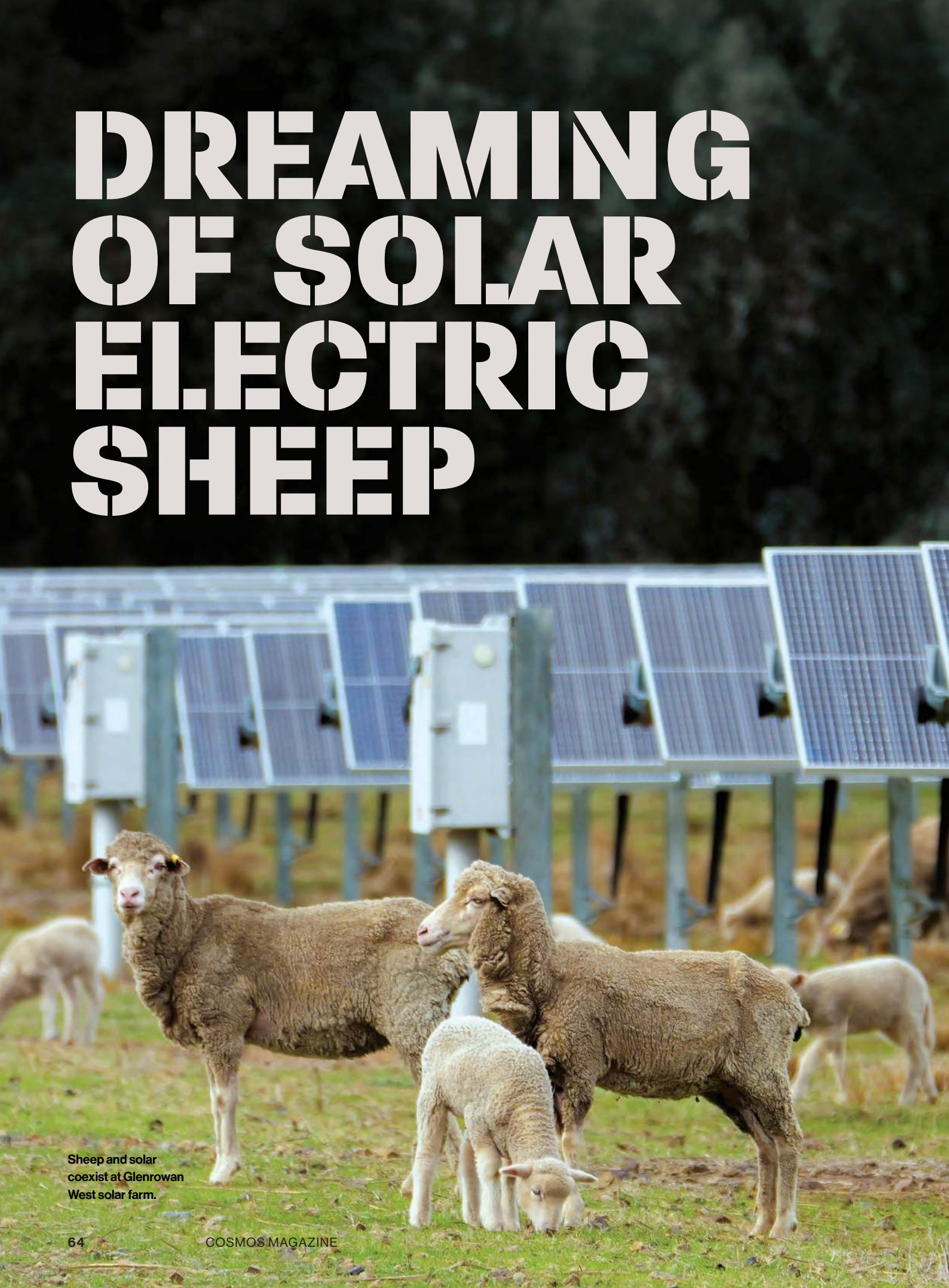
The drug, known also as marizomib, is currently in clinical trials for several types of cancer. But the journey from discovery to drug delivery is a long one. Salinosporamide was first discovered in 2003, and entered Phase I human trials 3 years later, but has still not come to market.

Nonetheless, plenty of new products are being investigated. The abyssomicins – a collection of natural products isolated from an actinomycete found in sediment in the Japanese Sea – show promising antibiotic, anti-tumour and antiviral activity.

"We talk a lot about the struggle for drug discovery, but it's also quite exciting," says Duncan. "Discovery is our job, and not many people get to say that."

Amalyah Hart is a science journalist based in Naarm/Melbourne. Her story on insect consciousness appeared in Cosmos 104.

DREAMING OF SOLAR ELECTRIC SHEEP



Sheep and solar coexist at Glenrowan West solar farm.

TESSA STEVENS, AUSTRALIAN CONSERVATION FOUNDATION

We might call them solar farms, but there's often no farming going on under solar panels. That's a real shame. But as **Rachel Williamson** reports, with some hard work and planning, a solar harvest doesn't need to impact agricultural output.

Gayle Lee's voice ripples with the special kind of incredulity rural people reserve for certain city folk as she recalls an anecdote about electricians and sheep.

Early in her family's experiment keeping sheep and solar panels in the same paddocks at their western Victoria farm, she fielded queries from worried electricians in Sydney, contracted to maintain the new power plant.

Who, they'd demanded, would put the sheep to bed at night?

"All the operations people on solar farms are electricians. They're not farmers. They've got no idea," Lee says.

"We just rolled around laughing. The other one was 'if you put the sheep in there and we need to work, who's going to take the sheep out'? And we said, 'no, the sheep won't come near you'.

"It's that sort of [lack of knowledge] that [farmers in the solar industry] need to counter. But I do think they're getting better at it."

Gayle and Tom Lee's property hosts part of the 149-megawatt (MW) Glenrowan West solar farm. Unintentionally, it became a model for how to successfully farm under solar in Australia.

But their tale is also a perfect microcosm of a much bigger story: one that marries years of overseas research with the urgent need for Australia's vast horizons to produce both food and electricity.

That research has shown that it's possible to farm and produce electricity at the same time. And with hard work and planning, it's possible while maintaining Australians' ideal of what the bush should be.

Luckily, we don't have to go into this situation blind. In Europe and Japan, limited land forced new ways of thinking about power and farming many years ago. And in the USA, business-savvy farmers developed a new multi-billion-dollar industry out of 'solar grazing'. Australia has a lot to gain from the idea that farming and solar can happily coexist.

Gayle Lee is a farmer in Victoria's Glenrowan West.

Ben Wynn was the Director at Wynergy.

Fight the fear

Australia's countryside is bearing the brunt – or the cornucopia, depending on who you talk to – of the country's energy transition.

In some districts, such as those around Engie's The Plains Energy Park near the New South Wales (NSW) town of Hay, people are being won over by the financial and community benefits provided by big renewable energy developments.

In central Victoria's spa district, a tiny town called Newstead decided as a community to play an active role in the transition. It switched on a 3MW solar farm and 5-megawatt-hour (MWh) battery in 2024. But just kilometres away, a badly handled community engagement process has left both the community of Colbinabbin and the local council actively opposing a proposed 500MW solar farm and battery project.

Generally, Australians are very supportive of renewable energy, citing the reason as their awareness of the urgency to cut fossil-fuel emissions, according to regular surveys by organisations such as CSIRO and the Climate Council.

But the fears about solar in the bush are not unfounded. Visually, the swathes of panels transform the landscape, and extra power lines can stretch for kilometres. Some people are concerned that contractors could inadvertently spread weeds or cause other forms of environmental degradation.

A sign at Glenrowan West solar farm.

TESSA STEVENS, AUSTRALIAN CONSERVATION FOUNDATION

A solar vinyard in Germany.

And some solar farms make productive land unusable – a loss that hurts the entire community.

The benefits also feel unfairly weighted to the cities. There is a sense that farmers and rural residents are being asked to bear radical changes to their views and the local environment, so that eco-conscious urbanites can buy renewable energy to charge their electric vehicles.

Ben Wynn encapsulates the conflicted position of many people who love the land, but understand the pressing need for reduced fossil fuel use.

He pioneered an Australian option for cattle-plus-solar in his company Wynergy, and is deeply knowledgeable about how to make farming-plus-solar work. But he's recently moved out of the sector in despair at the lack of care and action by developers.

"Why are we going to all of this effort to put some of these large-scale solar farms on such beautiful productive farmland [and] high-class soils, yet we don't have any moratorium or wind down on the coal we export or the gas we export? I feel like we're shooting ourselves in the foot a little," he says.

"You need to establish a design that provides the capacity to host [animals]. It's really difficult and challenging too. [For] some solar farms, it can't even happen. You get to the point where you can't actually do it because the panels didn't line up, or you didn't use the right tracking infrastructure."

Dr Eric Nordberg is the leader of the Reptile Ecology and Environmental Disturbance (REED) lab at the University of New England.

People like researcher Eric Nordberg at the University of New England, and farmer-consultant Karin Stark, are hoping the datasets they're building can change the narrative of rural loss.

"We often don't think about the social licence and getting the community's approval for having these big sites," says Nordberg, a wildlife ecologist.

"To the farmers that say, 'I don't want to lose my grazing landscape to a big solar company', we're trying to say, 'you don't necessarily have to lose that'."

The benefits don't just go to farmers, either. The solar companies that operate the panels get plenty from the deal too.

"Obviously [sheep under solar is] good for the solar companies," continues Nordberg. "They essentially get free vegetation management. If you've got sheep under there, you can also make the farmers happy, because they don't necessarily lose that area to the energy company."

Unfortunately, the message hasn't quite got through to most developers. These companies build solar farms and then sell them on to another company to manage.

There are a growing number of guidelines on how to set up solar farms right – NSW's state renewables rollout vehicle EnergyCo is funding one now. But surprisingly little local, on-the-ground data is available about the positives or negatives. This is where international research comes in.

GETTY IMAGES/IMAGEBROKER/DANIEL SCHOENEN

A solar-hydroponics farm in China.

GETTY IMAGES / FEI YANG

Learning from experience

The concept of solar-plus-farming has a long history. It was founded in a German research centre where learned boffins gave it the clunky, clumsy term 'agrivoltaics'.

In 1981, German scientists Armin Zastrow and Adolf Goetzberger, a pioneer of solar power, outlined how to configure solar panels to grow potatoes underneath.

Today in Japan, agrivoltaics takes the form of 3m-high, tree-like solar canopies over potato, aubergine, Japanese yam and ginger crops. By 2021, almost 2,000 farms had embraced what's known there as shared solar.

In the Netherlands, berry farmer Piet Albers went all-in with European renewables giant BayWa r.e. and solar installer GroenLeven to grow outdoor raspberries. According to BayWa r.e., the pilot showed better air circulation under the panels than by using traditional systems, and protected the fragile crop from the weather.

In the USA, sheep rentals or solar grazing – as it's branded there – was worth US$3.6 billion (A$5.8 billion) in 2021 and could more than triple that by 2031, according to market research company Allied Analytics last year.

Practically, sheep cut costs by keeping the grass and weeds down, thus reducing the number of times grass needs to be mowed.

The extra shading from panels also lets sheep stay out of the hot sun. The outer layers of their wool can be 7–8°C cooler, according to a 2023 study in *Applied Animal Behaviour Science*, and they produce higher-quality fleeces because the thin fibres aren't exposed to as much sun or rain.

"Although solar pastures decrease herbage 38% lower than conventional unshaded open pastures due to full shading ... this was offset by higher forage quality, resulting in similar spring lamb production to open pastures," said a 2024 study in *Applied Energy* on the financial impact of putting sheep under solar. "Other studies have seen increases in pasture yield, that means even more revenue per acre ... photovoltaic (PV) systems benefit the animals by offering shading that they prefer."

Increased soil moisture from shading meant that during 2018's very hot German summer – a climatic feature Australian farmers are well attuned too – the harvest at the solar-wheat field at Goetzberger's own Fraunhofer Institute for Solar Energy Systems ISE rose by 3% even with the solar equipment blocking 30% of the sunlight.

It's not just good news for harvests, either. Solar panels are most efficient at 25°C, so they also benefit from the partnership.

A 2023 study in *Applied Energy* led by Cornell University doctoral student Henry Williams found soybeans planted under 4m-high solar panels could reduce module temperatures by 10°C compared to a solar panel mounted 0.5m above bare ground.

"These results indicate that ground conditions and panel height play important roles in solar farm cooling, and that agrivoltaic systems can potentially help to resolve the global food-energy crisis by improving solar PV conversion efficiency while enabling agricultural production on the same land," the study concludes.

A solar grazing operation near Dubbo.

Working with a vibe

Australian research comparing the actual effects of grazing sheep underneath solar to sheep grazing offsite is thin on the ground, but it is emerging.

"There's not really empirical data to show we've compared the quality or the production underneath panels to something else," says Nordberg. "I think it's one of those things that sounds like a no-brainer and it would make sense that that is the case, but we don't really have any data."

A trial at the 66MW Parkes solar farm in NSW, which started in 2018, found higher wool yields from merino wethers that had been keeping the dry grass down.

A more recent comparison trial at the 174MW Wellington solar farm in NSW suggested the 1,700 solar merinos were producing wool that was not worse compared with a neighbouring mob of non-solar brethren. The data released by solar farm owner Lightsource bp in October 2024 showed that the mean number of thicker fibres was slightly smaller at 0.61% compared with 0.74%, meaning more of the solar fleece can be sold for a higher price. The comfort factor or softness against the skin was slightly higher, but spinning fineness was not quite as good.

Nordberg is leading the early stages of a grazing study at the massive 720MW New England solar farm and its 400MWh battery, under development by Acen Australia. The farmers originally thought the solar farm would reduce grazing capacity, along with grass yields and quality.

"We are trying to measure a whole bunch of food vegetation plots and quality to see if the grass cover and the nutrient values underneath panels is better or worse," explains Nordberg. "So obviously the panels themselves provide shade and holding moisture and all that kind of stuff. We actually think that [the growing conditions] might be quite good underneath those panels."

"We also have people that are interested in looking at the animal production side of things. Do you get better fleece quality from the sheep that are grazing under panels? Do they have more or less parasite load? What's their reproductive status? Can they put on more weight, more quickly?"

Making it work

Although as Nordberg puts it, the preliminary data indicating that running sheep under solar panels is a "no-brainer", the experts say there's plenty of reasons why it doesn't – or can't – happen.

Developers need to plan from the very start for fencing and water sources. And they need to make re-sowing pastures possible by ensuring the rows of panels are wide enough to fit a tractor down, according to agricultural consultant Karin Stark.

Karin Stark is the Director of Farm Renewables Consulting.

"[The issues could include] things like lack of land management and preparation prior to construction causing issues later on, having lack of access to adjacent pasture so animals can be taken off for health reasons and for chemical spraying," says Stark.

"It's really important for landholders and developers to have meaningful conversations early on ... Do they want to continue grazing? There will be some cost in putting in infrastructure, but that's much cheaper than doing it later."

Even the design of how the panels will move to follow the sun is important. On the Lee's property, the panels track the sun as a row. But the 4 new projects near their house connect each row of panels with a bar across the alley, so they move en masse. This means that vehicles that enter must back out, and worse, woolly sheep can sometimes get caught up on the bar.

Still, once the basics are in place, we've only begun to explore all the benefits.

Gayle Lee doesn't own the sheep running around the solar panels near her house – another farm does that work – but she is still deeply interested in the outcomes. She has a sense the sheep can graze for longer under panels than on a similar patch of land without panels, but would love to secure a PhD student to prove her hunch.

And the Lees are also trying out a new fertiliser method – a worm juice spray – instead of the granulated, acidic superphosphate that corrodes delicate solar panels. She's expecting the results in 4 years. No one ever said farming, or big builds, or winning community trust, were quick.

RACHEL WILLIAMSON is a business and science journalist based in Melbourne

KARIN STARK

In much of Australia, children as young as 10 can be convicted and jailed. Legal experts, human rights activists and politicians are locked in endless debate about whether it's right to lock up our kids. Reporter **Glenn Morrison** asks what science has to say about the issue.

Roughly 40% of the size it will reach by adulthood, the human brain at birth is short of a few important connections.

Think of them as your brain's 'wiring', a neural network that will eventually allow you to walk, talk, reason, connect one thought to the next, even shape an argument.

In fact, your brain at this age is something of 'a paradox', writes Dr Frances E. Jensen, professor of neurology at Perelman School of Medicine University of Pennsylvania, author of *The Teenage Brain*.

Arriving with an overabundance of grey matter – akin to a biological 'hard drive' – the newborn brain suffers an undersupply of white matter, that same 'wiring' that will ultimately ferry information between its parts.

By adolescence, Jensen suggests, the brain is like a brand-new Ferrari, primed and pumped but not yet road tested. "In other words, all revved up but doesn't quite know where to go," she says.

These few important years, perhaps life's most challenging, are often called a "coming of age", or puberty.

Puberty's biological push toward adulthood starts from ages 8 to 10 years, bringing new behavioural effects over the next few years that are profound.

For as any parent knows, adolescents can sometimes look and occasionally act as if they are already adults. But they are not.

Experts disagree whether by age 10 a child can tell right from wrong. Yet 10 years is exactly the age one might currently be tried and jailed under a 1963 ruling on an Australian minimum age for criminality.

According to Australian Bureau of Statistic figures, some 600 children under 14 are locked up every year. Indigenous Australians, comprising less than 3% of our population, nonetheless account for more than half of these juvenile detainees.

Yet important scientific questions remain unanswered about incarcerating youngsters and their arguably 'L-plated' brains.

Anglo-Australian jurisprudence demands defendants be competent to stand trial, meaning, according to the Australian Law Reform Commission, to have "sufficient mental or intellectual capacity to understand (court) proceedings or make a defence".

Does a 10-year-old child have that? Or are we demanding levels of understanding their young brains cannot yet achieve? And if they cannot, why is Australia incarcerating 10-year-olds given the United Nations Committee on the Rights of the Child sets 14 as an absolute minimum?

Furthermore, what consideration might be granted for the effects of disability? Trauma? Disadvantage?

Might incarceration itself make matters worse? And why are Indigenous youngsters more at risk?

Professor Susan Sawyer is the chair of Adolescent Health at the University of Melbourne.

ROBERT CIANFLONE/GETTY IMAGES

The growing brain

The human organ closest to the heart of this debate sits atop the spinal cord.

Light grey in colour and of a consistency Jensen describes as between "overcooked pasta and jelly", its birth weight averages 350-400g growing to 1.3kg for an adult man, slightly less for a woman.

As an area of study, the teen brain was until recently underfunded and under researched and so remained poorly understood.

Even the idea of a 'teenager' is relatively new, the word first appearing in a 1941 magazine article.

Many thought brain growth pretty much done by kindergarten, the whole thing explainable from then on through a prism of adult neurobiology.

Rather, puberty is our brain's engine of change. And it ignites in upper primary school, says paediatrician and inaugural chair of Adolescent Health at The University of Melbourne, Professor Susan Sawyer.

"What we call *adrenarche* or activation of the adrenal gland is the earliest feature of puberty," Sawyer says.

"It occurs around age 8-9 years, before the timing of the sex hormones of oestrogen and testosterone that lead to what we call the secondary sexual characteristics and accompanying growth spurt of puberty."

With external changes spanning 5 or 6 years, puberty arrives earlier in girls than boys, Sawyer says. And its onset sparks dramatic change, including maturation of the brain's cognitive aspects, executive functions like forward planning, which continue developing through the mid-20s.

And the order in which parts of the brain develop in this race to adulthood is significant, with its wiring connecting first from the back of the skull, says Jensen.

At the back are brain structures to deal with immediate needs: regulate vision, hearing, balance, touch and sense of space. These structures get first dibs on connectivity, including via the cerebellum at

the back (balance and coordination), also the thalamus (relaying sensory signals) and hypothalamus (command central for hunger, thirst, sex and aggression).

However, those parts of the brain where actions are weighed, situations judged and decisions made, sit behind the forehead in the frontal lobes. They mature later.

What will my mates say?

It is significant the frontal lobes governing 'adult' thinking develop last.

The matter leads Jensen to counsel parents to "be your teen's frontal lobes until their brains are fully wired and hooked up and ready to go on their own".

For without working executive functions, adolescence is a potential minefield. And such context is crucial to judging criminality in children aged 10 to 14 who encounter Australia's youth justice system.

Might they understand courtroom proceedings? Be capable of rationalising crime and punishment?

Turns out, says Sawyer, young brains are too occupied with social comparison and social shame.

"For some, that's wanting the latest jeans or top or shoes; this is about social status … if you don't have that then you don't cut it with your mates."

"NOT EVERYONE AGREES A 10-YEAR-OLD CANNOT TELL RIGHT FROM WRONG."

Puberty sparks "increased sensation seeking and impulsive behaviours", she says, the brain structures that process such emotions having already started to mature "in a part of the midbrain called the ventral striatum, which is involved in reward and motivation".

"The part that lights up when you're on a rollercoaster, for example. And the *amygdala*, which encodes for fear and stress."

Nonetheless, even at this age "children can tell right from wrong," Sawyer asserts, then quickly adds, but that is not the right question to ask.

"In the heat of the moment many young people are not thinking about whether things are right or wrong, but rather what their mates will say … it's that ability to make decisions in the context of their peers."

Nevertheless, if risk taking and sensation seeking intersect with the justice system, how might we judge any degree of criminality?

That should depend intimately on the science, argues forensic psychiatrist Yolisha Singh, who assesses young offenders due to come before the courts.

In her 2023 paper entitled 'Old enough to offend but not to buy a hamster', published in the *Journal of Psychiatry, Psychology and Law*, Singh brands Australia's current threshold of criminality "unscientific".

"Science proves unequivocally that adolescents aged below 14 have underdeveloped brains," she writes.

Singh points to puberty's remodelling of the system that regulates our supply of dopamine, a neurotransmitter playing a "critical role in the brain's reward circuitry".

"Dopaminergic activity in the prefrontal cortex increases significantly in early adolescence and is highest in this period."

Importantly, adolescent structural changes occur in sectors crucial to telling right from wrong.

Singh points to the process called myelination, whereby a fatty layer called myelin is deposited around nerve cells allowing them to transmit information more swiftly, resulting in improved thinking.

However, not everyone agrees a 10-year-old cannot tell right from wrong.

In fact, the converse has broad appeal, says Tim Bateman, reader in Youth Justice at University of Bedfordshire. And underpins common aphorisms such as 'adult crime, adult time'.

In a paper for UK's Centre for Crime and Justice Studies, Bateman argues a 10-year-old who knows right from wrong accords with the experience of many parents, and many young people exhibit 'older' knowledge much earlier.

"But the argument involves a categorical error," Bateman writes. "Acquiring a moral understanding is not like learning to walk, a once-and-for-all achievement; it is rather a skill that improves incrementally over an extended period."

And a child's reasoning is inherently different from an adult's, he argues.

"Just as we would not expect an infant who has grasped the rudiments of arithmetic to solve quadratic equations, so too a primary school child who understands that damaging property is 'wrong' is not manifesting an ethical stance that would properly qualify him or her for jury service."

So how to gauge legal standing for a 10-year-old? And how does a criminality threshold, whether 10 or 14 years, relate to brain science?

The minimum age of criminal responsibility

Science tells us the teenage brain is a work in progress. That's clear.

But exactly how much consideration is due a child who commits a crime?

Australia's primary legal barrier to criminalisation is called the Minimum Age of Criminal Responsibility, or MACR.

Compared with a global median of 14, Australia's MACR of 10 ranks alongside Syria, Bhutan, Cameroon, Malaysia and Nepal.

Given science argues a brain younger than 14 years cannot readily comprehend jurisprudence, Australia's incarcerating of 10-year-olds attracts strident criticism from the UN and considerable pressure from Australian health and legal experts to raise the MACR.

Currently, Australian law rules *only* a child under 10 years is *incapable* of committing an offence, as "they are not criminally responsible for (it)".

Where does that leave 10- to 14-year-olds?

And what of Indigenous children, who are adversely affected by Australia's low MACR, asks researcher Chris Cuneen, of Jumbunna Institute for Indigenous Education and Research.

In a 2020 report *Arguments for Raising the MACR*, Cuneen suggests that before jailing such young offenders we must first assess their mental health, prior trauma, potential harms from incarceration, hidden disabilities, and intergenerational effects of colonisation.

But politics looms large at the heart of Australia's youth crime issues. And community attitudes often hold sway politically.

A view of Alice Springs.

FREEAUSSIESTOCK.COM

Alice Springs: a case study

Some 28,000 people live in Alice Springs/*Mparntwe* at Australia's heart, 5000 of them Aboriginal. All are divided over youth crime.

The long-standing issue rose again to national prominence for our Outback capital in 2022, during a shocking crime wave that saw extra police flown to the town from interstate.

Widely reported nationally, gangs of young children were roaming the town's main shopping and tourist precinct late at night, spitting at passers-by, throwing rocks, breaking windows, stealing, sniffing volatile substances.

Kids as young as 10 or 11 were seen stealing cars, hooning around in them and driving head-on at police, baiting them into pursuits. All while live streaming.

The situation had worsened after legislated dry area alcohol restrictions expired in July 2022.

As a result, alcohol-related assaults and domestic violence that year rose by more than two thirds, 1800 homes and businesses were broken into, and more than 400 cars stolen.

Local security patrols of Aboriginal elders stepped in to walk the town's main shopping precinct at night. Police twice enforced government-mandated youth curfews during 2024.

But the youngsters know their rights. Even when caught, police can only take them to a safe place or responsible adult.

Many are frustrated the kids "get away with murder", including Aboriginal crime victims who call for perpetrators to be jailed.

Aboriginal Labor MP for Lingiari Marion Scrymgour, for example, has many times demanded a rethink on youth crime, lamenting to the media that people in Alice were "under siege in their own homes".

"You can't just keep grabbing these kids and taking them home, because there's a real problem at home," Scrymgour told the ABC. "A lot of them ... once the police leave, they're back out on the street again with their friends."

During the social chaos of summer 2022, the Northern Territory Labor government raised the MACR from 10 years to 12, the first Australian jurisdiction to do so. Youth justice advocates applauded.

In mid-2024 the Australian Human Rights Commission recommended raising the MACR to 14 years, and the (still) NT Labor government concurred.

By October 2024, however, Territory voters had dumped Labor for the Country Liberals, who promised "tough on crime" policies and to lower the MACR from 12 back to 10.

The new government flooded Alice Springs with police.

Arrests skyrocketed and prisoner numbers climbed – by March the NT had topped the nation for having incarcerated more than 1% of its residents. Were the NT a country, wrote one ABC reporter, it would be second only to El Salvador.

The NT Law Society condemned the MACR lowering. Australian Law Council president Greg McIntyre was concerned for First Nations children, his fears confirmed when a census later revealed that 100% of NT juveniles in detention were Aboriginal.

Most if not all the youngsters were from disadvantaged backgrounds, and had, as Cuneen's research argues, "complex needs better addressed outside the criminal justice system".

Critics of the "soft-on-crime" approach nonetheless point to an existing "default legal protection" for the under-14s. Lawyers call it doli incapax, a presumption that the youngsters can't be held responsible for criminal offending because they're not aware their behaviour is seriously wrong.

The presumption is rebuttable, in other words proving the child knew what they were doing can still result in imprisonment.

But in practice, this is rare. In February, for instance, NT police confirmed only one 11-year-old child had been arrested at Alice Springs since October, and was let go with a warning.

Still, between July 2021 and June 2024, 14 children aged 10 or 11 were remanded to youth detention 49 times (some more than once), the NT Government says.

Some argue doli incapax demonstrates the system is not oblivious to children's needs. Others how the system is still failing them.

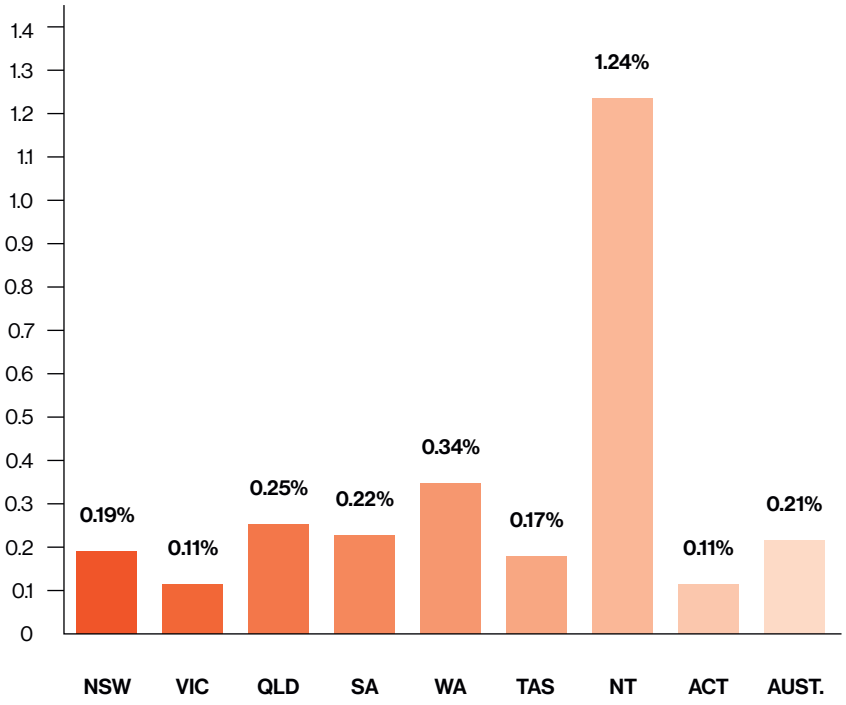
Many frame incarcerating 10 to 14-year-olds as a way of "protecting the public".

"We see this everywhere throughout the world," says Sawyer, who wonders whether "the children themselves might not also be thought of as victims".

"We know they're more likely than kids not in trouble with the law to come from highly disadvantaged families … to have developmental disabilities, acquired brain injury or even intellectual disability, ADHD, autistic spectrum disorder.

"Or (are) under child welfare, living in an out-of-home context, Indigenous, or have foetal alcohol syndrome."

December quarter 2024 average daily imprisonment rate



The Northern Territory has a much higher rate of imprisonment than any other state or territory in Australia, with more than 1% of Territorians in prison.

Incarceration and neurodisability

Does incarcerating youngsters "protect the public"? Or make matters worse for young offenders?

The latter was the clear result from a 2013 review of relevant research since 2000 in *Clinical Psychology Review* by Professor Ian Lambie and psychologist Isabel Randell, of the University of Auckland.

The worsening effects of incarceration often related to pre-existing health and mental health conditions, including neurodisability. Troublingly, research on prior incidence of neurodisability among NT juvenile offenders is scant.

One study, by Sydney based lawyer Clement Ng who previously worked in Darwin and Alice Springs courts, is being finalised as a UNSW PhD "The Criminalisation of Neurodisability in the NT Juvenile Justice System".

At the 2023 NT Children's Court Conference Ng presented preliminary findings from court records of 189 juveniles who came through the Darwin Children's Court during 2021 and 2022.

"Seventy-one of the 189 juveniles (38%) were diagnosed with at least one neurodisability, including 33 females," Ng told *Cosmos*.

"Thirty juveniles had FASD [Foetal Alcohol Spectrum Disorder] and 28 had intellectual disability. Almost half with neurodisability had more than one neurodisability."

Similarly, the Don Dale Royal Commission found "56% of juveniles with prior detention who gave evidence had FASD and 31% some form of brain injury", says Ng.

Recently FASD has been receiving more attention. Again, NT research is scant. Widely cited, however, is a 2017 study by Carol Bower et al of 99 juveniles detained at Banksia Hill Detention Centre in Western Australia.

The research found 88 youngsters (89%) had at least one neurodevelopmental impairment and 36 had FASD (36%), suggesting both FASD's high prevalence and how authorities failed to identify the cases prior to incarceration.

In Alice Springs, FASD rates reportedly mirror Bower's, though estimates vary, and no published research is available.

Dr James Dowler is an experienced paediatrician working in FASD diagnostics and management in Alice Springs and surrounding communities and explains that FASD can result when alcohol is consumed during pregnancy.

"FASD itself is a brain injury that occurs in utero," Dowler says. "In some cases,

SOURCE: AUSTRALIAN BUREAU OF STATISTICS, CORRECTIVE SERVICES, AUSTRALIA DECEMBER QUARTER 2024

Clement Ng was a lawyer at the NT Legal Aid Commission, and is now a Scientia PhD Candidate at the University of New South Wales.

Dr James Dowler is a paediatrician based in Alice Springs.

babies come out and they're (not) feeding, they have small heads, they have different facial features and are clearly delayed from the outset.

"(Conversely), you have babies who grow and develop normally but when they reach childhood there are defects in brain development, in their executive function, cognition, decision making."

Almost invariably there is co-occurring trauma, he says, along with depression and anxiety.

"You have all these compounding aspects, so it's not a pure diagnosis (of FASD) at any point.

"Unless you catch it early and it's severe, then you can say: 'Oh it's all alcohol that's done this'."

Many don't end up being FASD, says Dowler, though diagnosis becomes easier as children get older.

"As the brain develops differently into adolescence, that's when you see the clearer things."

Dowler says more attention is now paid to FASD than five years ago, "leading to more diagnosis and assessment.

"But we're going in that direction rather than supporting young mothers, solving overcrowding, domestic violence … it's a little frustrating."

No easy answers

For adult perpetrators, incarceration remains Australia's go to response.

For troubled 10- to 14-year-olds the way forward remains complicated, even elusive perhaps. Yet the science is clear. Many might say the horse has already bolted. Meantime, Indigenous children remain most affected.

Considered one of Australia's most experienced Aboriginal Controlled Health Services, congress suggests the vast majority (more than 80%) of young people in detention have "an undiagnosed or inaccurately diagnosed neurodevelopment disorder and have often had involvement with child protection services".

Last year, in a submission to the Inquiry into Australia's Youth Justice and Incarceration System, Congress pointed to emerging solutions beyond incarceration.

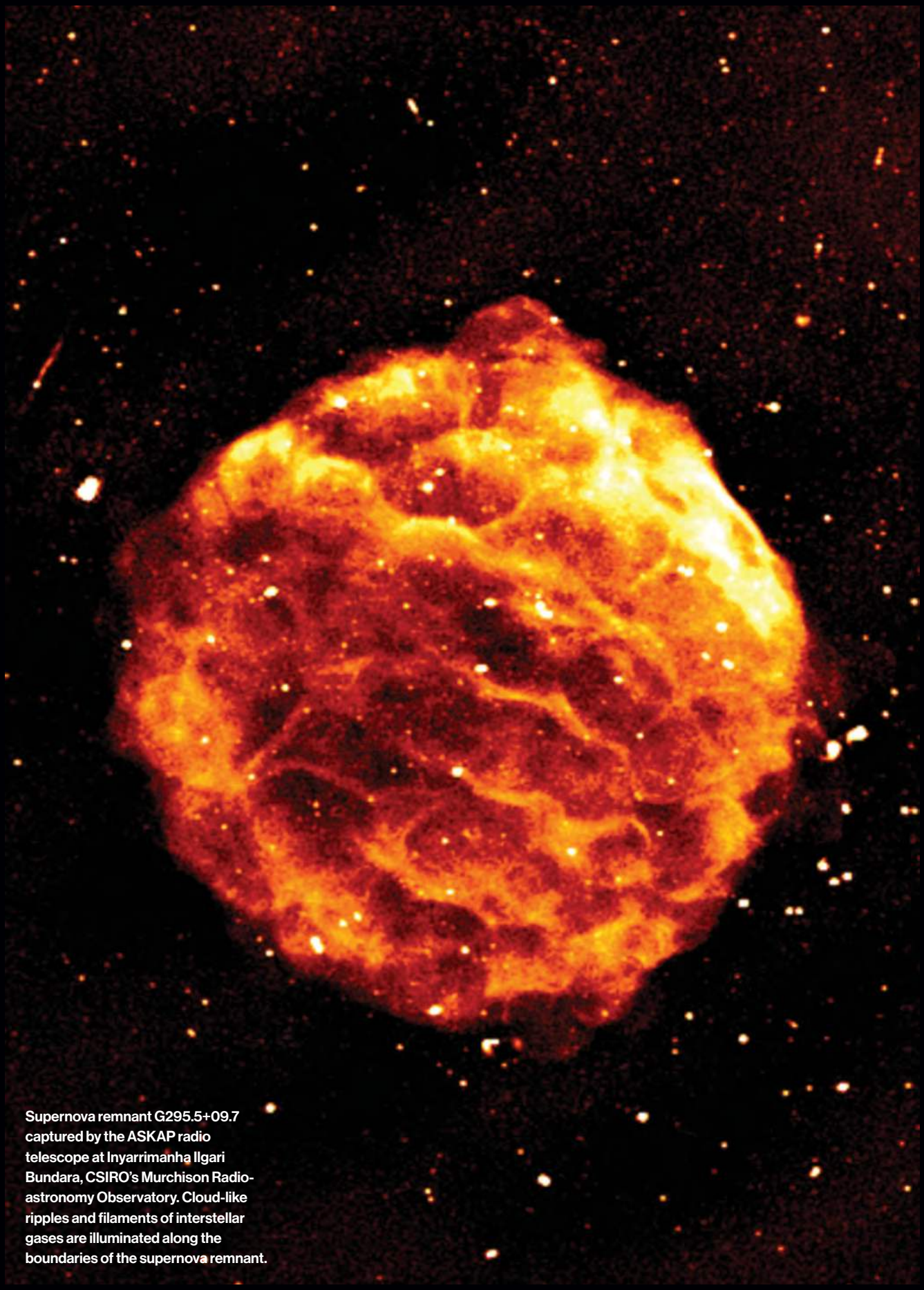
Its 21 recommendations, all evidence based, aim to help Indigenous children and their families avoid the youth justice system.

Nonethless, the submission put matters plainly: "There are young people being criminalised for their disability whereby they cognitively could not understand the severity and consequences of their behaviour."

Science suggests consideration for such youngsters is warranted. And lessons learned in the Indigenous sector and the Red Centre may help more broadly across the country.

Perhaps only time will tell whether, in Australia, all or any of this can translate into policy.

Glenn Morrison is an award-winning journalist, researcher and author who has written of Australia's Centre and North for more than 25 years.



Supernova remnant G295.5+09.7 captured by the ASKAP radio telescope at Inyarrimanha Ilgari Bundara, CSIRO's Murchison Radio-astronomy Observatory. Cloud-like ripples and filaments of interstellar gases are illuminated along the boundaries of the supernova remnant.

ASKAP EVOLUTIONARY MAP OF THE UNIVERSE (EMU) TEAM & KOVI ROSE

THE GHOSTS OF DEAD STARS

Supernova remnants are some of the most visually impressive objects in space. Astronomer **Kovi Rose** offers us a unique window into these violent and powerful celestial events.

Something explosive always seems to be happening in space. We often see headlines in the news about dramatic events like a flaring star, a gravitational wave from colliding neutron stars, or the latest supernova erupting in a galaxy far, far away. The stories normally tend to focus on the peak periods of these energetic events, which generate in a week roughly a trillion-trillion times as much energy as we generated on Earth last year. But what remains after a star's collapse – a supernova remnant, as astronomers call it – is both spectacular and scientifically interesting.

The end of a star

Stars are endlessly collapsing under gravity. This immense pressure drives a fusion reaction, where hydrogen particles join together into heavier elements. The energy produced by this fusion reaction pushes outwards, stopping the star from collapsing in on itself. However, when a star starts to run out of fuel for its fusion engine, the balance breaks down and things get interesting.

For stars roughly the size of our Sun, there is no big explosion as they reach their final years. Instead, when they run out of fuel, they gently shrink into a glowing lump of carbon and oxygen called a white dwarf. White dwarfs don't collapse entirely under the force of gravity, because the electrons in the remaining atoms are strong enough to push back. This is thanks to a quirky quantum effect called electron pressure.

A white dwarf can produce a supernova, but only under very specific circumstances, when the white dwarf is orbiting another star. When a white dwarf gets too close to the other star – which could even be another white dwarf – its gravitational influence will start to pull in material from the other star. This breaks the balance between gravity and those simmering electrons, ultimately causing the white dwarf to explode!

Bigger stars do end their lives in a supernova, and usually without any outside help. These stars – with more than 8 times the mass of our Sun – live fast and die young. They burn through their nuclear fuel faster than their smaller cousins, with lifetimes of millions (not billions) of years. These stars start by fusing hydrogen into helium in the core. As that runs out, they start fusing helium atoms together instead. And so it continues up the periodic table. The heavier the element, the faster the star runs out of fuel – with carbon and oxygen burning for mere years and months, respectively. But this can't go on forever.

Once the core is made of iron, the fusion process grinds to a halt. With no new energy keeping the star inflated, its layers suddenly collapse. The rush of material inwards hits the remaining iron core and produces a shockwave that moves outwards at speeds nearing a quarter of the speed of light. These aptly named core-collapse supernovae usually leave their densely packed remains behind in the form of a neutron star – or, depending on how massive they were, a black hole.

Supernova remnant SN1006 captured by CSIRO's ASKAP radio telescope. SN1006 is the remnant of a supernova that was observed in the year 1006 by astronomers all over the world, from Egypt to China. It was first recognised as a supernova remnant in 1965, following radio observations at Murriyang (the Parkes radio telescope).

DR EMIL LENC & KOVI ROSE

Tuning the radio

For both classes of supernova, the stellar matter from the explosion is launched out across space at thousands, or even tens of thousands, of kilometres per second. Moving at these speeds, the leading front of the supernova can take tens of thousands of years to slow down, usually after spreading out across several light-years of space (one light-year is about 9.5 trillion kilometres) and sweeping up any additional material they encounter along the way. This is a supernova remnant: an interstellar bubble created by the wake of one of nature's most energetic explosions.

This powerful blast wave contains fast-moving electrons that interact with nearby material in a fascinating way. The space around a supernova is filled with magnetised matter, and because of the special relationship between electricity and magnetism, the electrons curve rather than flying straight. As their paths change, the electrons are forced to slow down. Some of their energy is converted into light – but not always as light our eyes can see.

Visible light is just one window into the full spectrum of electromagnetic waves. It has a short wavelength of a few hundred nanometres; for context, the average width of a single human hair is nearly 100,000 nanometres. Most of the light in supernova 'bubbles' has much less energy, with a wavelength of tens of centimetres or even metres. This particular type of light is called radio.

Radio astronomers have built just the right instruments to detect this kind of light emitted by supernovae. From the initial blast to the giant bubble-like structures they create as the explosion moves out through space, radio telescopes can detect these explosive supernova 'bubbles' expanding and eventually slowing down as they become a remnant.

We also see the brightness and energy of the light changing depending on how much material the shockwave sweeps up as it expands, or how strongly magnetised the surrounding material is. By studying the radio light generated by supernova remnants, we can learn when and how they formed, as well as what kind of dense objects the explosion left behind.

CSIRO's ASKAP is a telescope made of 36 smaller (12-metre) dish-like antennas spread over a large area on Wajarri Yamaji Country in Western Australia.

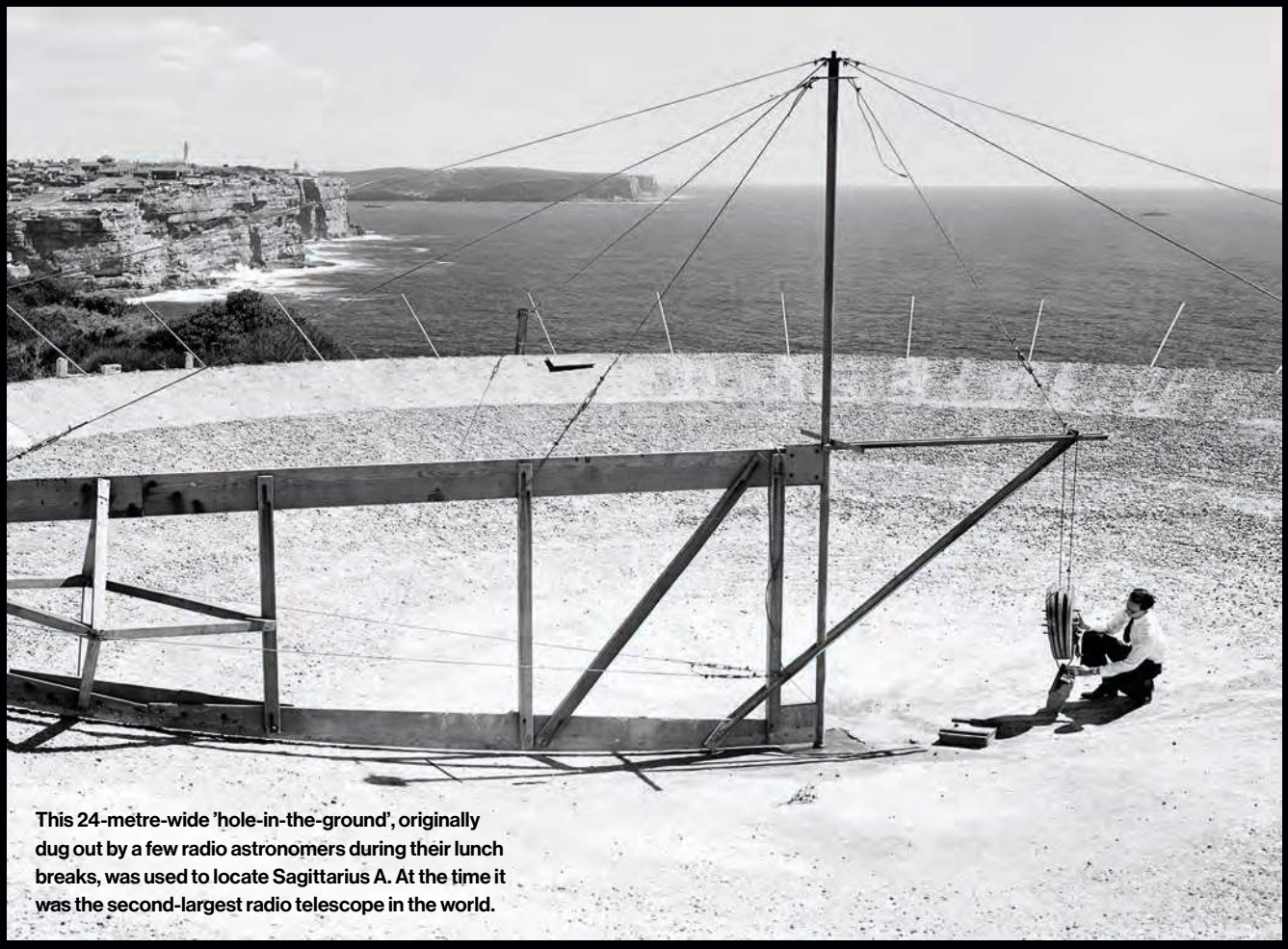
LAURA DRIESSEN

Australia's view

Radio astronomy has a long, continuous history in Australia. We were one of the first countries in the world to use radio instruments to study celestial objects. The American radio engineer Karl Jansky, widely considered the founder of radio astronomy, first detected radio emission in 1933 from a dense region somewhere in the Milky Way. However, in 1954, CSIRO astronomers in Sydney figured out that the source of Jansky's detection was located right at the centre of our galaxy.

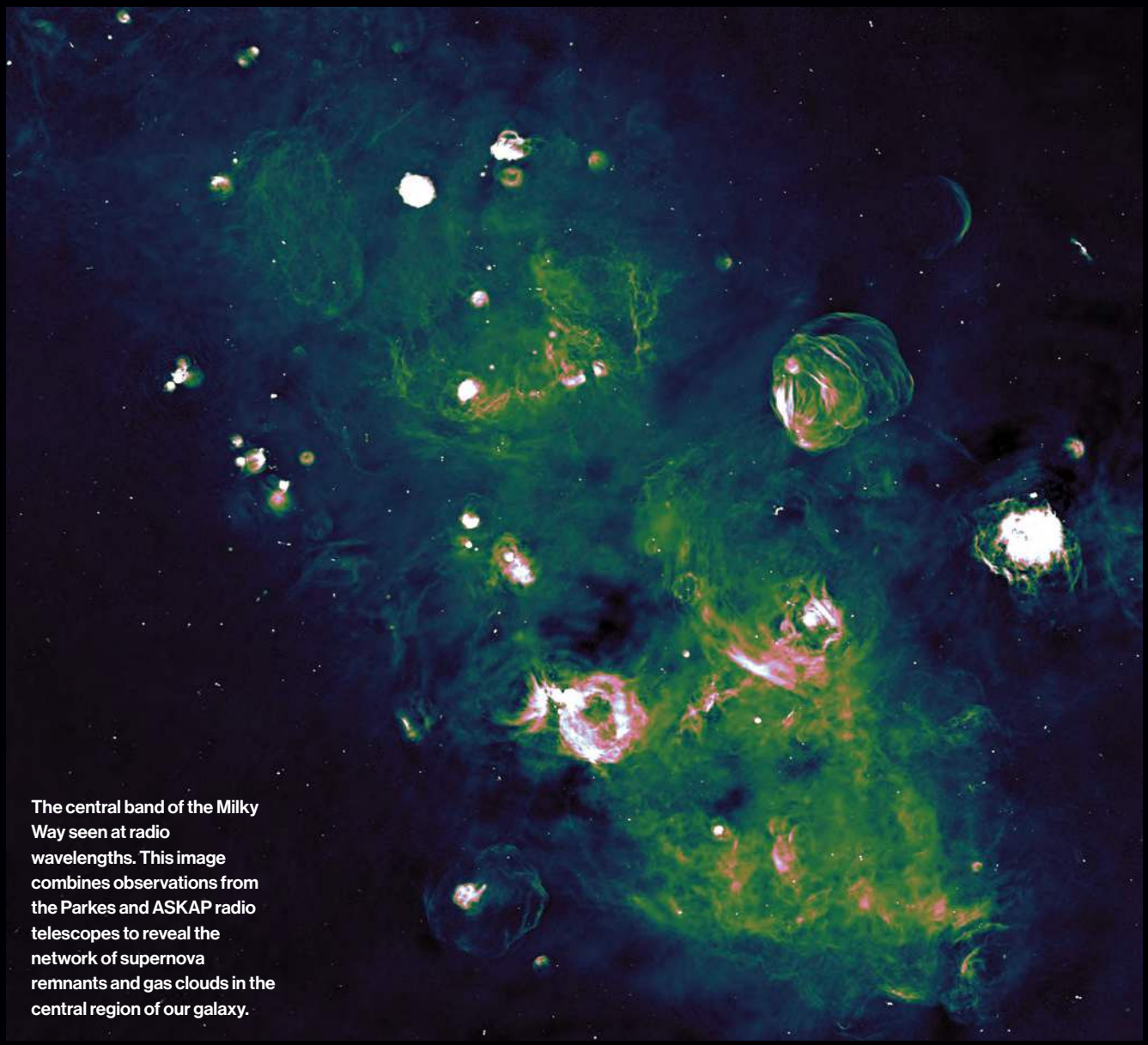
As the field of radio astronomy developed, astronomers and engineers began exploring different types of telescopes that could be used to study a range of objects in the sky. Depending on the design of the instrument, we can use them to detect point-like radio sources – like the centres of distant galaxies – or diffuse clouds and filaments, like the boundaries of a supernova remnant. And using advanced image-processing techniques and modern telescopes like CSIRO's ASKAP radio telescope, we can create images that show the beauty of the radio sky at both small and large scales.

▲ Supernova remnant G278.94+1.35, dubbed 'Diprotodon', captured by CSIRO's ASKAP radio telescope.



This 24-metre-wide 'hole-in-the-ground', originally dug out by a few radio astronomers during their lunch breaks, was used to locate Sagittarius A. At the time it was the second-largest radio telescope in the world.

FROM TOP: SANJA LAZAREVIĆ/ CSIRO



The central band of the Milky Way seen at radio wavelengths. This image combines observations from the Parkes and ASKAP radio telescopes to reveal the network of supernova remnants and gas clouds in the central region of our galaxy.

R KOTHES (NRC) AND THE PEGASUS TEAM

Exploring our galaxy

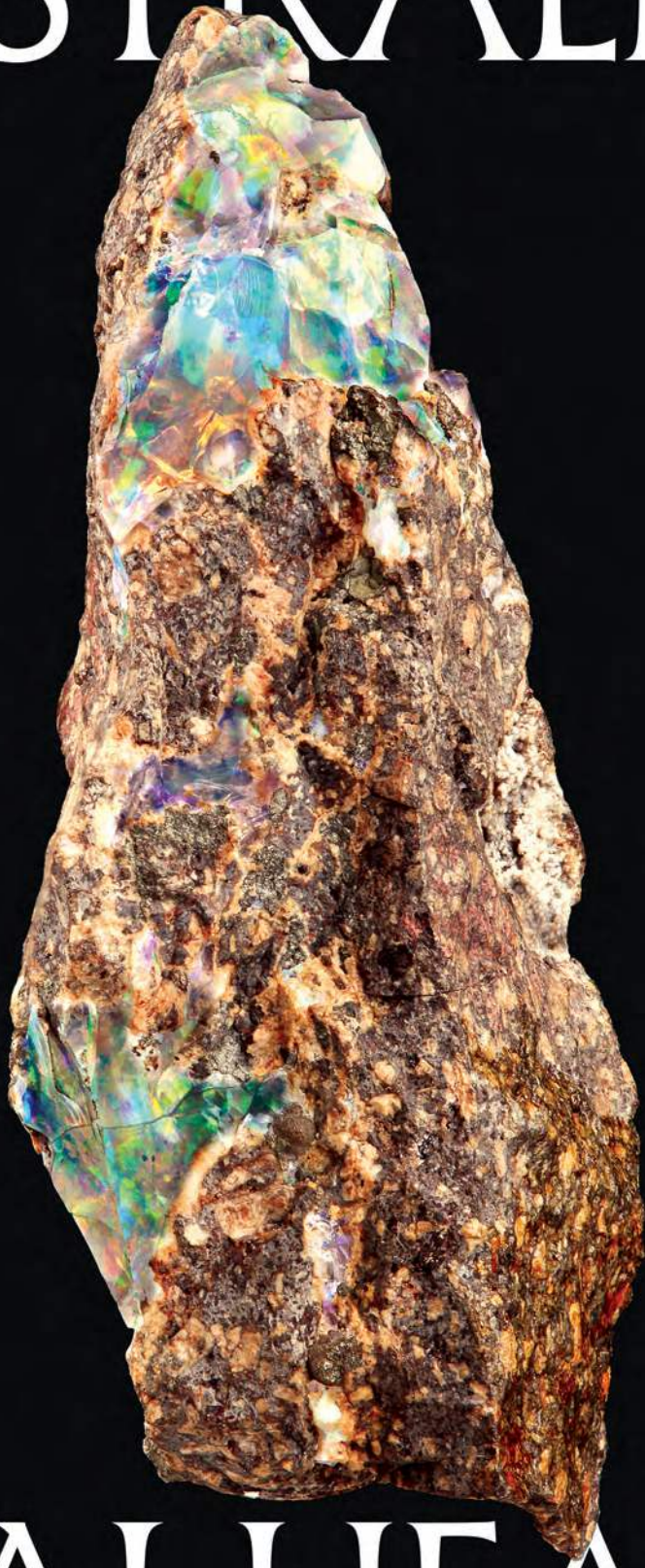
Supernova remnants are stunning markers of the explosive history of our galaxy. And luckily for astronomers, we've already discovered hundreds of them. Observations of that white road of stars that runs across the sky, the Milky Way, have revealed a foamy sea of interstellar bubbles created by ancient supernovae.

The shapes of supernova remnants reflect the circumstances of their formation and their encounters with neighbouring objects, including cosmic clouds of gas and dust. Some appear symmetrical, while others take on distorted forms, moulded by interactions with nearby material or overlapping with other expanding bubbles. In fact, our whole solar system sits near the centre of a 'superbubble' – a vast cavity containing most of the stars visible to the naked eye. Scientists reckon the superbubble was carved out by the cumulative explosions of multiple supernovae over millions of years.

Radio astronomers estimate that as many as 1,500 supernova remnants may be still hiding in our galaxy undiscovered. New observations with highly sensitive radio instruments like ASKAP and the upcoming SKA telescopes will help us uncover these elusive interstellar bubbles, and reveal more details about the energetic processes that shaped the Milky Way.

Kovi Rose is an astrophysics PhD candidate at the University of Sydney who studies the radio light from nearby dwarf stars and distant supernovae.

AUSTRALIA'S



OPAL HEART

There's something quintessentially Australian about opal. **Jonica Newby** heads to Lightning Ridge to uncover the secrets hidden deep within the stones.

I'd never thought deeply about opal until I glimpsed my first one in the wild. "Oh, oh, there, LOOK!" I exclaimed in excitement. I swear my eyes started doing that big swirly cartoon thing. "You've got the fever," chuckled my companion. "I do, I do," I squeaked. "Can we get it out?"

It was 2024, my first visit to the legendary outback opal town of Lightning Ridge, and local miner Tim Warhurst had invited me into his mine. After traversing a flat red landscape dotted with little piles of mining rubble, I'd dubiously eyed the narrow hole, tested my arm strength on a 40ft shuddering ladder, followed my headtorch through a maze of rough tunnels and caverns supported by tree trunks – when a flash of blue set fire to my brain. Tim grabbed a pickaxe and kindly dug it out for me.

Opal fever, apparently, is real. "You can't sleep, you're a bit excited," admits Tim. "Never lick it because you'll get addicted," warns another miner. (Too late – I licked mine – it's what the miners do to bring out the colour.) And that addiction can be so powerful casual visitors end up moving here. Just ask palaeontologist Jenni Brammall, who came 28 years ago, looking for opalised fossils – and stayed.

"I remember the first time I saw opal glittering in a mine wall, I was enchanted, just seeing that dance of colour and light. That night, as I shut my eyes, I saw the colours of opal on the inside of my eyelids. And that was it – I was gone," she laughs.

These stones have fire. Which is why, after a lifetime of taking opals for granted as common tourist trinkets, I'm now ablaze with questions. Why does 95% of the world's precious opal come from Australia? Why is it so different to other gems with its dancing colours? And why does it make such amazing fossils?

When you stare at an opal, you look into a time tunnel that shoots you back 100 million years to a land of dinosaurs and volcanoes and a newly discovered "lost age" of egg laying mammals. Twist one way for a pre-European view of powerful rainbow-stones, another for the colourful backcountry lives of the miners.

In some ways, the story of opal is the story of Australia. And in Lightning Ridge, it's never had a home worthy of the tale. Until now.

Tim Warhurst is an opal miner in Lightning Ridge.

JONICA NEWBY

Outback opal cathedral

Which is why I've made the decision in mid-2025 to drive back to Lightning Ridge.

This is a grand dream born 30 years ago – of a big, bold, architecturally outstanding, world-class museum and research hub here in the outback. It's the other reason Jenni Brammall stayed. While the project is a community-wide effort, it's been her job as chief executive of the Australian Opal Centre to nurse it to life – and she's about to show me the near completed building.

The building nestles into a low-slung landscape of white dirt and red gravel smattered with trees, old caravans, and little rubble mounds; tell-tale signs of opal mining. Surprisingly, there are no big mining companies here. Opal is still dug by individuals working their own claims – a goldrush lifestyle little changed in 100 years.

And just like the mines, what we see from the surface is a fraction of what lies beneath. "So as we pass through this underground entry tunnel you'll hear a soundscape," Jenni explains, "of Yuwaalaraay language, other voices, wind, a mining pick, birds, water."

We emerge into a truly breathtaking space. We're on a mezzanine; a ceiling rippled by skylights hangs high above us.

"It's like an outback cathedral," says Jenni, "for treasures of national significance. And I love that it's built into the earth, and embedded with pebbles of this landscape that are part of our geological heritage."

But the architecture is second to the true drawcard; the fossils and opals themselves.

Mounds of rubble indicate that this is opal mining country.

Concept art of the new Australian Opal Centre, set to open this year.

FROM THE TOP: JONICA NEWBY / DARCSTUDIO

Time travel to the Cretaceous

Jenni bypasses a fabulous set of opal dentures (local residents do love a colourful statement) to unwrap a dazzling relic of Australia's deep past.

"This is one of the supreme hero pieces of the collection. Apart from the fact that it's a glowing green opalised shark tooth, what's interesting is that this was a freshwater environment and this shark lived in saltwater. What was it doing here? One theory is it swam upriver from the inland sea – maybe to breed or drop parasites that couldn't tolerate fresh water."

Extraordinarily, all the opalised fossils from Lightning Ridge have been dated to a narrow time band during the Cretaceous period 96-100 million years ago.

Glowing pearlescent yabby buttons, lungfish bones, crocodile teeth, turtle bones and exquisite pinecones in rippling greens and purples catapult us back to a lush Gondwanan Eden. To a land of vast rivers plummeting from 4km-high mountains which rimmed the continent, slowing here onto a massive floodplain before flowing into the distant sparkle of the inland Eromanga Sea.

"This foot bone is from perhaps our most famous dinosaur; Lightning Claw," says Jenni. "It doesn't have a scientific name yet, but we believe it's a new species of megaraptor." It had massive claws on its forefeet and a metre-long skull with razor-sharp teeth.

Lightning Ridge is the only major dinosaur site in NSW, so its scientific significance is immeasurable. And it blows my mind that these fossils are opal – many common grey potch, but others streaked with flashing gemstone.

"This is *Fostoria*, a large herbivorous iguanodontid dinosaur, maybe 5m long. It got around on its hind legs and had a beak-like structure it probably used to pluck leaves and ferns. These bones were found by the Foster family, hence the name. And the species name *dhimbangunmal* is a beautiful gift from the Yuwaalaraay language. It's a literal translation of 'sheepyard' after the opal field it came from."

Next, the less mighty but deliciously named *Weewarrasaurus*. "This was a small herbivorous dinosaur related to *Fostoria*. It was about the size of a dog, might've made a cute pet. Weewarra was the name of the place it was found – [it means] 'standing fire'. Again, the language of the people who lived here for tens of thousands of years is coming through, which is wonderful."

While the dinosaur bones are big and flashy – some literally – what excites me most is a tiny grey bone in the next cabinet. This bone is from a monotreme – whose only living relatives today are the echidna and the platypus. And they're turning our understanding of mammal evolution on its head.

Local hero Harold Hodges created a set of opal dentures.

This opalised shark tooth dates to around 100 million years ago.

The toe bone of *Fostoria*.

Fostoria **was a herbivore, related to Muttaburrasaurus.**

FROM THE TOP: JENNI BRAMMALL/ROBERT A. SMITH AND AUSTRALIAN OPAL CENTRE/ JAMES KUETHER / ROBERT A. SMITH

In 2024, palaeontologists described and named 3 entirely new ancient monotreme species, based on opalised fossils from Lightning Ridge. It brought to 6 the total number of 100-million-year-old monotremes discovered here, of which 5 were from separate families – as different as cats to horses – suggesting many more species once existed. It's an entire lost era: the Age of Monotremes.

The jawbone of *Weewarrasaurus*.

Far from the earliest mammals all being tiny, shrew-like creatures cowering until dinosaurs vanished, 100 million years ago, Lightning Ridge teemed with egg-laying mammals, large and small. There was platypus-like *Dharragarra*, a pig-sized *Stirtodon*, tiny *Parvopalis*, and *Opalios* the "echidnapus".

Opals truly are a time traveller's treasure trove. Which raises the question – why?

Weewarrasaurus was about the size of a large dog.

An opal-hearted country

The most famous line in Dorothea Mackellar's iconic ode to Australia is "I love a sunburnt country". Less known is her final stanza:

"An opal-hearted country,
A wilful lavish land"
"All you who have not loved here,
You will not understand."

Mackellar understood that opal lies literally at the heart of the Australian story – a quintessentially Australian gem found only in the Red Centre. Yet astonishingly, no one really had a good scientific explanation why – which shocked French geologist Dr Patrice Rey when he became Professor of Geology at the University of Sydney.

"It's the national gemstone, most of the world's precious opal comes from here and we don't know how it forms? I was embarrassed for the nation," he laughs.

Patrice had caught the opal bug as a French schoolboy after watching a documentary on Coober Pedy. "Even if you don't find opal, you get an underground house and a swimming pool!" While he might never be an outback treasure hunter, perhaps he could crack opal's secret planetary recipe.

It took years until the final clue came, perversely, from another planet entirely: Mars. "Opaline silica was discovered on Mars. So I started wondering; what do Mars and central Australia have in common?"

Unlike most gems, which are crystal, opal consists of nanoglobules of silica. It's the diffraction of light by these tiny spheres that creates opal's mesmerising play of colour.

It turned out, both Mars and central Australia had an ideal source of silica – basalt, from ancient volcanoes. To become opal though, the silica needed exposure to acidic conditions; common on Mars, but rare on Earth because widespread limestone neutralises any acid. And this is where the penny dropped for Patrice.

The Great Artesian Basin in Australia's centre has very little limestone. And he had an idea for a source of acid; not a mineral process, but a biological one.

Anaerobic bacteria excrete pyrite, which in the presence of oxygen releases sulfuric acid. And where do anaerobic bacteria hang out? Muddy swamps. And there was only one place in all Earth's history with that unique confluence of volcanoes, vast swamplands and little limestone; central Australia starting 130 million years ago.

Australia was still part of the supercontinent of Gondwana then and sat much further south. It was too cold for coral reefs to grow – hence low limestone. Moving east, the continent passed over a subduction zone, sucking central Australia into a bowl shape,

FROM THE TOP: ROBERT A. SMITH / JAMES KUETHER

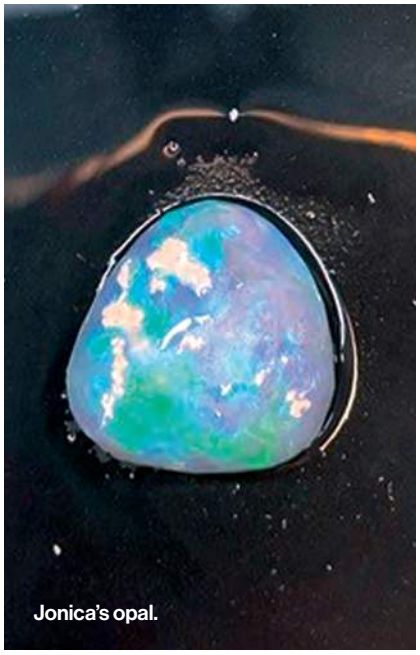
creating an inland sea surrounded by volcanoes and rivers which, unusually, flowed inland.

So picture our *Weewarrasaurus*. 100 million years ago, she dies by a river, is swept into a muddy lake and smothered in sediment. Anaerobic bacteria eat her soft flesh, excreting pyrite. Meanwhile, in this oxygen free environment, her bones are perfectly preserved as fossils.

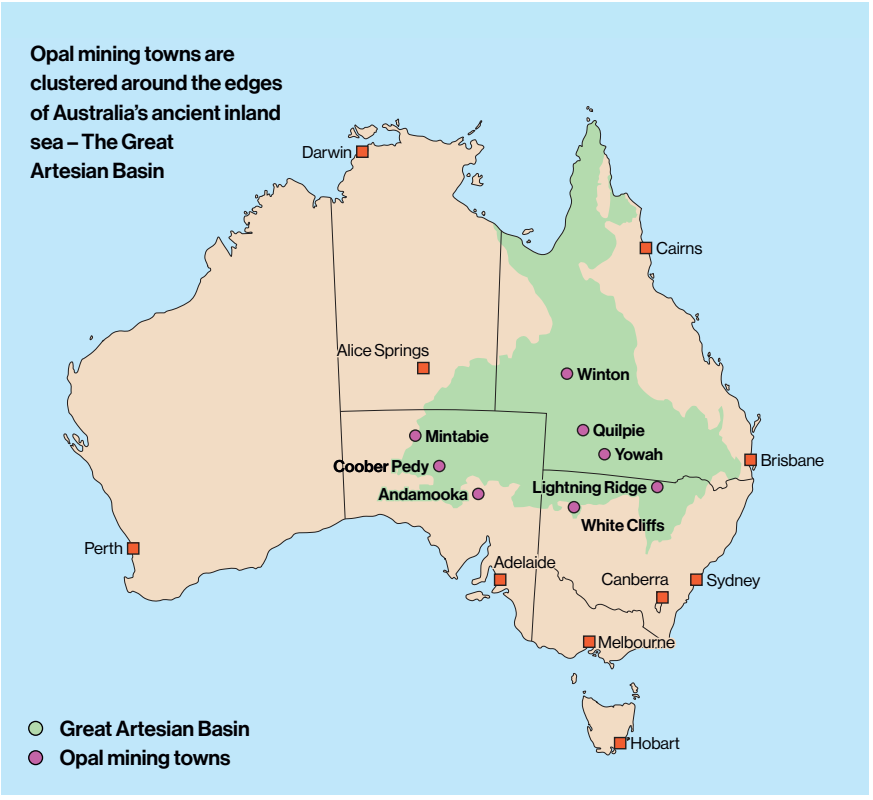
But they are not yet opal. That requires an alchemic transformation so unlikely it's a miracle it happened at all. From 97-60 million years ago, the subduction stops. The bowl bounces back up, the inland sea dries up. Oxygen begins to reach down through the rock layers toward the buried bones, reacting chemically with the pyrite, releasing sulfuric acid which dissolves the bones. Meanwhile, the acid also reacts with basalt-derived clay to create a silica gel – which slowly seeps into voids in the rocks – including the beautiful *Weewarrasaurus* fossils, gently replacing the dissolving bones, molecule by molecule.

"It turns out for precious opal to form, it needs a very narrow range of acidity," says Patrice. "If the balance was exactly right between the amount of pyrite and clay, then the silica organised itself into perfect spheres, forming this beautiful gemstone.

"It seems impossible, basically, for this gemstone to exist," marvels Patrice. "And yet it does."



Jonica's opal.



Rainbow stones

Before I leave Lightning Ridge, I have one more important opal story to hear. Auntie Brenda McBride is a Gamilaraay, Yuwaalaaray, Wailian woman; a local elder and long-term collaborator with the Australian Opal Centre. I ask her the word for opal in her language. "Yuluwirri" means rainbow", she tells me, "so they're rainbow stones."

She knows two exquisite stories about how opal came to be. In one, a rainbow kept coming and putting her colours into the stones. In another; a pretty butterfly went to the Warrumbungles and her colours went into the earth and formed the opals underground.

These are powerful stones. "We can't keep them because of the rainbow serpent," she explains. "It's taboo to us because it's a snake. And a lot of people only hold their opal for a while and sell it off because they reckon if you keep it, a sickness was going to fall on the family."

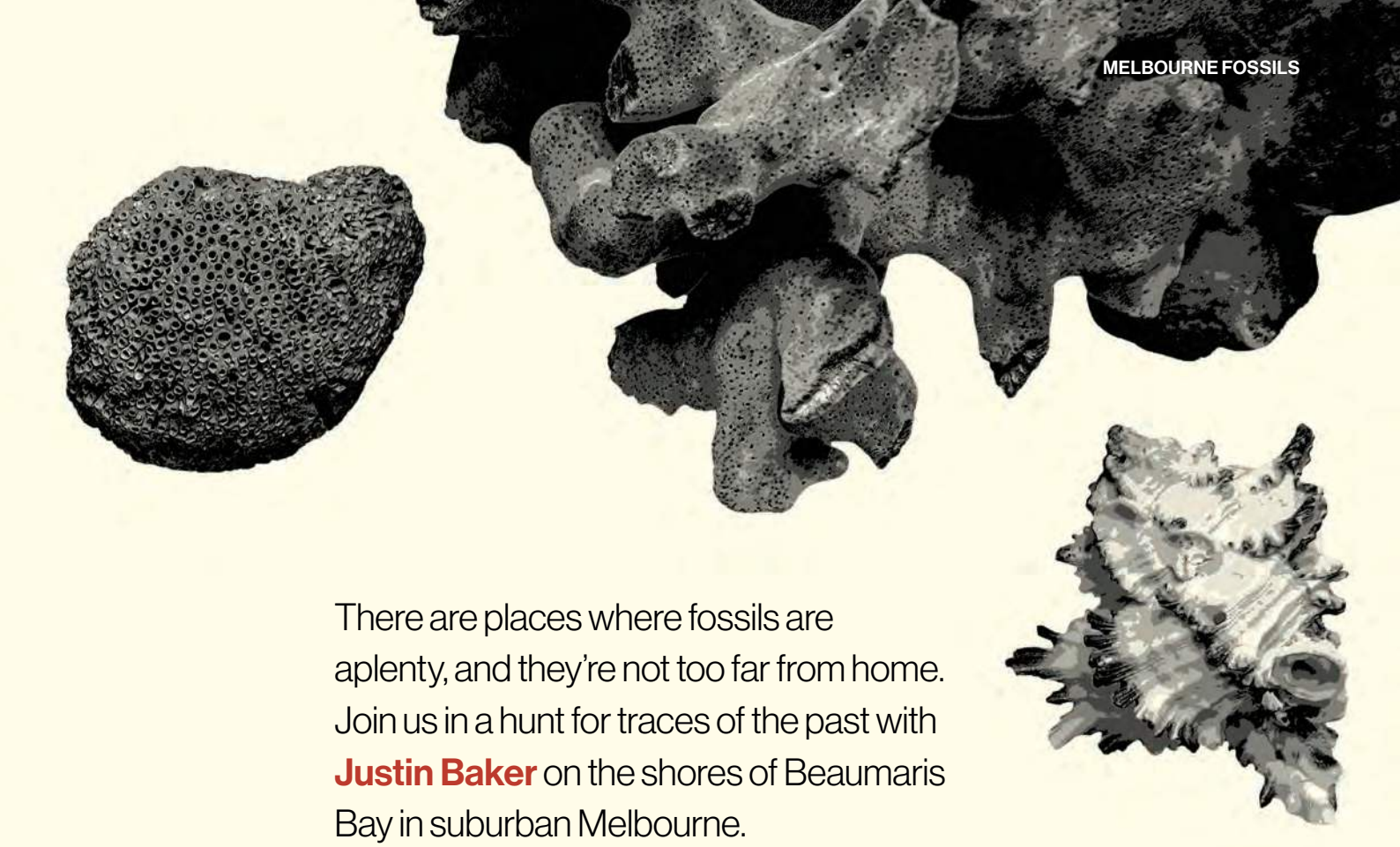
Aboriginal people have nevertheless long been prominent opal miners. Brenda mined opal with her dad. And remember the Foster family who found the magnificent sheepyard opal dinosaur, *Fostoria dhimbangunmal*? Greg Foster was Auntie Brenda's nephew. "So they asked me to name it for them, so I named it *dhimbangunmal* – means sheepyard." Auntie Brenda has given Indigenous names to several of the new opal fossil species, including *Dhurrugarra*, the ancient platypus from the Age of Monotremes.

Opal contains multitudes. And I'm so pleased these powerful stones will soon have the grand new outback cathedral home they deserve.

A few months after I get back from my first visit to Lightning Ridge, a package arrives. Before I'd left, opal miner Tim Warhurst gifted me the opal we'd found. A friend of Jenni Brammall's gifted me the gemstone polish. And now, here it is in my home. A piece of rainbow, a butterfly's wing, forged in the alchemic confluence of acid and ancient swamps and volcanoes. A gift from deep in my country – all the way across the ages – to me.

Dr Jonica Newby is an award-winning science reporter, author, TV presenter and director, best known for her two decades on ABC TV's science program, *Catalyst*.

VISIT MELBOURNE'S FOSSIL BEACH



There are places where fossils are aplenty, and they're not too far from home. Join us in a hunt for traces of the past with **Justin Baker** on the shores of Beaumaris Bay in suburban Melbourne.

I've loved fossils for as long as I can remember. Since I was very young, my family used to go fossil hunting. Even now, I get a buzz out of finding something so ancient that it's remained unseen for millions of years. Fossils are the ultimate time travellers. They have defied the odds and managed to survive for an unimaginable length of time.

Most Australian fossil sites are in remote locations, requiring hours of driving along long, dusty, unsurfaced roads. However, only 30km or so from Melbourne's CBD lies one of Australia's most important locations for fossils: the Beaumaris Bay Fossil Site.

In this rugged coastal area, the weathered sandstone cliffs have yielded a remarkable collection of fossils, including molluscs, sharks' teeth, and even occasional mammal and bird specimens.

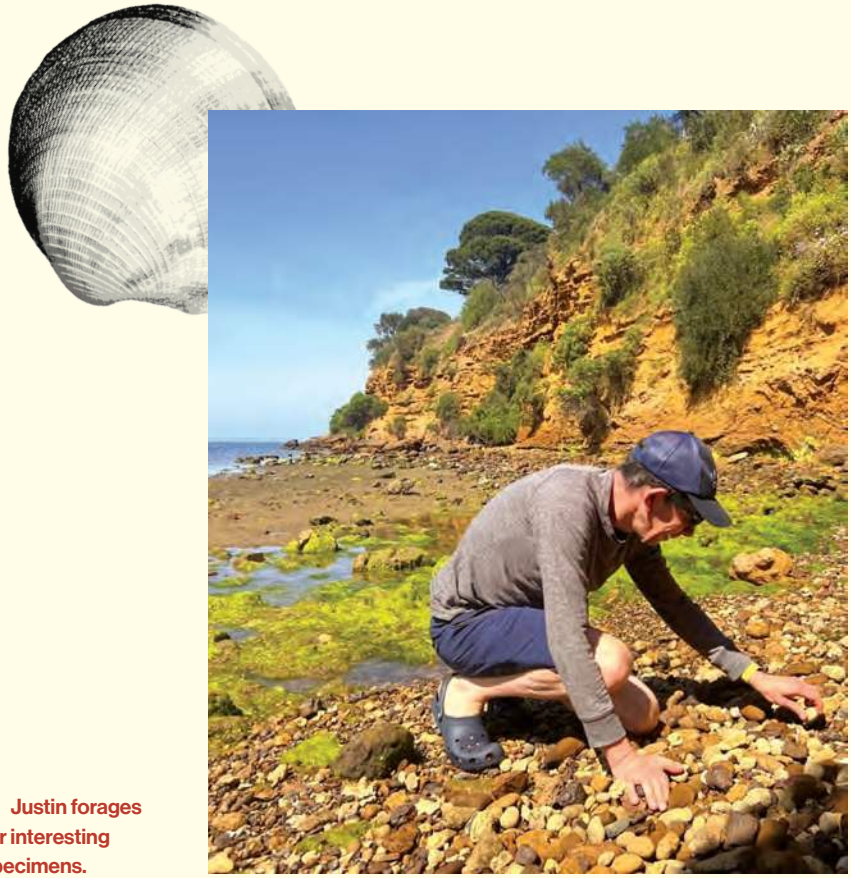
Professor Tim Flannery calls it "one of the most significant fossil sites in Australia".

PEER INTO THE PAST

So exactly how old are the fossils found at Beaumaris Bay?

Based on a combination of dating from microfossils in the sandstone and isotopic dating of the overlying rock bed, the Beaumaris specimens are estimated to be 5-6 million years old. On the geological time-scale, this is referred to as the late Miocene or early Pliocene.

The cliffs themselves are orange and red, due to iron oxide from volcanic activity at a much earlier time.



Justin forages for interesting specimens.

TOP FOSSIL HUNTING TIPS

You need to keep a few things in mind when visiting Beaumaris Bay.

Be prepared. It's quite rocky, so sturdy, waterproof shoes are needed to clamber over rocks. Sun protection is important, along with containers or small bags to put fossils in.

Keep an eye on the tides. The beach is only fully accessible around low tide. More adventurous fossil hunters have great success while snorkelling and scuba-diving offshore.

The cliffs themselves can be quite dangerous. It's much safer to stay near the shore.

You don't need any specialised tools like picks, and especially not dynamite! Digging is not permitted. Almost all the fossils are found lying on the beach or in the shallows among the rocks – they rarely need to be broken out of anything.

SUPPLIED: JUSTIN BAKER

FABULOUS FINDS

The most common fossil is a species of sea urchin or echinoid, known formally as *Lovenia woodsii*. Once you have the starfish-like pattern fixed in your mind, they are relatively easy to find – sometimes in quite large numbers. The colour differences between specimens can vary quite dramatically.

If you know what to look for, you can also find ear bones from various species of extinct whales and dolphins. These are slightly unusual-looking, nodule-shaped objects.

Friendly "found anything interesting?" conversation often arises as you pass others on the beach. I hear one of the most sought-after specimens for amateurs are fossilised shark teeth.

While they are hard to find nowadays, fossilised shark teeth have been identified from at least 20 different species. The most common ones are probably from the extinct white shark *(Carcharodon hastalis)*.

It's not uncommon to find fossilised whale bone. It looks much like fossilised wood, is very dense, usually dark brown in colour, and has a grain running in one direction. Whale bone finds are usually fragments, so it can be hard to work out where they are from anatomically.

It's also quite common to find pipe-shaped rocks. These are roughly cylindrical in shape and can be completely hollow on the inside.

The consensus is that they are the fossilised casts of burrows from mud lobsters. When the surrounding rock hardens over a very long period, iron oxide often leaches into the casts as well. This gives them a distinct metallic appearance.

I've always wanted to find a serrated tooth from the truly enormous megalodon shark *(Carcharocles megalodon)*. Recent estimates suggest the largest megalodon was up to 16m long and weighed 50 tonnes. Megalodon teeth are also proportionally huge at around 10cm in length!

SUPPLIED: JUSTIN BAKER / BEN FRANCISCHELLI

To help identify all these different types of specimens, grab a copy of the free online handbook from Museums Victoria, titled Fossils of Beaumaris by Erich Fitzgerald and Rolf Schmidt.

CITIZEN SCIENCE IN ACTION

If you find a surprising fossil while searching the beach, be sure to report it to Museums Victoria. Many years ago, a friend and I were exploring the tidal rocky zone at Beaumaris Bay when he found a fossilised bone. It was quite chunky and seemed to come from a mammal.

My friend made an appointment to speak to someone at Melbourne Museum, and a few weeks later we excitedly headed there to present our find.

The palaeontologist quickly assessed it as a seal bone and thanked my friend for his 'donation'. It was duly tagged and then added to a large collection of other finds on a big, slide-out steel drawer.

About 20 years later, a new academic paper about early Australian seals was published in the *Zoological Journal of the Linnean Society*. I was delighted to see my friend acknowledged for his contribution. That's citizen science in action!

RARE FINDS

While I haven't managed to find anything very rare at Beaumaris (yet!), others have discovered an ever-increasing array of specimens. Ben Francischelli showcased many of these in his Prehistoric Bayside exhibition in mid-2024. (If you missed the exhibition, it's still available online as a virtual tour.) These include:

- A huge, 30cm-long tooth from a killer sperm whale. The whale was estimated to have been about 18m long and weighed 40 tonnes!
- The jawbone of the extinct bird *Pelagornis*, which had a 6m wingspan – more than twice the wingspan of an albatross. Pelagornis had unusual bony projections along its beak instead of teeth.
- The bones of the marsupial *Zygomaturus*, a Miocene megafauna that looked somewhat like a rhinoceros. Adults weighed more than 500kg.

Ben Francischelli poses with the jaw of an undescribed killer sperm whale species.

A 30cm-long tooth from a killer sperm whale.

SUPPLIED: BEN FRANCISCHELLI

SUPPLIED: BEN FRANCISCHELLI

The jawbone of the extinct bird *Pelagornis*.

The bones of the marsupial *Zygomaturus*.

"IT'S A GREAT EXPERIENCE SPENDING A FEW HOURS EXPLORING ALONG THE ROCK POOLS"

YOUR OWN FOSSIL ADVENTURE

We are so lucky to have the Beaumaris Bay site on our doorstep. I have taken groups of friends down here over summer for many years now. It's a great experience spending a few hours exploring along the rock pools. If you're in Melbourne, you can do the same.

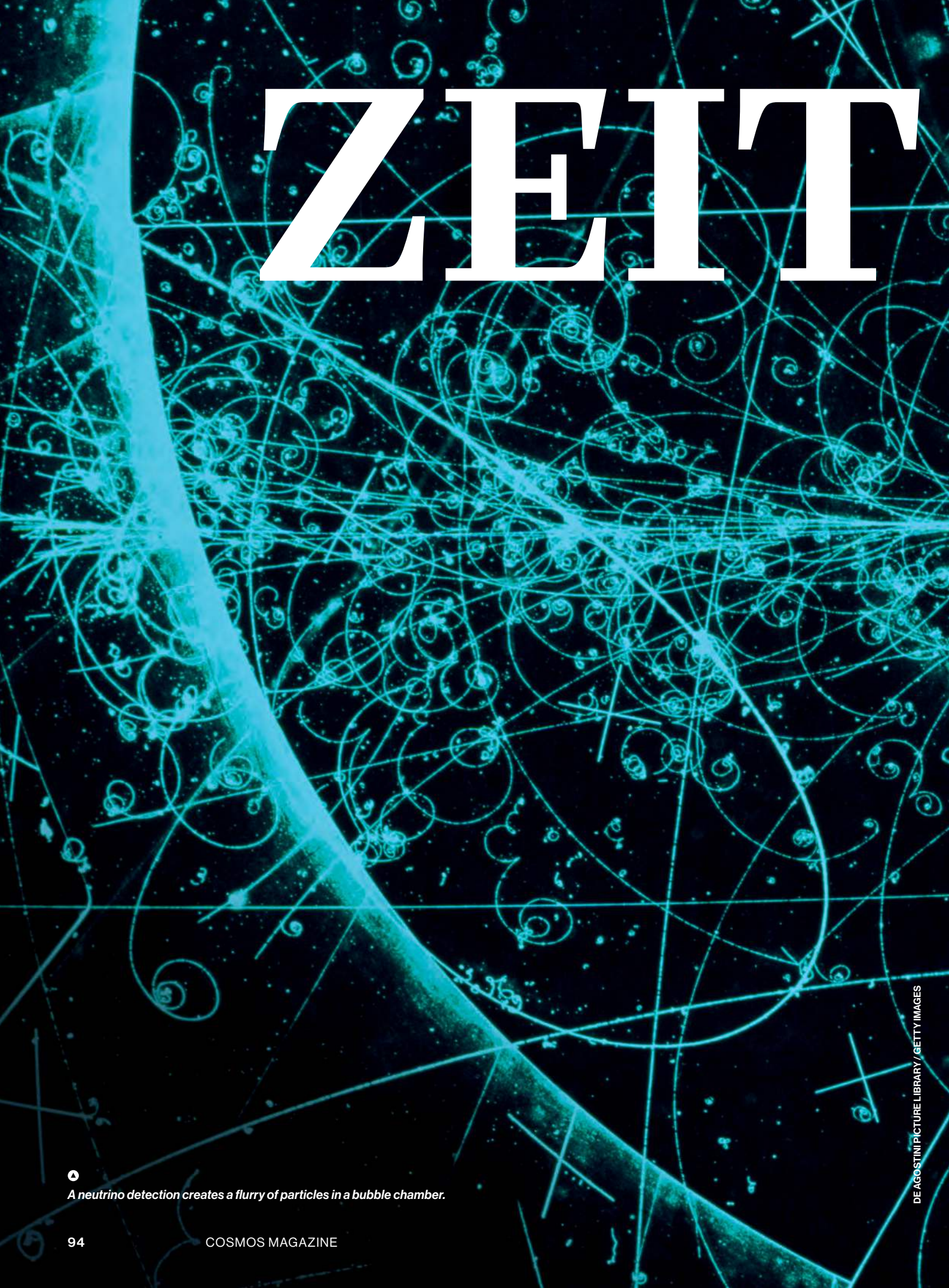
In other parts of Australia, you might visit Point Peron near Perth, Woolshed Creek near Canberra or Fossil Cove near Hobart.

Just be sure to check the rules about handling fossils in the area.

You never know what you might find!

Justin Baker is an avid citizen scientist. His article on astrophotography at home appeared last issue.

ZEIT



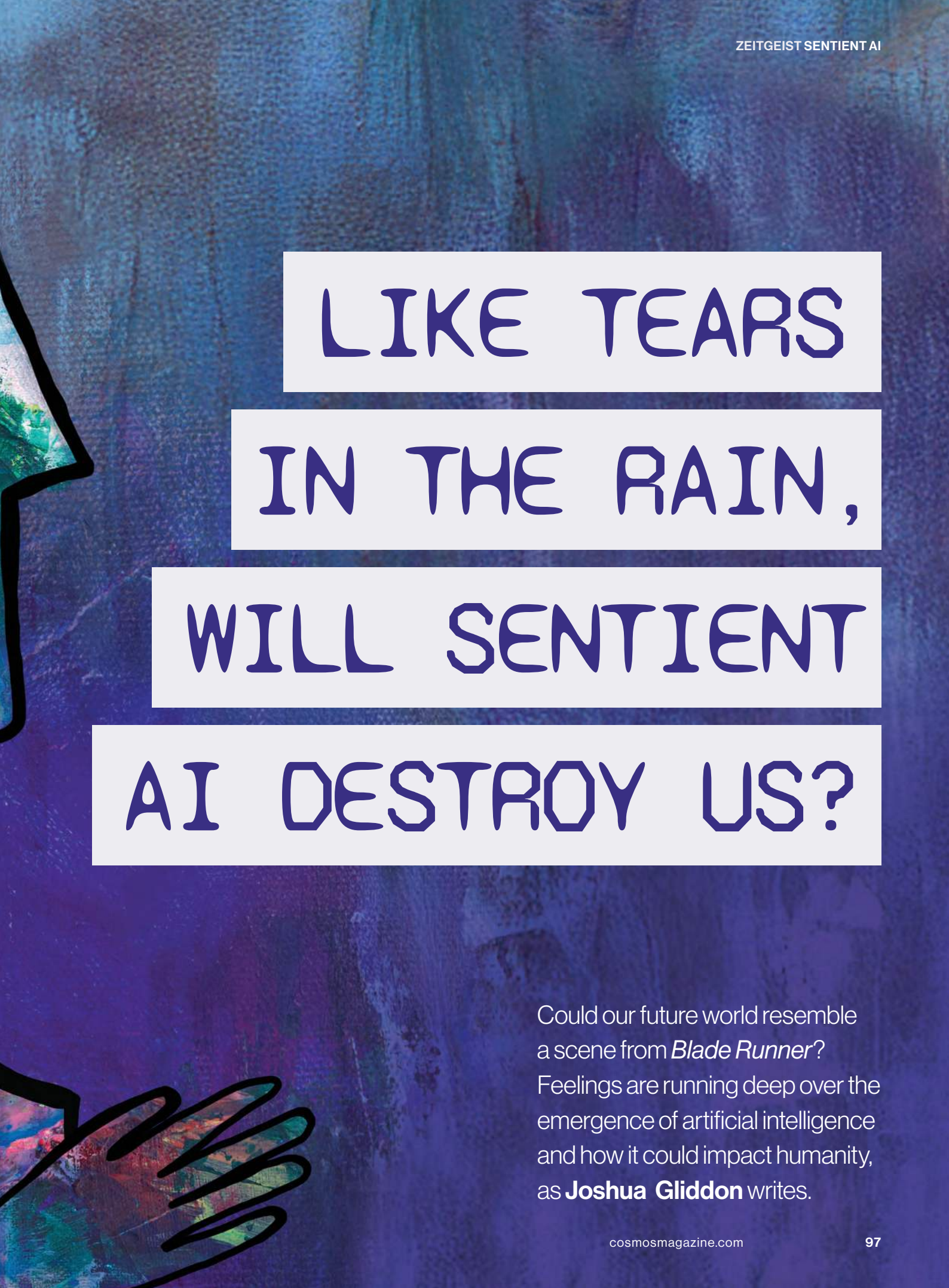
A neutrino detection creates a flurry of particles in a bubble chamber.

DE AGOSTINI PICTURE LIBRARY / GETTY IMAGES

GEIST

› Science meets life

GETTY IMAGES / STELLA LEVI



LIKE TEARS IN THE RAIN, WILL SENTIENT AI DESTROY US?

Could our future world resemble a scene from *Blade Runner*? Feelings are running deep over the emergence of artificial intelligence and how it could impact humanity, as **Joshua Gliddon** writes.

From Pinocchio through to Frankenstein's monster, and more recently the replicants in *Blade Runner* and the sentient AI in the movie *Her*, humans have long been fascinated with the idea of creating machines that can think, feel and respond just as we do. We're also fascinated with the implications of those creations – will they keep us company, supplant us or even try to eliminate us altogether? Should those machines have rights? And if it's possible to make sentient machines, what does this mean for us being human?

Whether or not AI will become sentient is a wide-open debate, and there's real tension between what the technologists and futurists think, and the beliefs of those working in the fields of philosophy and theories of consciousness. What we do know, however, is the harms posed by AI – sentient or not – aren't just theoretical. AI might not be sentient right now, but it is harming humans today.

Tech vs philosophy

The tension between the tech and futurist crowd and the philosophy people on sentience comes down to one idea: emergence. Tech people broadly believe sentience is an emergent phenomenon; that is, throw enough resources in terms of time, money and compute power at the problem, and sentience must emerge within the system.

It's a position held by Australian futurist Ross Dawson, who argues it's likely we'll see sentient AI systems in the not-too-distant future.

"If you look at theories of consciousness, then sentience is an emergent phenomenon," he says. "We know that we've basically got a bunch of brain cells and there's nothing there which we can observe in terms of the functioning of the brain or the body that points to what consciousness is or how it emerges, but it does emerge.

"So, I think you can't say that it's impossible to create a system out of which consciousness emerges which is not based on human cells."

There's no reason, Dawson adds, that we can't achieve something which we would describe as having a sense of self.

Philosophers like Monash University's Professor of Philosophy, Robert Sparrow, disagree. Sparrow, who specialises in areas including human enhancement, robotics and weapons, notes there's too much going on with biological sentience to automatically ascribe this ability to a machine simply because it's a good mimic.

Ross Dawson is a futurist and entrepreneur, and founder of the Advanced Human Technologies Group.

Robert Sparrow is a Professor of Philosophy at Monash University's Data Futures Institute.

"When you talk to someone who deals with the human mind – people like psychiatrists, psychologists and counsellors – and ask them how much we understand about minds, and the answer is nothing at all," he says. "We just don't know where consciousness comes from, how it works, or what its relationship is to the brain."

There are many theories of consciousness, and one recently emerged idea is consciousness is a quantum phenomenon. If it's quantum, and linked to the biology of the brain, then it's unlikely sentience will emerge in AI, but at this stage the quantum nature of consciousness is still a theory. Given how little we know about the quantum world, it's unlikely proof or otherwise of this theory will emerge anytime soon.

Not all tech people are lined up on the side of the likelihood of sentient AI, either. Professor Flora Salim, from UNSW's School of Computer Science and Engineering, says it may be theoretically possible to make sentient AI, but the key is the fact it would remain artificial.

"It could seemingly be anthropomorphised as sentient, but it's not really because all it's doing is making deductions and inferences on its training data," she notes. "But none of that means it's capable of being self-aware and conscious of self."

As Sparrow says, sentience doesn't require high degrees of intelligence – sentience is simply the capacity to feel, something most living creatures are capable of. And it's unclear whether machines will ever be able to feel or have a sense of self.

Embodiment - would you kill a machine?

Think about it – would you kill a machine? If sentient AI is developed, then this is a real ethical issue. If a sentient AI is switched off at the wall, would this end its life? Or does the fact the AI isn't bound to a body, and can replicate itself any number of times make this question moot?

Sparrow has developed a concept he's dubbed The Turing Triage Test as a way of understanding the possible ethical dilemma of whether a machine is sentient. It posits a scenario where there's a human patient in ICU at a hospital, and an AI. The power goes down, and the backup is only sufficient to keep either the human patient alive or maintain the AI.

This creates a moral dilemma, but if someone isn't willing to turn off the human's life support to save the machine, then it's apparent we don't believe the machine is sentient.

He also says AI not having bodies is another hurdle in machine sentience. Humans understand other creatures, from dolphins to birds, and dogs to rats, are sentient because they have bodies. Having a body lets us see how they react to stimuli, and it's also us having bodies that allows us to see sentience in our fellow humans. Poke someone and we'll see them flinch.

It's the embodiment problem that really stands in the way of us recognising sentient AI, because we can't see how it reacts. Sure, ask it if it's in pain, or scared about the future and have it reply in the affirmative is one thing, but we won't ever know if that filing cabinet in the corner is really feeling pain or fear, because we can't see it.

"If I was to put AI into something that looked like a filing cabinet, and then I showed you the cabinet and said, 'by the way, that's a thousand times more intelligent than you, it's more perceptive and feels more pain than you,' you would have absolutely no way of engaging with those claims," Sparrow says.

"And this is why I don't think an AI can be sentient, because they don't have bodies of the sort we can recognise as having feelings."

Maybe not sentient AI, but superintelligence?

OpenAI, developers of the ChatGPT AI chatbot, and its controversial CEO, Sam Altman, have long talked about the company's goal being the creation of Artificial General Intelligence, or AGI. Last year Altman said AGI was just "thousands of days" away, or sometime within the next decade.

More recently, there's been a terminology shift at OpenAI and in the broader industry. AGI is out, and the new term, superintelligence, is in. Superintelligence is generally regarded as an AI able to solve problems, react to external inputs and come up with seemingly novel works at a level beyond human capability.

There's an important difference between superintelligence and something we might think of as being sentient, however, says Dawson. "Sentience is the ability to have a sense of self. All superintelligence is, is just extremely complex problem solving."

With superintelligence, no matter how capable it is, there's no 'there, there', no deus ex machina. It's just a machine really good at crunching numbers and making inferences. It may convincingly mimic sentience, but for that to happen, humans must first anthropomorphise the AI and its outputs.

"...sentience doesn't require high degrees of intelligence – (it) is simply the capacity to feel..."

Flora Salim is a Professor of Engineering at the University of New South Wales and the Deputy Director (Engagement) of UNSW AI Institute.

Many researchers, including Salim, believe OpenAI's Altman is being optimistic with his several thousand days superintelligence breakthrough prediction, saying there are several reasons for this.

The first is current AI large language models (LLMs) like ChatGPT have essentially exhausted mining the open web for model training data. AI companies are turning to licensing agreements with publishers and other proprietary data owners to deepen the pool of training data, but the reality is there's only so much data out there, and so the pace of innovation in the current crop of AI models is slowing.

There are also problems with the underlying models and how they learn. "The way these models are being trained today, it's very much about learning for associations and correlation of what was important in the past," Salim says.

"It doesn't do well in understanding new knowledge or how to reason. It doesn't learn the way a baby learns, so unless there's a breakthrough in machine learning, simply adding data won't work anymore."

That's not to say superintelligence doesn't exist – it does. But current superintelligence is narrow in scope, not the broad, general-purpose superintelligence envisioned by OpenAI's Altman and others.

US computer scientist Meredith Ringel Morris and her colleagues at Google developed a way of thinking about AI and intelligence by dividing it into six distinct categories, from level zero, with no AI, such as a pocket calculator, through to level five, which is superhuman AI.

According to Morris, narrow application level five superintelligence applications, such as AlphaFold, which uses machine learning to predict the structure of protein molecules and earned its creators the Nobel Prize in Chemistry last year, already exist.

General AI tools like ChatGPT are far less capable than their narrow counterparts, being categorised by Morris as level one, or 'emerging', meaning they're equal to or somewhat better than an unskilled human.

Or, to put it in perspective, ChatGPT may seem amazing, but in terms of its actual intelligence, it's only one step above a pocket calculator. "We'll need real scientific breakthroughs to get to superintelligence, let alone sentient machines," says Salim. "Devising AI models' capabilities to acquire human-level reasoning and open-ended learning and discovery is particularly essential to get us to the next step."

AI harms are not theoretical

AI doesn't need sentience to pose a threat to humans and our society. Nor is superintelligence required; AI, as primitive as it is today, according to Morris's taxonomy, is already causing harms. The risk is only going to grow as AI improves, and much of that risk concerns dangers to our social structures and relationships.

Robert Brooks, Scientia Professor of Evolution at the University of New South Wales, says AI will probably affect human evolution and as a result, human brains will get smaller. "Things like individual intelligence, memory, language and social processing that are pushing for bigger brains is probably being relieved a bit because we have machines to externalise that," he says.

It could be this reduction in brain size due to outsourcing some of its functions

Robert Brooks is the Scientia Professor of Evolution at the University of New South Wales.

means we're ultimately smarter for navigating the new world because of what our brains aren't doing. It also could mean a significant change in social relationships and what it means to be human, Brooks says.

As we evolved and became social, our brains became larger and language capacity improved, making us even better at being social in a 'virtuous cycle'. But what if that gets disrupted or completely replaced and AI does all the remembering, and we lost that capacity?

"If our brains didn't need to do that anymore and lost their capacity to ever learn how to do that entirely, not only would you have a breakdown of the culture, but you might have a breakdown of the hardware underpinning that culture," Brooks says.

"I don't know if it's going to happen, but it's conceivable."

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GETTY IMAGES / STELLALEVI

We'll make great pets

Superintelligent AI could also change our society and humanity by enslaving us or, at best, keeping us as pets, argues Sparrow in his 2022 paper *Friendly AI will still be our master. Or, why we should not want to be the pets of super-intelligent computers.*

Sparrow draws on the neo-republican philosophy in his paper, which holds that freedom requires equality. If superintelligent machines emerge, even assuming they were benevolent towards us, then our relationship with them would be, to paraphrase computer scientist Marvin Minsky, the same as between pets and humans, in this instance the human being the pet.

Where the republican tradition feeds into this is the relationship between pet and owner is never one of equality, and the same goes for the possible relationship between people and AI superintelligence.

"Benevolence is not enough," says Sparrow. "As long as AI has the power to interfere in humanity's choices, and the capacity to do so without reference to our interests, then it will dominate us and thereby render us unfree.

"The pets of kind owners are still pets, which is not a status which humanity should embrace. If we really think that there is a risk that research on AI will lead to the emergence of a superintelligence, then we need to think again about the wisdom of researching AI at all."

Much of the fear about what AI may be capable of in the future, and its impacts on humanity, including the narrative AI could destroy us, is purely theoretical and fearmongering, says Associate Professor, Philosophy, Samuel Baron, from the University of Melbourne.

His concern is AI is doing real harms today, and arguments about AI annihilation and being enslaved are narratives pushed by the large tech companies to hide the impact AI is having now.

Sam Baron is associate professor of philosophy at the University of Melbourne and convenor for AI research.

"If we really think that there is a risk that research on AI will lead to the emergence of a super intelligence, then we need to think again about the wisdom of researching AI at all."

"We're running machine learning algorithms on criminal recidivism prediction, on loan prediction, like loan and credit scoring prediction, on medical diagnosis, on fraud detection and prosecution, on policing, all of these things we're currently using algorithms for, and all of them are producing harms," he argues.

"People aren't talking about that so much because they're talking about this possible situation in which these things rise up and kill us. And the cynical view that I have is that tech companies are purposely pulling our focus away from what is the real harms of these things."

What it comes down to, says Salim, is how we go about building safe AI and safe superintelligence. Regardless of whether OpenAI's Altman is correct, and superintelligence is a matter of thousands of days away or if it's further out, safety is something we need to be thinking about and having conversations about now, she says.

"Innovation must go hand-in-hand with responsible AI," says Salim. "Innovation can improve the guardrails we put in place, but the funding needs to be there. And in Australia, we're just not putting the funding in place, ranking in the bottom two in the OECD in terms of AI innovation. It's shameful."

Will the AI Pinocchio kill the human Geppetto? Or will the puppet just turn master? As Brooks puts it, "predicting the future is a mug's game". What we do know is AI is creating harms today, and at some point, in the future, superintelligence will arise. As individuals and a society, we must be thinking about these things now, before it's too late.

Joshua Gliddon s a veteran science and technology writer based in regional Australia.

ENCOURAGING INTERNATIONAL INNOVATION STARTS WITH VIETNAM

To generate economic growth and sustainable development goals, science and research must be accompanied by an environment that harnesses innovation. **Jasmine Fellows** and **Kate Langford** dive deep into how innovation is being fostered in Vietnam through a partnership with Australia.

Knowledge and innovation are transformative. They have the potential to underpin the future growth and prosperity of any nation. But fostering a developing innovation system is no easy feat. Vietnam's National Agency for Technology Entrepreneurship and Commercialisation (NATEC) has been working with CSIRO and Australia to break down barriers to innovation.

A strong innovation system is complex. It relies on cohesion, connectivity, and communication. Actors across the system, from farmers to businesses, government and research organisations, must be able to work together to deal with challenges as they arise. It's about generating, sharing and using new ideas, technologies and processes, and adapting and responding to opportunities.

The research sector must have capability not only in science but also in engaging with the private sector. And policies and regulations must enable innovation.

Vietnam has set itself a goal of becoming a developed, industrialised nation with a high-income by 2045. Instead of supplying aid in traditional ways, Australia has set itself up as an innovation partner to Vietnam.

Aus4Innovation (A4I) is a 10-year $33.5 million government-funded program aimed at strengthening Vietnam's innovation system for inclusive and sustainable socioeconomic development. It makes sense, as Vietnam is one of the fastest growing economies in the ASEAN region and one of Australia's most important partners in the region.

"In 2017, DFAT and MOST [Vietnam's Ministry of Science and Technology] established the Australia Vietnam Innovation Partnership," says CSIRO's Kim Wimbush, A4I program director. "And it was around this time that DFAT envisioned that development assistance could be utilised to support ambitious countries such as Vietnam to utilise science, technology and innovation to build the economy of the future."

Kim Wimbush is the A4I program director at CSIRO.

Pham Duc Nghiem is the deputy director of NATEC.

Together, NATEC (which sits under the Ministry) and CSIRO sought to understand what was needed to translate research into practical solutions that could help Vietnam achieve its economic ambitions. The partnership is now smashing barriers to innovation by enabling policy change and building connections and capacity.

Removing the bottlenecks

Pham Duc Nghiem, the Deputy Director of the National Agency for Technology Entrepreneurship and Commercialization Development (NATEC) of the Ministry of Science and Technology of Vietnam sees 3 clear barriers to innovation.

"The primary challenge is a lack of awareness. In some cases, scientists and researchers do not have a clear understanding of how to convert their research findings into practical applications," says Nghiem. It indicates that building capacity is the first piece of the puzzle.

"The second challenge is inadequate legal and regulatory framework to facilitate the transfer and application of research results," continues Nghiem. That indicates a closer look at policy and government relations is needed.

"The third challenge involves limited infrastructure and the technological adoption capabilities of enterprises." While some infrastructure shortcomings can only be solved with time and investment, many have alternative solutions – a simplifying insight, or a new partner with underutilised capacity. The key here is building and nurturing connections. What may seem like serendipity or luck from the outside, can actually be encouraged by ensuring the right people are in the right place at the right time.

Understanding innovation

Some people think of innovation as a technological solution, gadget, invention or computer program that solves a problem. But the full innovation system must be leveraged for an innovation to truly take off.

"Initially, we must develop ideas and these ideas need to be innovative," says Dr Ha Phuong Thu, an expert in biomedical nanomaterials, and one of the scientists involved in A4I. Thu is director of the Centre for Advanced Biomedical Materials under the Vietnam Academy of Science and Technology (VAST).

Thu explains the full innovation process from the researcher perspective. "These ideas then undergo rigorous systematic research to collect data, identify patterns, and define characteristics, all of which form the foundation of our research. Subsequently, once we have the results, we proceed to publish them in both prestigious national and international journals globally.

"Following the initial phase of fundamental research, we move on to the development and optimisation of the technology. Our focus is on ensuring that our technology is not only new but also creative and groundbreaking, with the capacity to produce useful products.

"Additionally, it is crucial that our process is scalable to the level required for industrial production. Following this, we secure patent protection to safeguard our innovations.

"The final step involves establishing a solid foundation of basic research and a technological base with protected patents. At this stage, we seek partnerships with businesses interested in collaborating to develop and bring these products to market."

Ha Phuong Thu is director of the Centre for Advanced Biomedical Materials at VAST.

It's an involved process, one that typically requires connections, policy, networks and collaboration across government, research and the private sector.

Through the CSIRO-NATEC partnership, the Commercialisation PLUS guide was born. CSIRO and Vietnamese partners co-developed and tested the how-to guide, which includes global best practice.

Commercialisation PLUS includes comprehensive tools and methods supporting researchers through a structured commercialisation process, within Vietnam's context and is available free online, supporting researchers to better understand the innovation system.

Building connections

Building strong relationships, especially international, takes considerable time. Trust is essential for support and investment in innovation.

"In essence, the key to fruitful collaboration lies in open communication, mutual trust, and a willingness to share challenges and insights," says Nguyen Quoc Thang, Technical Chief at Phong Thuy Company.

The A4I program does not shy away from the fact it can take 5 to 10 years to form concrete partnerships. "We create innovation hubs and clusters to connect industry with research and with government to co-create solutions around focused thematic areas such as aquaculture in the Mekong, [and] horticulture across the whole country," says Wimbush.

Given the complexity of the innovation system and the need to build connections, it's no surprise that a new role has emerged to make those connections.

Much as financial brokers connect buyers and sellers, innovation brokers work across disciplines to connect companies, entrepreneurs, researchers, end-users, educators, products, services, potential partners and more. Being an innovation broker requires the right mix of personality, skills and experience required to operate effectively.

While CSIRO has a history of being an intermediary between researchers and industry, this type of innovation brokering has only been recognised in the past 10 to 20 years internationally. As such, perhaps it's no surprise that even developed countries are racing to build skills in innovation brokerage.

Ha Phuong Thu uses an electron microscope.

Workers at Phong Thuy process chillis.

A worker at Phong Thuy tends to seedlings.

Talking policy

All over the world, governments struggle to ensure their policies and legislation allow innovation to flourish, while having appropriate guardrails in place.

The quality of policy can make or break a technology's application in the real world. "Delaying the approval process could render the technology obsolete and hinder its adoption by businesses," says Thang.

A research manager at the VAST acknowledged the challenges and the improvements that can be made.

"Currently, some policies are inconsistent and not aligned with practical realities. For instance, according to the State Budget Law, if a research institute commercialises or transfers technology, and generates revenue, that revenue will be deducted from the following year's state budget. This effectively disincentivises research organisations," he said earlier this year.

But things are already changing. In February, Vietnam enacted Resolution 193, a collection of mechanisms and policies to support the entire innovation pipeline. Public research organisations can now retain intellectual property rights to research and can invest in spin-offs to commercialise their findings. Researchers can undertake riskier research projects as they no longer need to return funding if their experiments fail to deliver expected outcomes. And there are a range of tax incentives to encourage investment into research and innovation.

Many of these solutions were debated in capability building activities undertaken through the A4I program. It's a sign that Vietnam's policymakers are listening and ready to support innovation.

Where to next?

With A4I slated to run to 2028, there are still several years to go. A4I will now be focusing on supporting the government in Vietnam to implement these policies that better enable innovation and support the country's economic and sustainable development ambitions.

The company Phong Thuy is a leader in high-tech horticultural farming in the Central Highlands of Vietnam and specialises in growing vegetables for local and regional markets under hydroponics. Removing bottlenecks to commercialisation will help companies like this connect with researchers, who can understand their specific challenges and develop technologies to further automate and grow their operations.

Nguyen Quoc Thang uses innovative techniques to grow hydroponic lettuce.

A4I established a Horticulture Innovation Club in the Central Highlands, and through this Phong Thuy formed a partnership with the Institute of Agriculture Science for Southern Vietnam. This partnership has given the company access to high-quality research advice and joint R&D projects.

Several hundred farmers in the region and from the Mekong Delta have visited their farming operations models and brought back knowledge and technologies that they learned to apply on their own farms.

"It's difficult for a business to independently develop a solution. Working with scientists and institutes that have already conducted research is crucial for transferring technology to businesses like ours," says Thang.

As for the big picture, "I'm hopeful that the legacy of this program will lead to sustained, strong partnerships between Australia and Vietnam on science, technology and innovation, and that Vietnam will continue to see Australia as a trusted partner in this area," says the A4I program director Wimbush.

Vietnam's innovation system, like Australia's, will play a key role in how it navigates increasingly extreme environmental challenges, which are expected to impact food production and sustainable development into the future.

"The robust bilateral agreements and excellent diplomatic relations between the two countries lay a solid foundation for expanding cooperation in science, technology, and innovation in the future," says says NATEC's Nghiem.

Jasmine Fellows and **Kate Langford** both communicated science at CSIRO.

GETTING A FEEL FOR QUANTUM MECHANICS

You have probably heard about the 'weirdness' of quantum mechanics. It's hard to come by a piece of writing on the subject that doesn't quote a famous physicist lamenting the incomprehensibility of quantum behaviour. But as **Conor Feehly** discovers, there are new ways to get a quantum of intuition.

Yes, quantum physics, at least initially, can feel counterintuitive. Quantum mechanical systems appear to obey a different set of rules compared to the systems we encounter on a daily basis in our macroscopic world. And yet, over time, quantum scientists have been able to intimately acquaint themselves with the concepts and mathematics that underpin the quantum world. Scientists who work in this area on a daily basis can come to see events through a quantum lens. This strange space of ideas can become second nature as they develop an intuition for what was once alien.

"I feel like we are ready to move on from the way quantum mechanics has been portrayed," says Nicole Yunger Halpern, who studies quantum information theory and quantum thermodynamics at the National Institute of Standards and Technology (NIST) in Maryland. Yunger Halpern is also the most frequent contributor to the blog Quantum Frontiers, which communicates the science of quantum mechanics for the Institute of Quantum Information and Matter at Caltech.

The effort to demystify the quantum world also has a new tool – gaming. Over the last few years, quantum educators have been integrating features of quantum behaviour into a variety of video games, with the hope that introducing this world to younger and younger people, they might be able to build intuitive quantum mechanical knowledge in the next generation of scientists.

"If I had come across these games when I was 8, 10, or 12 years old, how could that have influenced me?" asks Carrie Weidner, a quantum engineer at the University of Bristol. Weidner spent three years developing quantum games and other educational outreach tools at Aarhus University in Denmark.

Human intuition, whether we are willing to admit it or not, is a central component in the story of science. It empowers scientists to visualise, to predict, to ask interesting questions and devise ways to answer them. Scientists intuit their way towards progress by telling stories about the quantum world, checking how far their guesses stray from the truth, and correcting their stories with experimentation and math. In a broader sense, the intuition that quantum scientists possess demonstrates the remarkable plasticity of the human mind, and its ability to wire itself to concepts that defy our everyday experience.

Nicole Yunger Halpern is a theoretical physicist at the Joint Center for Quantum Information and Computer Science at the University of Maryland.

Intuitive physics

From the first day you enter the world, you are exposed to an environment that has certain regularities. Things fall down. Objects don't pass through one another. Items persist. These regularities help us form subconscious rules for how objects interact and events unfold in the world around us. Developmental psychologists call this our 'intuitive physics'.

"Infants are born with a skeletal framework of abstract physical principles and concepts," says Renee Baillargeon, a developmental psychologist who studies physical reasoning in infants at the University of Illinois. "These guide how infants reason about physical events and form expectations about their outcomes."

If, for instance, you were to hide a cup behind a screen, which you then lowered to reveal no cup, infants as young as 2 or 3 months old will be surprised. Their expectation of how the event should unfold involves the concept of persistence (all other things being equal, objects persist, as they are, in time and space) – objects don't just spontaneously disappear, right?

"Infants form event categories, such as occlusion, containment, support, collision, and so on, which correspond to the types of events they see in their daily lives," Baillargeon explains. "As they interact with their physical environment, infants learn, one by one, the features that are important for each event category."

All of this means that when we run into events or concepts that seem to violate the intuitive physics we emerged with at infancy and developed through childhood, we are likely to see it as something counterintuitive – mystical, perhaps – or just downright weird. Quantum mechanics, of course, is full of such violations.

Going back to the cup from earlier, even infants have object permanence. They understand that even if they can't see an object, it continues to exist. However, one feature of quantum systems is fluctuation. This refers to random changes in the properties of particles and of space itself. To explain this variability, physicists often invoke particles popping into and out of existence. Not so permanent, then?

Objects also don't tend to pass through impenetrable barriers in our scaled-up reality. "How many throws does it take for a ball to pass through a concrete wall?' Weidner rhetorically asks. Another bizarre feature of the quantum world, called 'quantum tunneling' describes that, by chance, subatomic particles will sometimes find themselves on the other side of an energetic or structural blockade. So does this mean objects can pass through one another...?

"The fact that I can sit here (in my lab) and talk about what is happening to an atom like, well it is probably tunneling. That statement is so anathema to everything I was exposed to for the first 18, 20 years of my life. It's akin to me saying, here hand me that grand piano," explains Weidner.

Locality also plays an important role in our intuitive physics, where we expect objects to interact with one another only if they are close in time and space. And yet, quantum entanglement allows for two particles to be linked across vast distances, a connection Einstein referred to as 'spooky action at a distance'.

"When you learn classical physics, it's relatively easy to see what's going on," Weidner adds. "You drop something and it falls. With quantum behaviour, the hard bit is that there is nothing here that I have on my desk that I could show you and say ok, here's how we can demonstrate quantum mechanics ... so there is this mystique."

Science and intuition

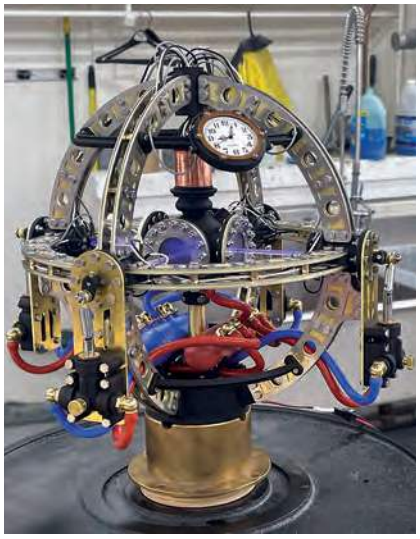
In science, intuition could be considered a bit of a dirty word. Scientists do experiments. They go where the data tells them. Nowhere is there room for something as 'woo woo' as feelings or intuition. This view, however, mischaracterises intuition – turning it into something mystical, rather than a subconscious skill that is developed through time and understanding. Just as our 'intuitive' physics, in large part, is formed through interacting with the world as an infant and child, scientists are capable of developing intuitive knowledge in the abstract, arcane corners of science that they spend their days toiling in. "A colleague told me she finds quantum physics more intuitive than classical physics, because she has been working on it for so long," says Yunger Halpern.

The history of science has also been a process of breaking down what we think we know about the world, and building up something new. Even if new ideas initially felt unintuitive, say, that Earth wasn't the centre of the universe (thanks Copernicus), or that time was actually relative (thanks Einstein), it didn't stop the next generation of scientists incorporating that 'counterintuitive' knowledge into their model of the world. And crucially, it didn't stop them building on it.

"If we didn't have intuition, we probably couldn't do much research at all. We need some sense of where we are going, where we expect to get, how we might get there, and there is plenty of opportunity for finding out that we are wrong, so we can readjust our path," says Yunger Halpern.

Yunger Halpern has also been working to develop a visual aesthetic through sculpture for a specific area of her research – quantum thermodynamics. Thermodynamics is the science of energy, heat, and work. It was developed during the 1800s and was inspired by the industrial revolution. Steam engines were powering factories, and people naturally wanted to understand how efficiently the engines could operate. But these thermodynamic concepts – heat, work, temperature – are also relevant to small, quantum systems. It's the meeting of old and new, the past and the future – quantum steampunk.

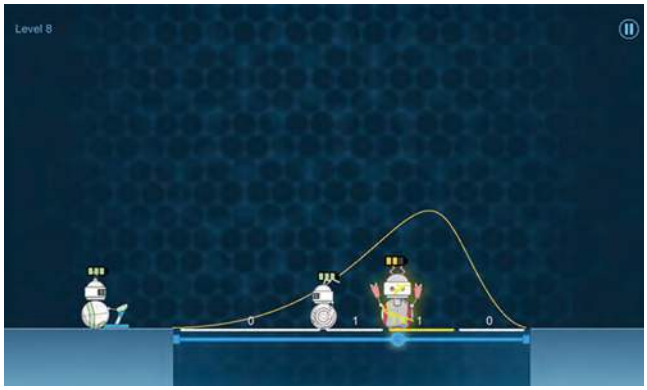
"This sculpture is meant to be a quantum engine. The idea is to engage viewers in quantum thermodynamics and quantum physics, especially viewers who don't think of themselves as science people, but think of themselves as art-type people. Hopefully they will be drawn into the sculpture. Then they can scan a QR code and learn more about its scientific elements," explains Yunger Halpern. "A decent part of theoretical physics involves aesthetics and I find it really interesting that quantum thermodynamics has an aesthetic. Aesthetics are, in a way, part of intuition."



Devised by Yunger Halpern and artist Bruce Rosenbaum, the Quantum Engine is a sculpture that juxtaposes quantum thermodynamics with the thermodynamics harnessed by steam engines.

Renee Baillargeon is Alumni Distinguished Professor Emerita at the University of Illinois.

SUPPLIED: NICOLE YUNGER HALPERN



A screenshot from Virtual Lab, a game by Quantum Flytrap.

A screenshot from Psi and Delta, a game by Aditya Anupam.

Quantum games

The seeming weirdness of the quantum world might not last. That's because individuals and organisations have been working on ways to introduce quantum concepts to younger people in new, engaging ways. Back in 2013, Caltech's Institute for Quantum Information and Matter partnered with Google to produce Qcraft. This variation of the game Minecraft incorporates quantum behaviours into gameplay. In 2017, Chris Cantwell developed quantum chess at Quantum Realm Games in California, which even had some international tournaments.

Quantum researchers like Jacob Sherson at Aarhus University have also been developing quantum games and novel approaches to educational outreach. Weidner spent 3 years working with Sherson on quantum games and games for education in general in the quantum physics sphere during a postdoc at Aarhus. "This idea is that through a combination of educational tools, and solving puzzles, you can develop an intuition for these concepts. The difference between me and my students is that I have had time with these ideas ... and so any tool that is going to ease that transition, whether you start at age 12, 18 or 30, is going to be a massive help," says Weidner.

Everybody enters the world a scientist. Play is really just an infant's way of doing experimentation. Through play, children develop their intuitive physics for how things in the world behave and interact – so why not create a space for play in the quantum world?

"Exposure and getting it wrong is a big part of it. If you can hand someone a game and say 'play with it', whether it's a virtual lab or quantum chess, people will learn how things work; by playing it, you build up that intuition. And then if you are interested, you can take it further," Weidner explains.

Limits to intuition

Labelling quantum behaviour as counterintuitive disregards the capacity of the human mind to wire itself to new ideas and concepts through exposure. "It's crazy what you can get used to," says Weidner. Yes, features like entanglement and tunneling might be strange at first. But undoubtedly, quantum scientists have developed an intuition that allows them to play with these ideas, to challenge them with experiments that could lead to new insight or apply them to problems that nobody considered.

Quantum intuition in scientists speaks to a broader ability in humans to work with ideas that by all rights, we have no reason to be so competent with. We evolved to solve problems at the scale of reality that we can perceive. The once secret quantum world, orders of magnitude smaller than anything we can access with our senses, is now comprehensible to us in a meaningful way.

"Our skeletal framework does not bind us to a particular physical reality. We can enjoy sci-fi movies and *Harry Potter* movies that violate many basic physical assumptions ... We can appreciate other physical realities, but revert to our own when it's time to make a salad or fold laundry or rake the leaves or drive the children to school," says Baillargeon.

What hidden layers of reality will we have to learn to intuit next?

Carrie Weidner is a senior lecturer with the School of Physics at the University of Bristol.

Conor Feehly is a science writer based in New Zealand.

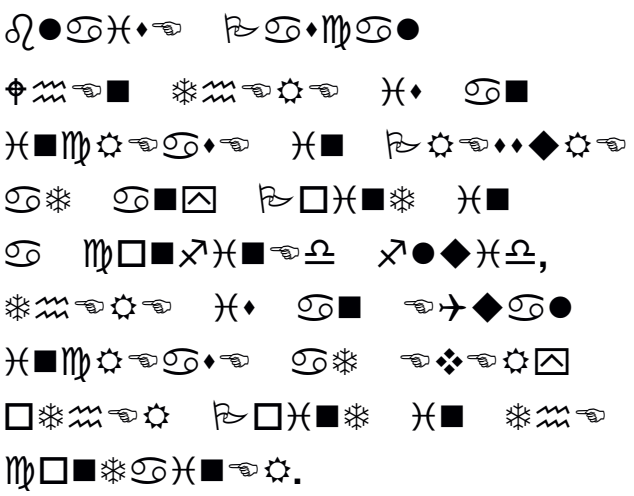
COSMOS PUZZLES

NO.33

Answers on page 114

GUESS WHO?

Question
Whose Theorem? Decode where ♓ = i



Hint: He invented one of the first mechanical calculators.

QUICK QUIZ

Questions

1. What is the largest body in the asteroid belt?
2. Gregor Mendel's famous inheritance experiments were conducted on what lifeform?
3. What is the name given to the process of hardening rubber, often using sulfur?
4. What do petrologists study?
5. Benoit Mandelbrot famously asked how long the coast of Britain was. What was his answer?

GUESS THE OBJECT ANSWER

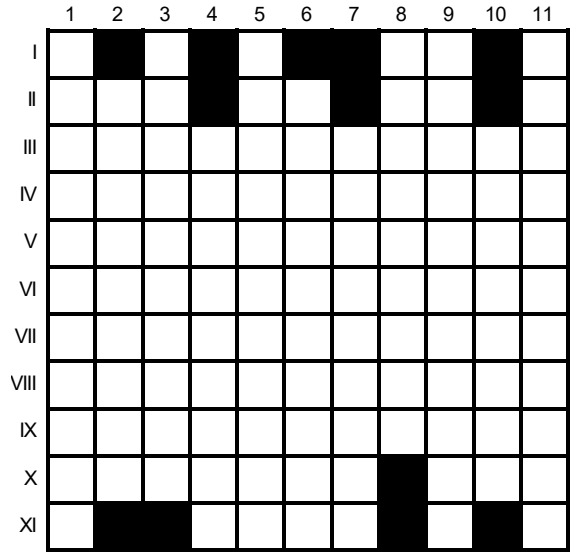
This cute little robot is a modified version of the Harvard Ambulatory Microrobot. Originally modelled after a cockroach, it has been outfitted with a forked, tail-like appendage called a furcula. Borrowed from the hexapedal arthropods known as springtails, the elastic limb allows this robot to jump high into air!

MIND GAMES

NO.33

Who Said?

"With so much conflict in the world, space exploration can be a beacon of hope."



Instructions

Answer each of the clues in columns 1 to 11. Row VI reveals the answer.

Clues and columns

1. Which projection system was used by Twentieth Century Fox in the 1950s and had the aspect ratio of 2.35:1? (11)
2. Who invented the polaroid camera? (5,4)
3. Which palaeontologist worked in the Lyme Regis area, discovered many fossils and gave rise to the ditty 'She sells seashells by the seashore'? (4,6)
4. With Australia dubbed a continent, what is the largest island in the world? (9)
5. With clusters of pinkish flowers and native to Europe, what is the common name for the plant, *Althaea officinalis*?
6. What is the name for group of atoms, attached to a coloured molecule, that intensifies the colour? (10)
7. What is a common name for the sugar alcohol known as propane-1,2,3-triol? (9)
8. Which science studies the nose and its diseases? (9)
9. In the spacecraft Vostok 1, which Russian cosmonaut made the first space flight in 1961? (4,7)
10. What is an animal that eats both meat and vegetables? (8)
11. Which branch of physiology and anatomy deals with secretions? (11)

COSMOS CODEWORD

NO.33

Codeword requires inspired guesswork. It is a crossword without clues. Each letter of the alphabet is used and each letter has its own number. For example, in this puzzle 'M' is 9.

Through your knowledge of the English language you will be able to break the code. We have given you three letters to get you started.

4 P	24	13	14	25	10	6	13	■	2	24	13	23	14	22
7	■	5	■	16	■	5	■	17	■	17	■	17	■	1
6	16	9 M	6	16	23	16	■	6	23	20	16	24	24	12 D
3	■	24	■	24	■	14	■	13	■	6	■	■	■	7
6	13	7	5	16	22	■	16	14	23	10	9	25	14	25
5	■	23	■	16	■	16	■	24	■	5	■	17	■	5
13	■	17	6	9	4	20	24	18	■	24	13	7	6	20
12	■	25	■	24	■	24	■	14	■	■	■	23	■	23
■	19	20	5	13	12	24	7	■	25	17	23	12	23	17
25	■	■	■	14	■	4	■	23	■	6	■	■	9	■
17	25	20	9	■	16	11	23	9	■	20	24	25	4	14
15	■	25	■	24	■	25	■	4	■	20	■	11	■	22
5	13	7	25	26	24	20	■	6	7	23	10	25	9	23
23	■	26	■	24	■	8	■	16	■	12	■	23	■	7
14	7	25	23	13	16	■	7	24	21	24	17	14	24	12

1	2	3	4	5	6	7	8	9	10	11	12	13
14	15	16	17	18	19	20	21	22	23	24	25	26

ALL PUZZLES DESIGNED AND COMPILED BY SNODGER.COM.AU

IT FIGURES

NO.33

	1	2	3	4
A				
B				
C				
D				

Instructions

Using the clues below place the numbers 1 to 16 correctly in the grid. How many clues do you need?

Level 1 – Chief Scientist

1 Row D is the only row whose average is not equal to its range.

2 There are no square numbers sharing a row, column, or diagonal.

3 The sum of Column 2 is equal to the third number in Row B squared.

4 The product of Column 4 is 195.

5 The only even number to the right of the column ending in 11 is single digit.

Level 2 – Senior Analyst

6 The largest number in Row B is at the end of the row.

7 The first number in Row A is double the last.

Level 3 – Lab Assistant

8 The product of the last two numbers in Column 3 is 30.

SOLUTIONS: COSMOS 106

CODEWORD

A	R	G	O	N	A	U	T	■	W	I	S	D	O	M
S	■	A	■	I	■	P	■	N	■	N	■	O	■	I
P	U	Z	Z	L	E	■	J	U	R	A	S	S	I	C
H	■	E	■	■	■	M	■	T	■	P	■	I	■	R
Y	T	T	E	R	B	I	U	M	■	T	E	M	P	O
X	■	T	■	A	■	C	■	E	■	■	■	E	■	N
I	C	E	■	D	E	R	E	G	U	L	A	T	E	■
A	■	■	■	I	■	O	■	■	■	E	■	E	■	P
■	F	A	M	O	U	S	■	Q	U	A	R	R	E	L
F	■	R	■	A	■	C	■	U	■	R	■	■	■	A
A	R	T	I	C	H	O	K	E	■	N	I	G	H	T
U	■	I	■	T	■	P	■	R	■	■	■	R	■	I
C	A	C	T	I	■	I	M	I	T	A	T	I	O	N
E	■	L	■	V	■	C	■	E	■	X	■	N	■	U
T	H	E	S	E	S	■	A	D	D	E	N	D	U	M

1 E	2 O	3 K	4 C	5 N	6 L	7 T	8 J	9 D	10 P	11 X	12 B	13 M
14 V	15 H	16 F	17 W	18 S	19 G	20 R	21 U	22 Z	23 Y	24 Q	25 I	26 A

GUESS WHO?

Amalie Emmy Noether

The action S of a physical system is an integral of a Lagrangian function L, from which the system's behaviour can be determined by the principle of least action.

IT FIGURES

15	8	3	1
4	6	13	10
7	5	9	2
11	16	14	12

SPEED ROUND

1. The Anthropocene, **2.** Penicillin, **3.** b) 31, **4.** Rubidium, **5.** Sirius

WHO SAID?

Ernest Rutherford

H	■	■	F	■	■	S	C	■	E
O	B	H	R	S	■	E	O	B	M
V	O	A	E	A	C	T	L	O	P
E	T	R	D	T	E	I	E	T	E
R	U	T	H	E	R	F	O	R	D
C	L	F	O	L	E	O	P	Y	O
R	I	O	Y	L	B	R	T	T	C
A	N	R	L	I	R	M	I	I	L
F	U	D	E	T	U	■	L	S	E
T	M	■	■	E	M	■	E	■	S

CURIOSITY CORNER

BEE-COME A BEE HERO

SAFETY

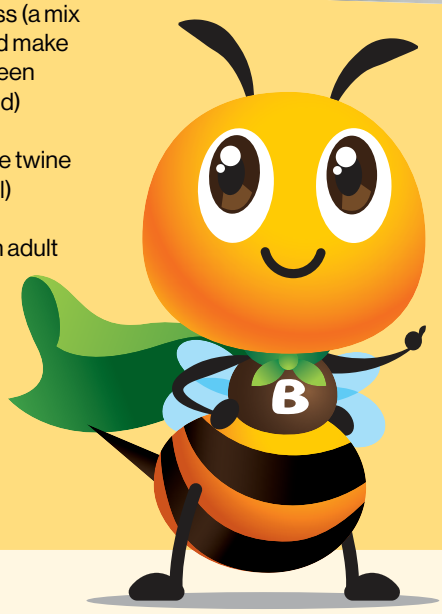
- This activity uses a saw – get an adult to do the sawing.
- When outside, be sun-safe and let an adult know where you are.
- Don't touch insects and other creepy-crawlies!

YOU WILL NEED

- Metal can with a 'pop' lid, like a Milo or powdered milk can. (Don't use cans with pull lids as they have sharp edges.)
- Ruler, permanent marker and scissors
- Bamboo stakes with inside holes 4-9mm across (a mix of sizes is good, and make sure they haven't been treated or fumigated)
- Brown string or jute twine (something natural)
- A hand saw and an adult to do the sawing

WHAT TO DO
FOLLOW THE STEPS IN ORDER

1. Empty your metal can. Remove any labels and wash inside and outside with warm soapy water. Then rinse and dry.
2. Use a ruler to measure the height of the can. Write the height down – you will need it shortly.



3. Pick up one of your bamboo stakes. Find one of the 'lumpy, knuckle like' nodes. Using your permanent mark place a small mark at the bottom of the node.
4. Using your ruler start measuring from the mark. Place a mark at the distance that matches the height of your can.

5. Ask an adult to saw the bamboo stake at the 2 marks. Put the cut bamboo length into your metal can, with the node end in the can.

6 Keep marking and cutting pieces of bamboo until you can't fit any more in your can. Try to pack it tightly enough so that the bamboo stakes stay put even when you turn the can.

7 You can poke smaller twigs or pieces of bamboo in between the cut lengths.

8 Cut a 1 metre piece of string or twine. Tie a slipknot with a loop at each end.

9 Put 1 slipknot around the open end of the can and the other around the base. Then tighten both loops.

10 Find an outdoor location for you bee hotel. The location should be sunny or semi-shaded with some shelter from wind and rain. Hang it at least 1 metre above the ground but no higher than 2 metres. Rember to place it near a garden bed where the bees can get food.

BY THE NUMBERS

EXPLORE THIS ISSUE OF COSMOS THROUGH FASCINATING FACTS AND FIGURES.

0 The number of people required to put a 'solar sheep' to bed. In *Dreaming of solar electric sheep*, Rachel shines a light on how solar panels can share the land with sheep and crops. Australia doesn't have to go it alone – Japan, Germany and the USA all have clever experiments we can learn from. You might be surprised to discover why energy companies, farmers and sheep are happy to share. Learn more from page 64.

1928 The year Alexander Fleming came home from holiday to discover a fungus killing all the bacteria in one of his experiments. That discovery led to the invention of antibiotics, medicines that save millions of lives every year. But as diseases evolve, we need to discover new antibiotics. Join Amalyah as she explores the deep ocean, looking for the next new antibiotic. Her adventure uncovering these new *Drugs from the deep* starts on page 58.

6 The number of tips from scientists that could help you manage feelings of climate concern. Many of us share concerns, worries and powerful feelings about the future of our planet. Should scientists only talk about the facts, or should they share their emotions too? Check out *Great Barrier grief* from page 46 to learn along with Denise as she talks to scientists about their feelings and discovers how to be 'actively hopeful'.

1,700 The number of Australian native bee species living around us. Why not create a home for the native bees in your neighbourhood? Most native bees lay their eggs in narrow burrows in trees, on the ground or in dead sticks. You can mimic this with a bee hotel! Created by Ariel for *Double Helix* you can follow these steps to start a bee resort, full of 'bee bunkbeds' in your garden. Look to your left to find this activity on page 112. Then promote your hotel by planting native plants that provide nectar and pollen year-round nearby!

In case you missed it

Pterosaur tracks, booster shots, touching holograms

› Pterosaurs were the first vertebrates to evolve active flight, soaring through the skies until their untimely demise 66 million years ago. But some of these winged reptiles were just as comfortable legging it on the ground.

Palaeobiologists analysed pterosaur tracks using 3-dimensional modelling, and compared their characteristics to those of fossilised skeletons.

"They reveal not only where these creatures lived and how they moved, but also offer clues about their behaviour and daily activities in ecosystems that have long since vanished," says researcher Robert Smyth. Their findings support the idea that pterosaurs underwent a major ecological shift about 160 million years ago, when several groups became more terrestrial.

> Fossilised pterosaur tracks are just as common as their skeletons.

▲ Tracks resembling the hands and feet of *Balaenognathus* are quite common, suggesting these pterosaurs were well adapted to the ground

› Choosing to receive a vaccine's first dose and booster in the same arm, rather than in separate ones, generates more effective immune response more quickly, Australian scientists have found.

Experiments in mice revealed the key to this lies in the lymph node closest to the vaccination site, where the vaccine response is generated.

A clinical study in 30 volunteers who received the Pfizer-BioNTech COVID-19 mRNA vaccine confirmed that the animal results also apply to humans.

› Spanish engineers have made the world's first holograms that you can touch and manipulate, bringing science fiction into reality.

Volumetric displays work by projecting images onto a fast-oscillating sheet called a diffuser. But these displays cannot be touched because the fast moving diffuser could break or cause injury.

This new display uses an elastic diffuser, that bends when touched. images are corrected for the bending, and future oscillations of the diffuser are adjusted to accommodate manipulation.

SOLUTIONS: COSMOS 107

CODEWORD

P	E	N	T	A	G	O	N	■	Z	E	N	I	T	H
R	■	U	■	S	■	U	■	C	■	C	■	C	■	Y
O	S	M	O	S	I	S	■	O	I	L	S	E	E	D
F	■	E	■	E	■	T	■	N	■	O	■	■	■	R
O	N	R	U	S	H	■	S	T	I	G	M	A	T	A
U	■	I	■	S	■	S	■	E	■	U	■	C	■	U
N	■	C	O	M	P	L	E	X	■	E	N	R	O	L
D	■	A	■	E	■	E	■	T	■	■	■	I	■	I
■	B	L	U	N	D	E	R	■	A	C	I	D	I	C
A	■	■	■	T	■	P	■	I	■	O	■	■	M	■
C	A	L	M	■	S	W	I	M	■	L	E	A	P	T
Q	■	A	■	E	■	A	■	P	■	L	■	W	■	H
U	N	R	A	V	E	L	■	O	R	I	G	A	M	I
I	■	V	■	E	■	K	■	S	■	D	■	I	■	R
T	R	A	I	N	S	■	R	E	J	E	C	T	E	D

1 Y	2 Z	3 F	4 P	5 U	6 O	7 R	8 K	9 M	10 G	11 W	12 D	13 N		
14 T	15 Q	16 S	17 C	18 X	19 B	20 L	21 J	22 H	23 I	24 E	25 A	26 V		

GUESS WHO?

Blaise Pascal
When there is an increase in pressure at any point in a confined fluid, there is an equal increase at every other point in the container.

IT FIGURES

6	10	9	3
4	12	7	13
8	16	15	5
14	11	2	1

SPEED ROUND

1. The dwarf planet Ceres., **2.** Pea plants, **3.** Vulcanisation, **4.** Rocks, **5.** "Geographical curves are so involved in their detail that their lengths are often infinite or, rather, undefinable."

WHO SAID?

Anne McClain

C	■	M	■	M	■	■	R	Y	■	E
I	E	A	■	A	A	■	H	U	■	C
N	D	R	G	R	U	G	I	R	O	C
E	W	Y	R	S	X	L	N	I	M	R
M	I	A	E	H	O	Y	O	G	N	I
A	N	N	E	M	C	C	L	A	I	N
S	L	N	N	A	H	E	O	G	V	O
C	A	I	L	L	R	R	G	A	O	L
O	N	N	A	L	O	I	Y	R	R	O
P	D	G	N	O	M	N	■	I	E	G
E	■	■	D	W	E	E	■	N	■	Y

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